Progress In Electromagnetics Research Letters, Vol. 77, 129–136, 2018

Improving the Performance of Profiled Conical Horn Using Polynomial Interpolation and Targeting the Region of Interest

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Abstract—In this paper, design of a profiled conical horn using piecewise biarc hermite polynomial interpolation is proposed. In order to improve the performance of the horn, a novel concept of 'targeting the Region of Interest (RoI)' is used. The target specifications are decided based on the applicability of the horn in a reflectometry system for plasma diagnostics (D-band). Apart from the design details, the simulated results of the proposed horn are covered.

1. INTRODUCTION

Horn antennas with flared geometry are widely used as feed elements to illuminate the reflectors [1, 2]. In last decades, researchers have put significant efforts and proposed variety of horn geometries for many practical applications [3]. A few important examples are Potter horn [4], matched-feed horn [5, 6], corrugated horn [7], ridged horn [8], hybrid corrugated horn [9, 10], dielectric horn [11, 12], metamaterial based horn [13], Gaussian profiled horn [14], spline profiled horn [15], etc. All such horn configurations have their merits and demerits in terms of performance, fabrication complexity, cost, etc.

In this paper, a smooth walled profiled conical horn has been considered and achieved improved performance by applying piecewise biarc hermite polynomial interpolation and a concept of 'targeting the Region of Interest (RoI)'. The simulated results of the proposed horn are compared with that of a conventional spline profiled horn antenna discussed in [15]. This particular study was carried out considering an application of a horn antenna used in a reflectometry system for plasma diagnostics [16]. The expected horn specifications are: S_{11} better than -15 dB, peak gain of the order of 25 dB, side-lobe level and cross-polar isolation better than 30 dB over D-band (110–170 GHz).

2. PROFILED CONICAL HORN DESIGN USING BIARC HERMITE POLYNOMIAL INTERPOLATION

Polynomial interpolation is a method of estimating values between the known data points [17]. As a part of curve fitting, many interpolation methods [18, 19] can be adopted to connect the selected node points. The interpolation techniques help in smoothening the curvature of the horn. There are many such techniques, including spline interpolation, trigonometric interpolation, Birkhoff interpolation, multivariate interpolation, hermite interpolation, etc. Out of these, the hermite polynomial interpolation is relatively less explored for horn design. Thus, it was decided to use this technique and to take the benefit in improving the performance of the conical horn. The hermite polynomial interpolation technique applied to horn design is briefly explained in the next paragraph.

Two node points P_1 and P_2, one at the throat section and the other at the aperture section respectively, are considered to make the horn geometry. In fact, these points are the origins (or reference)

Received 25 June 2018, Accepted 1 August 2018, Scheduled 11 August 2018
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for individual sections of the horn. As input and aperture radius of a horn are fixed, points P_1 and P_2 are considered as (0, 0) as the reference points at throat and aperture section, respectively. Points $P_1(0,0)$ and (x_1, y_1) make the principal unit normal vector $\vec{n_1}$ at the throat section and similarly, and points $P_2(0,0)$ and (x_2, y_2) make vector $\vec{n_2}$ at the aperture section. Vectors $\vec{t_1}$ and $\vec{t_2}$ are tangent vectors of $\vec{n_1}$ and $\vec{n_2}$, respectively. Hence, with the change in the value of principal unit normal vector points, its corresponding vector $\vec{n_1}$ or $\vec{n_2}$ changes, which results in variation of tangent vectors accordingly. The total geometry of a horn changes, if the direction of tangent vectors (both at throat and aperture sections) gets changed.

Between the points, P_1 and P_2, the curve connects the path with tangent continuity starting with $\vec{t_1}$, ending with $\vec{t_2}$. As shown in Fig. 1, (x_1, y_1) and (x_2, y_2) both are taken as $(0, 1)$ with respect to the reference points P_1 and P_2. Considering these values, the geometry of a smooth walled profiled conical horn is prepared. Geometrical parameters of the horn such as input radius (r_{in}), aperture radius (r_{ap}) and length (L) are also depicted in Fig. 1.

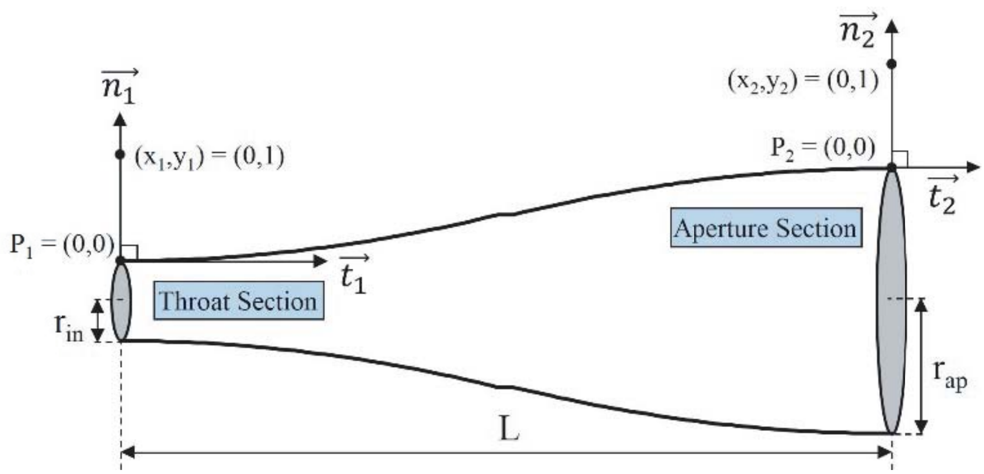

Figure 1. Geometry of smooth walled profiled conical horn designed using biarc hermite polynomial interpolation with principal unit normal vector points as $(x_1, y_1) = (x_2, y_2) = (0, 1)$; $r_{in} = 1.31$ mm; $r_{ap} = 8.50$ mm; $L = 49.93$ mm for centre frequency of 140 GHz.

In order to carry out the comparative study, various profiles have been formed by changing the location of principal unit normal vector points, i.e., (x_1, y_1) and (x_2, y_2). These variations are mentioned in Table 1, and they are also plotted in Fig. 2. The set of values under consideration for x_1 and x_2 are $\{0.1, 0, -0.1, -0.2, -0.3, -0.4, -0.5\}$. These values cover the area at the throat as well as at the aperture of a horn with geometrical feasibility, or the area within which the profile of a horn can start/end. For each of the values, the horns are designed using interpolation technique to connect their

Table 1. Values of unit normal vector points for various profiling options.

Principal Unit Normal Vector Points	
(x_1, y_1)	(x_2, y_2)
$(0.1, 1)$	$(0.1, 1)$; $(0, 1)$; $(-0.1, 1)$; $(-0.2, 1)$; $(-0.3, 1)$; $(-0.4, 1)$; $(-0.5, 1)$
$(0, 1)$	
$(-0.1, 1)$	
$(-0.2, 1)$	
$(-0.3, 1)$	
$(-0.4, 1)$	
$(-0.5, 1)$	

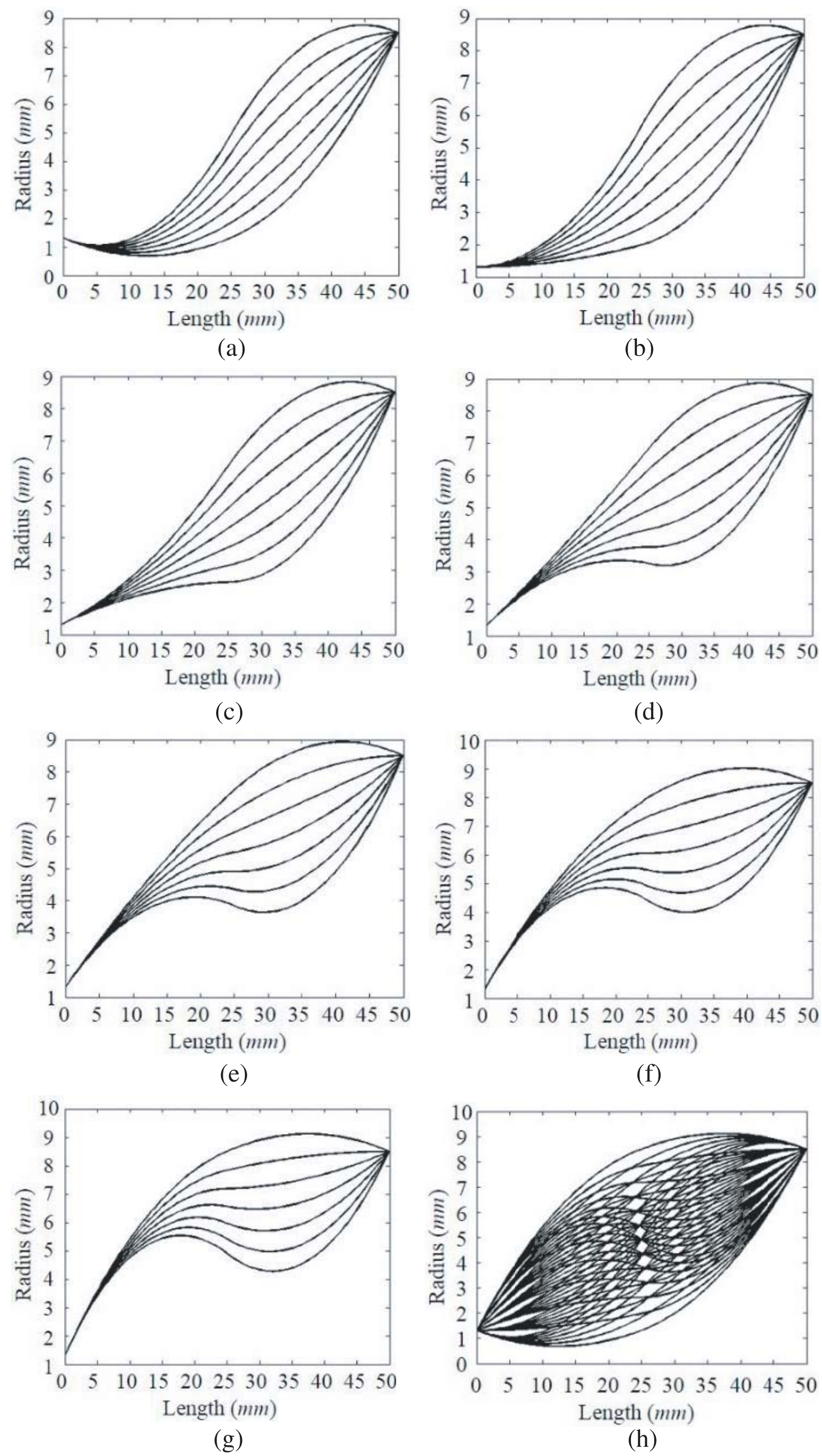

Figure 2. Different profiling options for (x_1, y_1) and (x_2, y_2) as (a) $(0.1, 1)$ and $(\{x_2\}, 1)$; (b) $(0, 1)$ and $(\{x_2\}, 1)$; (c) $(-0.1, 1)$ and $(\{x_2\}, 1)$; (d) $(-0.2, 1)$ and $(\{x_2\}, 1)$; (e) $(-0.3, 1)$ and $(\{x_2\}, 1)$; (f) $(-0.4, 1)$ and $(\{x_2\}, 1)$; (g) $(-0.5, 1)$ and $(\{x_2\}, 1)$; (h) $(\{x_1\}, 1)$ and $(\{x_2\}, 1)$.

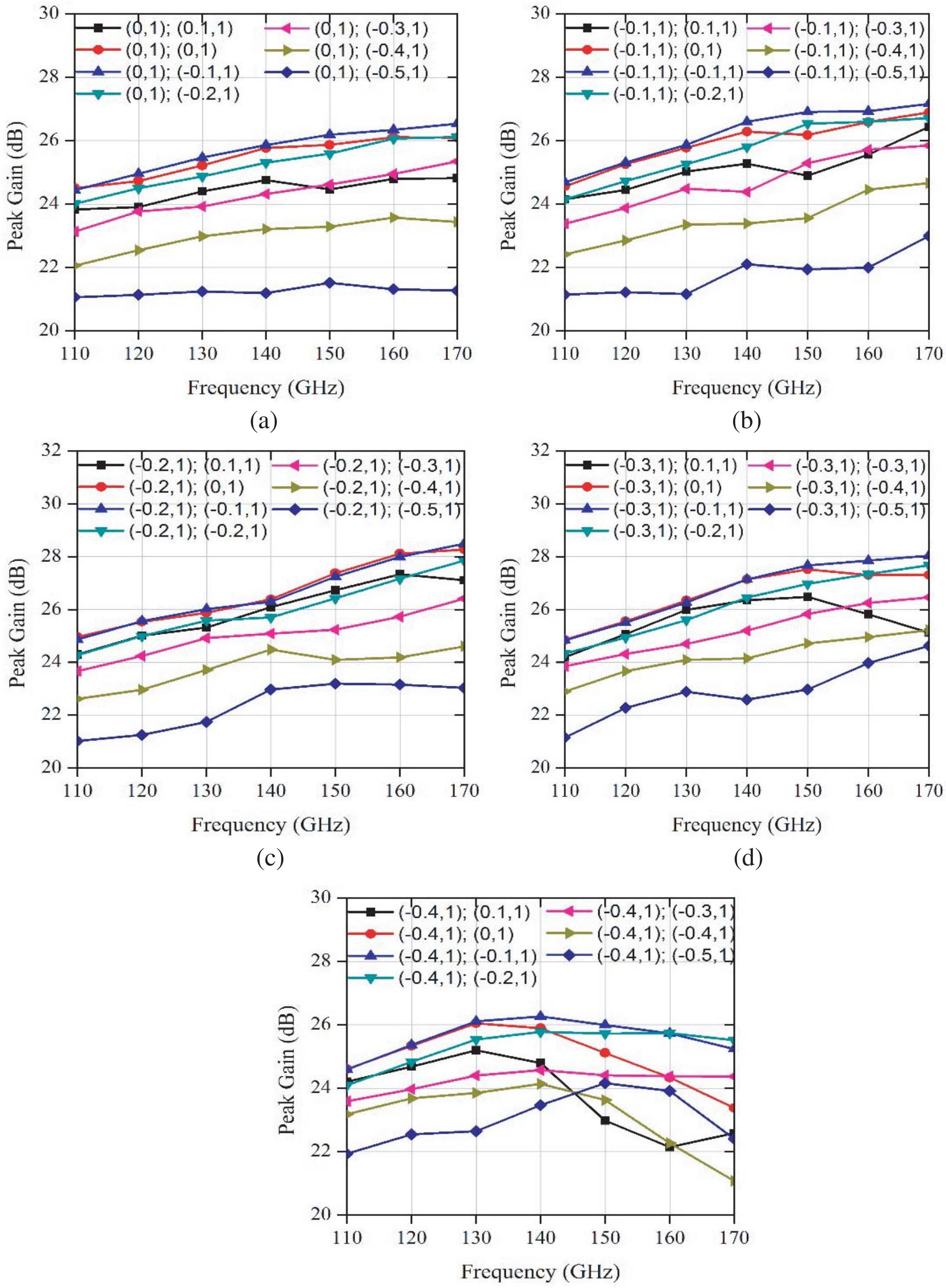

Figure 3. Peak gain (dB) by varying the position of principal unit normal vector points (x_1, y_1) and (x_2, y_2) as (a) $(0, 1)$ and $(\{x_2\}, 1)$; (b) $(-0.1, 1)$ and $(\{x_2\}, 1)$; (c) $(-0.2, 1)$ and $(\{x_2\}, 1)$; (d) $(-0.3, 1)$ and $(\{x_2\}, 1)$; (e) $(-0.4, 1)$ and $(\{x_2\}, 1)$.

first tangent vector ($\vec{t_1}$) to the last one ($\vec{t_2}$), and that too with a smooth curvature. Biarc hermite polynomial interpolation is used to satisfy the tangent continuity and maintain the smoothness of the horn profile by connecting the two extreme node points starting/ending with specified tangent direction. Accordingly, all the possible geometries of horn antenna using this interpolation technique are designed and simulated using the commercially available antenna design software (HFSS).

Among all the geometries, the horn profiles with $x_1 > 0$ are not valid according to the mode theory concept (as in the case of Fig. 2(a)). This is because the negative value of x_1 makes the radius of the horn even less than the input radius, which obstructs the propagation of fundamental mode through the circular guide. The horn geometries with values of x_1 around -0.5 give very poor radiation characteristics due to the abrupt change at throat section. Hence, these geometries are eliminated from the study. For all other geometries, a systematic analysis has been carried out to study the effect of profiling on the performance of the horn antenna.

Figure 3 shows the change in the value of peak gain for variations in position of principal unit normal vector point at aperture side. The reason of considering variable vector points at aperture side is high dependency of aperture profile on peak gain.

From the obtained results, it can be observed that the gain is improved with increase in the value of x_2 and has the best performance when x_2 is around 0 and -0.1.

The concept of targeting the Region of Interest (RoI) of the horn is explained in the subsequent section.

3. CONCEPT OF TARGETING REGION OF INTEREST

The region where the profile of a horn possesses better RF performance can be termed as the 'Region of Interest (RoI)' of a horn. Based on simulated results of the above mentioned profiles, it has been observed that the performance of a horn depends on two of the profiling sections (i) throat section and (ii) aperture section. After a rigorous study, the regions of interest for both these sections are obtained with a target to achieve the best gain and side-lobe performance.

3.1. Targeting the RoI for the Best Value of Gain

After an exhaustive study, the regions of interest at throat and aperture sections for the best possible value of gain were obtained and are drawn in Figs. 4(a) and 4(b), respectively. This ensures that if the profile of a horn lies within the given region, it provides the best possible gain for the horn design under consideration.

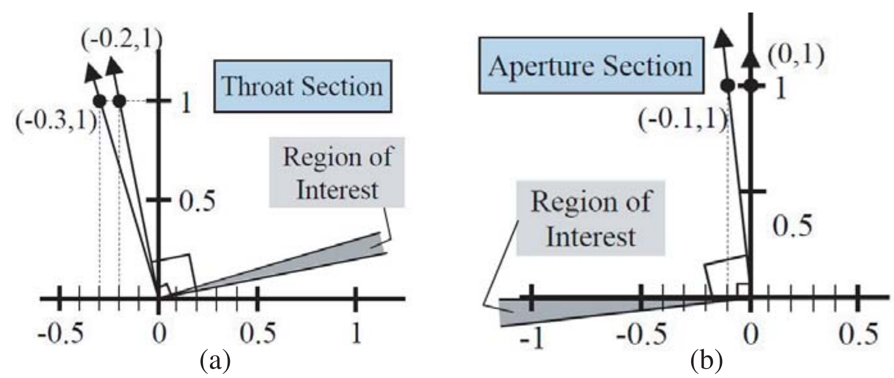

Figure 4. RoI at: (a) throat section; (b) aperture section for the best value of gain.

3.2. Targeting the RoI for the Best Side-Lobe Performance

By studying various profiling options, it was found that the side-lobes are more dependent on profiling at the aperture section of a horn. Fig. 5 shows the proposed RoI for the minimum values of side-lobes.

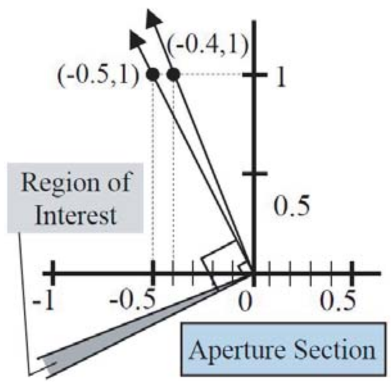

Figure 5. RoI at aperture section for the minimum side-lobes.

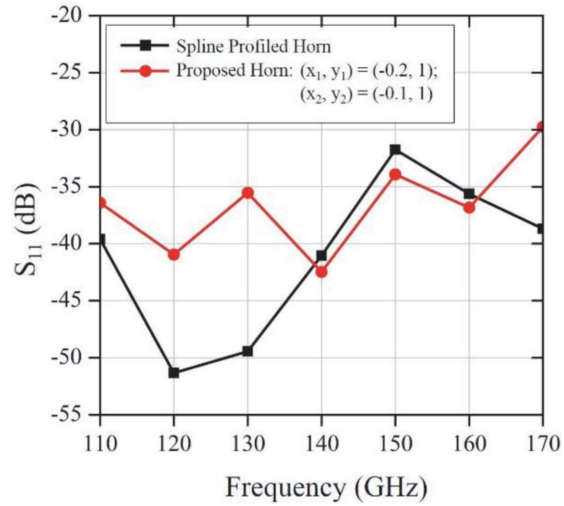

Figure 6. S_{11} (dB) for proposed horn using $(x_1, y_1) = (-0.2, 1)$ and $(x_2, y_2) = (-0.1, 1)$ compared with the spline profiled horn.

4. RESULTS AND DISCUSSION

In this section, results of a few selected profiles designed using the concept of 'RoI' are compared with a spline profiled horn. The simulated results in terms of S_{11} (dB) for $(x_1, y_1) = (-0.2, 1)$ and $(x_2, y_2) = (-0.1, 1)$ with that of a spline profiled horn are compared in Fig. 6. The performance of horns in terms of peak gain (dB) and radiation patterns at the centre frequency of 140 GHz are shown in Figs. 7 and 8, respectively. The radiation patterns of a spline profiled horn are shown in Fig. 9. By analyzing the results, it is observed that the proposed profile gives better gain than that of a spline profiled horn. Further, results for $(x_1, y_1) = (-0.3, 1)$ and $(x_2 y_2) = (-0.5, 1)$ are summarized in Figs. 10, 11 and 12. It is observed that the side-lobe level has improved as compared to the previous case. In both the cases, the cross-polar isolation is good.

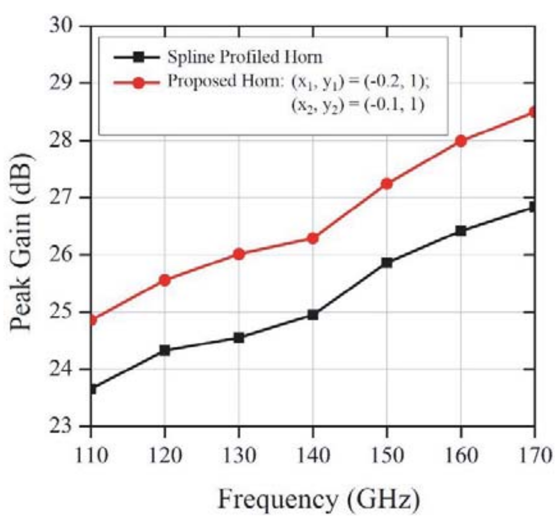

Figure 7. Peak gain (dB) for proposed horn using $(x_1, y_1) = (-0.2, 1)$ and $(x_2, y_2) = (-0.1, 1)$ compared with the spline profiled horn.

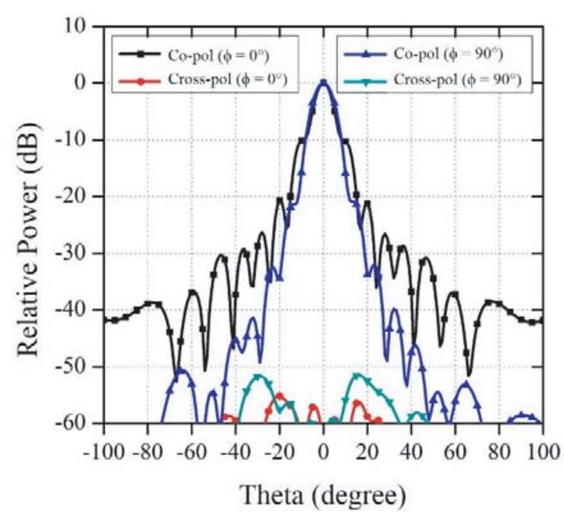

Figure 8. Radiation patterns (dB) for the proposed horn for the best gain performance [for $(x_1, y_1) = (-0.2, 1)$ and $(x_2, y_2) = (-0.1, 1)$].

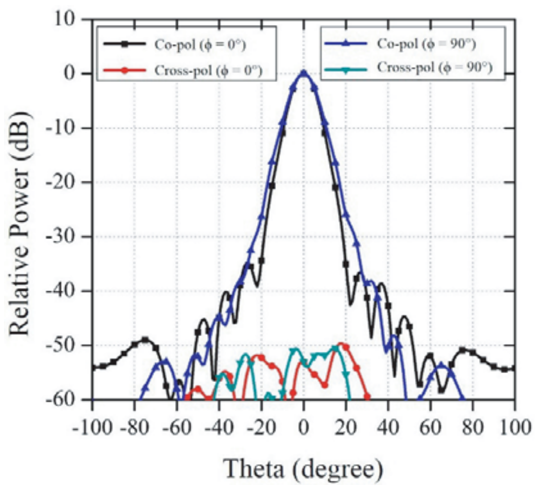

Figure 9. Radiation patterns (dB) for the spline profiled horn (reference horn antenna).

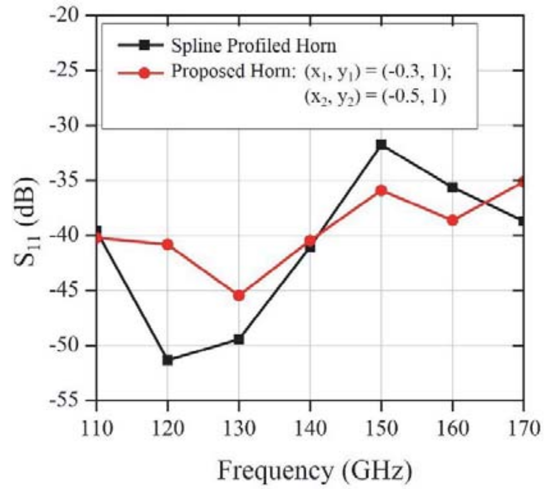

Figure 10. S_{11} (dB) for proposed horn using $(x_1, y_1) = (-0.3, 1)$ and $(x_2, y_2) = (-0.5, 1)$ compared with the spline profiled horn.

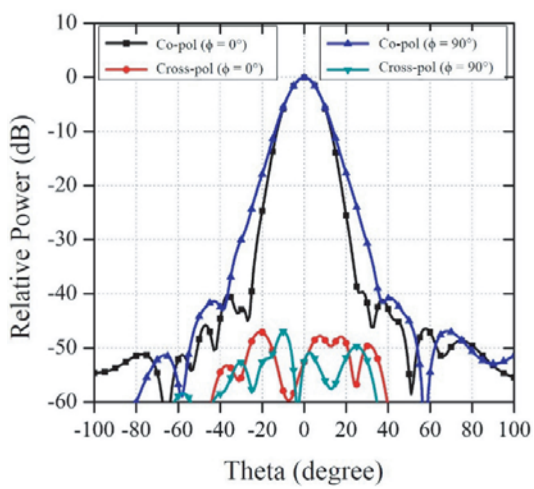

Figure 11. Radiation patterns (dB) for the proposed horn for the best side-lobe performance [for $(x_1, y_1) = (-0.3, 1)$ and $(x_2, y_2) = (-0.5, 1)$].

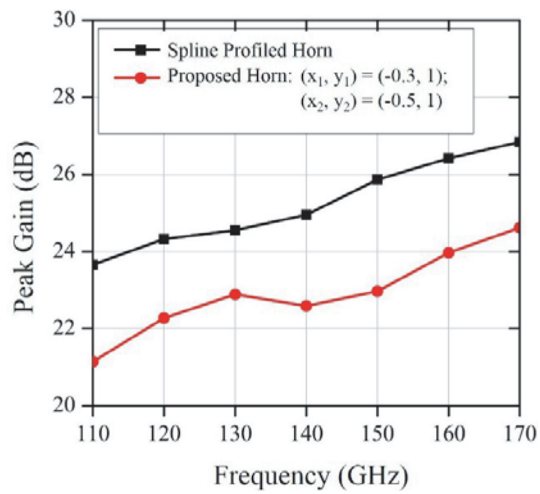

Figure 12. Peak gain (dB) for the proposed horn using $(x_1, y_1) = (-0.3, 1)$ and $(x_2, y_2) = (-0.5, 1)$ compared with the spline profiled horn.

It is observed that the performance of horn can be optimized by changing the location of the principal unit normal vector points at throat and aperture sections, whereas in the case of spline profiled horn, optimization can be done using multiple intermediate node points which is comparatively tedious.

5. CONCLUSIONS

The piecewise biarc hermite polynomial interpolation technique and the concept of 'targeting RoI' result in better RF performance of the proposed horn than the spline profiled horn. Moreover, a spline profiled horn requires optimization at multiple intermediate node points for obtaining the desired performance while the profile of proposed horn can be modified only by changing the locations of two principal unit normal vector points. Through simulated results, it is verified that the proposed horn can be used for the D-band reflectometry system in plasma diagnostics.

ACKNOWLEDGMENT

The authors of this paper are sincerely thankful to Nirma University and Institute of Technology, Nirma University, Ahmedabad, India for necessary support. This work has been carried out from the grant received from Visvesvaraya Ph.D. Scheme for Electronics and IT, Ministry of Electronics and Information Technology, Government of India.

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