Design of a Compact Gaussian Profiled Corrugated Horn Antenna for Low Sidelobe-Level Applications

Tohid Salimi, Amir Maghoul, and Ali A. Abbasid

***Abstract*—In this paper, the design of a circular corrugated horn antenna is presented for low sidelobe-level. The basic requirement of this design is compactness. Therefore, we use corrugated Gaussian profiled horn antennas to improve the size and sidelobe level simultaneously. Because of compact design of this horn, it is not expected to have a good symmetry in E and H planes. The obtained radiation patterns are sufficient for desired applications. The proposed corrugated antenna has a longitudinal section composed of a normal corrugated horn, some straight corrugations, and a Gaussian profile to complete transition between waveguide and the free space.**

***Index Terms*—Corrugated horn, compactness, gaussian profiled, sidelobe-level.**

I. Introduction

High-performance microwave satellite communications, radar and remote sensing systems often use a reflector antenna as end component of the transmitter and receiver front ends. A reflector antenna consists of two parts: the first one is the reflector itself and the second one is the horn at the focus. The horn antenna is a crucial component because it must match the microwave signal from the source to the reflector antenna with the minimum losses and the maximum efficiency. There are a variety of possible designs for this horn, but the preferred choice at the present for high-performance systems is the corrugated horn [1].

Directivity, gain, sidelobe and cross-polarization levels are important design parameters for many applications involving horn antennas. Additional design parameters, relevant to satellite applications are length and weight, which need to be minimized [2], [3].

The main goal of horn antenna in the last years was to excite a well-known HE_{11} mode from proper mixture of 85% of TE_{11} mode, and 15% of TM_{11} mode, with correct phase to produce a Gaussian like radiation pattern. This mode corresponds to the fundamental mode of a circular corrugated waveguide [4], [5]. This technique reported in [6]-[9], involves a gradual matching of the smooth monomode circular waveguide to another corrugated one wherein the corrugation depth is smoothly tapered from l/2 to l/4 of a wavelength, that is shown in Fig. 1.

The Gaussian (also called hyperbolic) profile is very useful for completing the transition of the horn flare from the mid-range matching section to the aperture. Also it results in a compact horns compared with a linear taper [10].

There are three main reasons for the existence of corrugated horn antennas. Firstly, they exhibit radiation pattern symmetry, which offers the potential for producing reflector antennas with high gain and low spillover; secondly, they radiate with very low cross-polarization, which is essential in dual polarization systems and finally, they offer a wide bandwidth responses.

Corrugated GPHA's are better than the rest of corrugated horn antennas in two particular aspects:

1) They present much lower sidelobes than any other corrugated profile.
2) They are usually shorter than the rest of corrugated profiles because their performance qualities are superior [11].

II. Design Procedure

A. TE_{11} to HE_{11} Mode Converters

Gaussian profiled horn antenna (GPHA) needs to be fed by a quite pure HE_{11} mode. We should select which type of TE_{11} to HE_{11} converter is suitable for feeding a Gaussian Profiled antenna.

This mode converter usually starts from a smooth circular monomode waveguide propagating the TE_{11} mode and ends at the required aperture diameter to feed the corrugated GPHA model. One could find several types of TE_{11} to HE_{11} mode converters. One of them is the horn type proposed by Potter; its disadvantage is a poor bandwidth. Another type of TE_{11} to HE_{11} mode converter could be just a conical corrugated horn antenna, its disadvantage is its size. Another corrugated GPHA can be another possibility of TE_{11} to HE_{11} converter with the same disadvantage of a conical corrugated one but with slightly better bandwidth characteristics [4]. It is well known that a choked antenna offers one of the shortest antenna profiles with rather good radiation features [12]. This antenna exhibits two principal disadvantages: a narrow bandwidth and it is very sensitive to manufacturing tolerances in the throat region (mode generator) [13]. We choose the normal corrugated horn antenna as a TE_{11} to HE_{11} converter.

Design frequency band is from 10.5GHz to 14.5GHz. The proposed conical corrugated horn design parameters as shown in Fig. 1, are θ_f=23.3°, w=3.7mm, t=1mm, p=4.7, and $2a$=24mm, with depths changing from $\lambda/2$ to $\lambda/4$ smoothly. The λ is the wavelength at center frequency.

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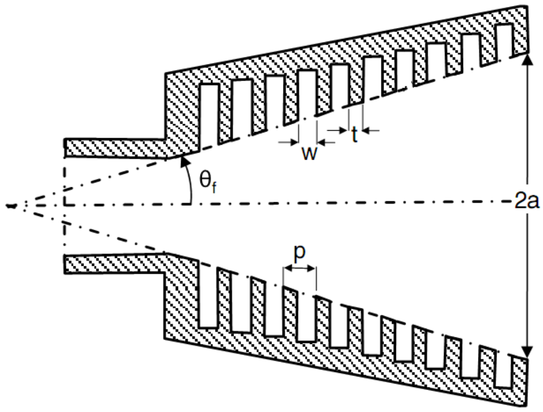

Fig. 1. Normal corrugated horn with design parameters has showed [8].

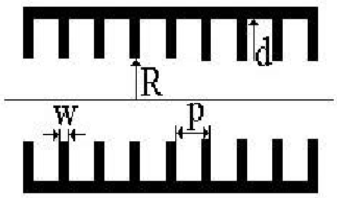

Fig. 2. Phasing section with corrugations.

B. Phasing Section

Because of compactness of corrugated horn antenna in first section, directivity is low and phase centers on E and H planes are not coincident. So we use a phasing section to place phase centers together in the desired frequency band. Also it improves the mixture of TE_{11} and TM_{11} modes. Actually when this section is attached to the normal corrugated horn, they result in a potter like horn with new characteristics in bandwidth and radiation pattern (We named it potter corrugated horn). The phasing section is shown in Fig. 2 and design parameters is w=3.7mm, p=4.7mm, and d=7.3mm.

C. Gaussian Profiled Horn Antenna (GPHA)

It is well known that one of the best ways to define a free space radiation from an antenna is by means of the paraxial free space modes, the Gaussian modes, which are a solution of the paraxial free space equation. A complete theory about properties of Gaussian modes is not presented here. The main mode for our corrugated horn radiation purposes is the fundamental Gaussian mode. This mode has null cross-polarization and null sidelobes. Its electric field propagation formula can be expressed as follows:

$$E\left(r,\varphi,z\right)=\frac{w_0}{w\left(z\right)}.\exp^{\frac{-r^2}{w^2(z)}}.\exp^{-j\frac{kr^2}{2.R(z)}}.\exp^{-j\left(kz-\xi(z)\right)} \quad (1)$$

where $r^2 = x^2+ y^2$ and $w(z)$ is the beamwidth where there is a field decay of $1/e$ respect to the maximum, (see Fig. 3). In $z = 0$, the function $w(z)$, (see (2)), has a minimum known as beamwaist and called w_0.

$$w\left(z\right)=w_0.\sqrt{1+\left(\frac{2.z}{k.w_0^2}\right)^2} \quad (2)$$

where $w_0=\alpha.r_0=\alpha.D_0/2$ is the beamwaist at $z=0$ related with the D_0 through the parameter α. The α parameter controls the aperture angle of the horn for a given frequency and waveguide radius, and $k=2\pi/\lambda$ is the wavenumber in free space. The corresponding waveguide profile which follows the curve for Gaussian equi-amplitude relative surface is given by:

$$R\left(z\right)=r_0.\sqrt{1+\left(\frac{2.z}{k.\alpha^2.r_0^2}\right)^2} \quad (3)$$

Fig. 4 shows the relationship between the horn profile (3) and the beamwaist propagation imposed by (2). The α parameter can vary between 0.5 and 0.8 but usually the optimum value is around 0.65. The last parameter we must define to completely design the corrugated GPHA is the profile length. If the antenna is very long we can say that we are over-guiding the Gaussian beam and the addition of more antenna length is not really improving the beam, so the efficiency can be the same than with a shorter antenna [11]. The best value for very nice Gaussian beam efficiency and not excessive length (which means low sidelobes) is obtained to be 33 mm.

The design parameter of this section is r_0=12mm, and α=0.65. Reason for choosing 0.65 is the proper mode mixture of HE_{11}. Designed horn is completely shown in Fig. 5 with the total length of 3.73λ and output aperture of 3.1λ.

III. Simulation Results

Fig. 6 shows the simulated radiation patterns of the designed corrugated horn antenna and Fig. 7 shows the simulated return loss. Fig. 6(a)-(g) shows the radiation patterns of the horn in desired and out of design frequency band. In the desired frequency band, the sidelobe level is below -38dB that is a good result. High frequency is the limitation in the sidelobe level bandwidth. As shown in Fig. 6(f), (g), the sidelobes rise at higher frequency and limit the sidelobe bandwidth to about 6GHz. Also maximum cross-polarization level is -28dB in the frequency band of 10GHz to 17GHz. Pattern symmetry is very good and -10dB beamwidth variations are about 6 degrees.

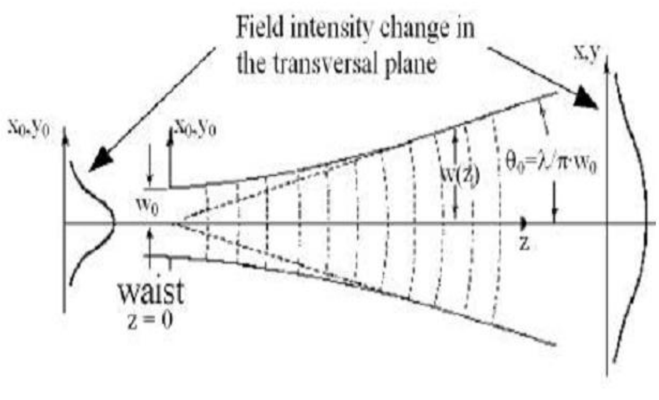

Fig. 3. Propagation of a fundamental Gaussian beam mode [13].

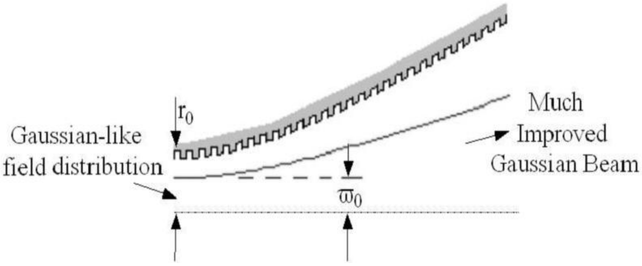

Fig. 4. Corrugated gaussian profiled horn antenna, (corrugated GPHA)[13].

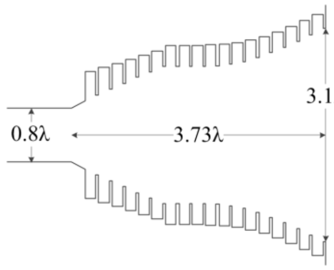

Fig. 5. proposed corrugated horn + GPHA.

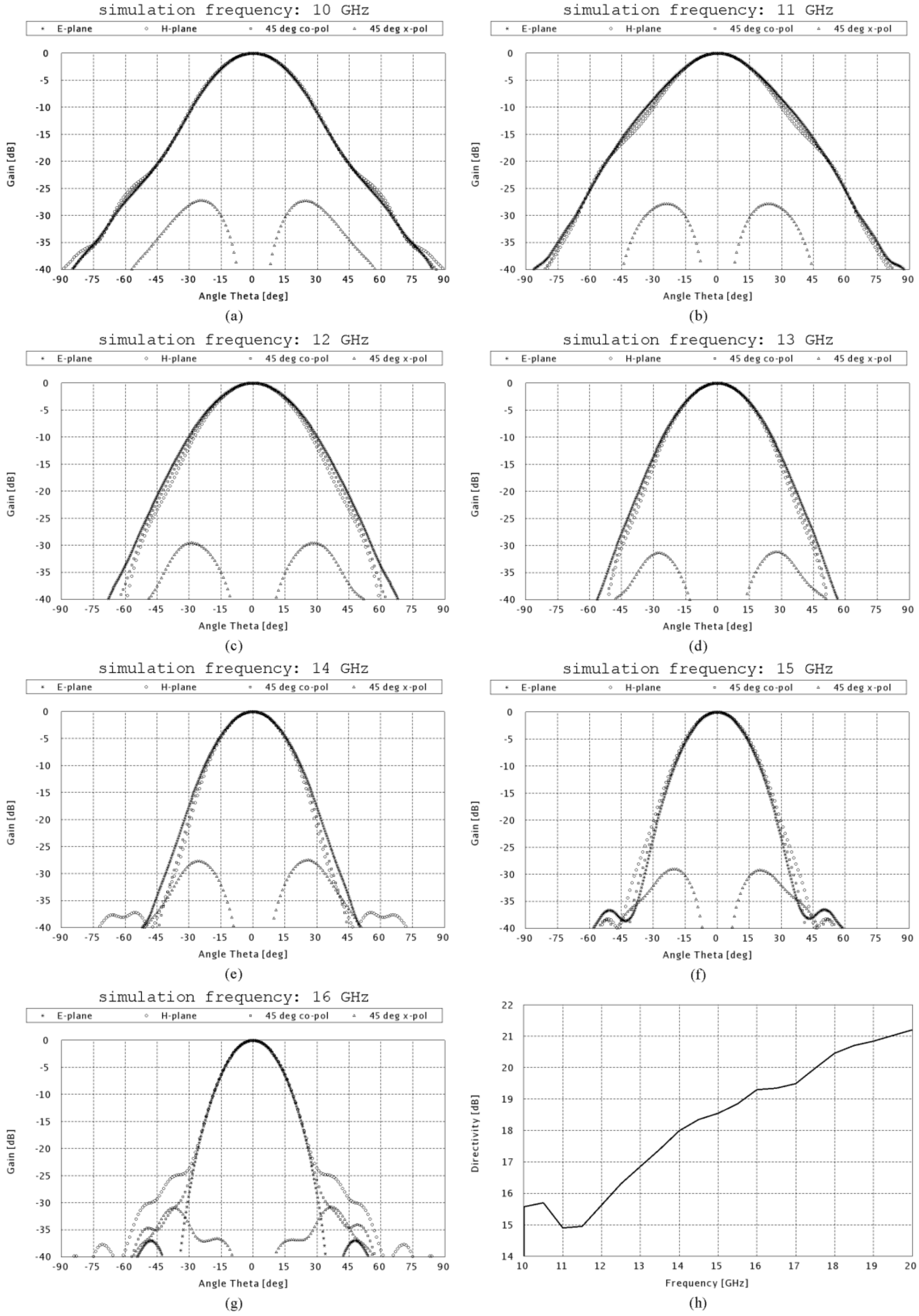

Fig. 6. Radiation characteristics of corrugated horn + GPHA. (a)-(g) gain, and (h) directivity.

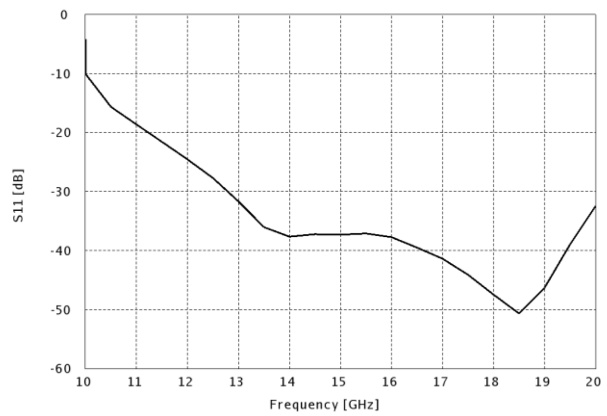

Fig. 7. Simulated return loss of corrugated horn + GPHA.

IV. Conclusion

In this paper the design of a compact corrugated horn antenna for low sidelobe level application using Gaussian profiled horn antennas is presented. Advantages of GPHAs versus other corrugated horns are mentioned. the proposed antenna uses the normal corrugated horn antenna as a mode conversion from TE_{11} to HE_{11}. Also it's possible to do this conversion with another GPHA to reduce the size slightly more. Also by increasing the length of the GPHA with proper feeding it by a high purity of HE_{11} mode, the cross-polarization level can be decreased to -50dB for the satellite applications. In these applications, there is a trade-off between size and cross-polarization level.

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