Miniaturization of asymmetrical gaussian profiled corrugated horn

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Abstract. In this paper, miniaturization of the asymmetrical profiled corrugated horn with low sidelobes, low cross-polarization, and good beam symmetry is presented. The miniaturized corrugated horn is designed at 2.48 GHz and optimizes the result between the frequency sweeps of 2 GHz to 4 GHz. At design frequency, the result of the $S_{11}$ Parameter is -30.2966 dB, and the $S_{11}$ Parameter remains below -20 dB between 2 GHz to 4 GHz. The asymmetrical profiled corrugated horn comprises the Gaussian Profiled Corrugation part and the most widely used Variable Depth Slot Mode Converter. The purpose of the mode converter is to generate hybrid mode in the corrugated horn antenna. The length of the asymmetrical profiled corrugated horn antenna after applying the miniaturization technique is only 3.5λ long. The designed horn full-fill the number of S-Band applications such as Satellite communication, Radio astronomy, Weather Radar, Surface ship radar.

1. Introduction

Corrugated horn widely used in Satellite Communication, Satellite Tracking, Radio Astronomy, Radar, and Remote sensing applications. It also used them as optimum feed for a reflector antenna and used it as a direct radiator antenna for wideband Measurement [1-3]. Corrugated horn has many advantages like a good beam symmetry, low cross-polarization level, low sidelobe and back lobe generation, low return loss, wideband performance, and high antenna efficiency compared with another horn antenna [1-6]. It is also called the gold antenna among all feed antenna [5]. The antenna size is optimized by reducing the number of slots and the optimum value of $\delta$ (Pitch to Width Ratio). The new miniaturize corrugated horn antenna was tested in HFSS. The simulation result shows that the antenna has a fair value of $S_{11}$ Parameter, cross-polarization, and beam symmetry. In this paper, an Asymmetrical Gaussian Profiled corrugated horn antenna has been designed and simulated by optimizing the different parameters of corrugated horn antenna with size compactness. This horn designed and simulated for the frequency range from 2 GHz to 4 GHz.

First, the Design Parameter of input wave-guide, mode converter, and Gaussian profile is described in Section 2. Then, the simulation results of the design shown in Section 3. last, the Summary and Conclusion of the design presented in Section 4.
2. Design Parameters
The Design Parameters of Gaussian profiled horn has three different parts: selection of circular waveguide, mode converter and, Gaussian profile.

2.1. Circular Waveguide Selection
The frequency range for a standard S-band antenna is 2 GHz to 4 GHz. There are two methods to select a circular waveguide. The first one is EIA designated standard circular waveguide used directly as the input radius. For S-band application, the Electronic Industries Association designated standard circular Waveguide are WC; 451, 385, 329, 281, 240, 175. In the second method, selecting the input radius using equation (1)[5].

\[ a_i = \frac{3\lambda}{2\pi} \]  \hspace{1cm} (1)

2.2. Hybrid Mode Conversion: TE_{11} to HE_{11}
The corrugated horn antenna has three main parts: waveguide, Mode Converter, and Corrugation profile part, shown in Figure 1. In this paper, a circular waveguide is used as a waveguide part. The fundamental mode of a circular waveguide is TE_{11}, while the corrugated profile has required HE_{11} mode for smooth wave propagation from waveguide to horn aperture. The mode conversion from TE_{11} to HE_{11} is accomplished by designing a smooth depth transition from \( \lambda/2 \) to \( \lambda/4 \) into the waveguide surface for smooth wave propagation in the antenna [7][8]. There are three types of mode converter: variable depth slot mode converter, ring loaded slot mode converter, variable pitch to width slot mode converter[5]. Ring loaded slot mode converter is an efficient mode converter but has a design difficulty. Variable pitch to width slot mode converter has a problem with S-band frequencies. In this paper, the most widely used variable depth slot mode converter is designed and simulated. The geometry of the variable depth slot mode converter is shown in Figure 1.

The design parameters and expressions are listed in Table 1 for the Variable depth slot mode converter[5]. In this design, the pitch to width ratio (\( \delta \)) and slot depth of the mode converter varied for the design optimization purpose that causes achieved the desired result.

2.3. Gaussian Profiled Corrugated Horn
The reason behind choosing the Gaussian profile is that they generate lower side lobes, back lobe, and good beam symmetry among all antennas. The main parameter is that they are compact compared to another corrugated horn antenna. The design formula of the Gaussian profile is given by (2)[5].

\[ E(x) = e^{-\frac{x^2}{2}} \]

Figure 1. Different Part of Corrugated Horn antenna
profiled corrugated horn antenna is as follows [5][8].

\[ R(x) = r_o \sqrt{1 + \left( \frac{2x}{k \alpha^2 r_o^2} \right)^2} \]  

(2)

\( r_o \) is the input radius, but it is the output radius of the mode converter. \( \alpha \) is an essential parameter for miniaturization, and its value is chosen 1. The design parameters of the Gaussian profiled corrugated part are described in Table 2, and the geometry of the Gaussian profile is shown in Figure 2.

Table 1. Design parameters of variable depth slot mode converter

| Parameters | Description |
|------------|-------------|
| \( f_c \)  | Designed Frequency |
| \( \lambda = c/f \) | Wavelength |
| \( a_i = 3\lambda / 2\pi \) | Input Radius |
| \( a_o \)  | Aperture Radius |
| \( a_j \)  | Radius of jth slot |
| \( d_j \)  | Depth of jth slot |
| \( N \)    | Total No. of slots |
| \( N_{MC} \) | No. of slot in mode converter |
| \( \rho = \lambda / 8 \) | Slot pitch |
| \( w = \delta \cdot \rho \) | Slot width |

\[ a_j = a_i + (j - 1) \left( \frac{a_o - a_i}{N_{MC} - 1} \right) \text{ for } 1 \leq j \leq N_{MC} \]

\[ d_j = 0.42 - \frac{j - 1}{N_{MC}} \left( 0.42 - 0.25e^{\left[ \frac{1}{2.114\left( \frac{2\pi a_j}{\lambda} \right)^2} \right]} \right) \lambda \]

Figure 2. Proposed Miniaturized Gaussian Profiled Horn

In this design, the optimum value of \( \delta \) (pitch to width ratio) is selected for size compactness with wider bandwidth performance. Three different values of \( \delta \) are possible for optimum design
Table 2. Design parameters of Gaussian Profiled Horn

| Parameters | Description                                      |
|------------|--------------------------------------------------|
| $a_i$      | Input radius of corrugated profile              |
| $a_o$      | Output radius of corrugated profile             |
| $a_j$      | Radius of jth slot                              |
| $d_j$      | Depth of jth slot                               |
| $L$        | Length of horn                                  |
| $N = L/N$  | No. of slots in horn                            |

\[
\begin{align*}
  a_j &= a_o \left( \sqrt{1 + \left( \frac{\lambda (x-1)}{\pi r_o^2} \right)^2} \right) \quad \text{for } 1 \leq j \leq N \\
  d_j &= 0.25\lambda \ast e^{\left[ \frac{1}{2.114} \left( \frac{2\pi a_j}{\lambda} \right)^{1.134} \right]} \lambda \quad \text{for } N_{MC+1} \leq j \leq N
\end{align*}
\]

of the proposed corrugated horn antenna, but removing manufacturing difficulties here in this design pitch to width ratio is selected for a maximum of 0.8.

3. Simulation and Result

The Proposed Miniaturization of Gaussian profiled corrugated horn antenna is simulated using the obtained different parameters from Table 3. The proposed Gaussian profiled corrugated horn is simulated using the ANSIS-HFSS software. From the below figures, the directivity of the proposed Gaussian profiled corrugated horn antenna remains above 15dBi for the whole S-Band. The Result summary and comparison of the design given as below.

Table 3. Design parameter of miniaturized Gaussian profiled corrugated horn

| Parameters                           | Dimension          |
|--------------------------------------|--------------------|
| input radius ($a_i$)                 | 57.7882 mm         |
| output radius ($a_o$)                | 175.2484 mm        |
| slot pitch ($\rho$)                  | 15.1212 mm         |
| Slot pitch-to-width ratio ($\delta$) | 0.8                |
| slot width ($w$)                     | 12.0970 mm         |
| Width of the slot teeth ($t$)        | 3.0242 mm          |
| Length ($L$)                         | 425 mm             |
| No. of slots in mode converter ($N_{MC}$) | 5                  |
| Total No. of slots ($N$)             | 20                 |

The $S_{11}$ parameters of Miniaturized GPCH plotted for the whole S-band (2 to 4 GHz) in Figure 6. The radiation characteristics of GPCH with E-plane, H-plane, Co polarization 45-plane, and cross-polarization 45 plane regarding power (dBi) shown in Figure 3, Figure 4, and Figure 5 for 2 GHz, 2.48 GHz, and 4 GHz.
Figure 3. Directivity at 2 GHz

Figure 4. Directivity at design frequency-2.48 GHz

Figure 5. Directivity at 4 GHz
Figure 6. $S_{11}$ Parameter over S-Band (2-4 GHz)

Figure 7. Cross Polarization between 2 to 4 GHz

Table 4. Design comparison of proposed Gaussian profiled horn with available horn

| Parameters            | Proposed Design | Design-1$^{[17]}$ | Design-2$^{[18]}$ | Design-3$^{[9]}$ |
|-----------------------|-----------------|-------------------|-------------------|-------------------|
| Profile               | Gaussian        | Gaussian          | Gaussian          | Gaussian          |
| $a_t$                 | 0.477λ          | −                 | −                 | 0.8λ              |
| $a_o$                 | 1.708λ          | −                 | 2.4λ              | 3.1λ              |
| L                     | 3.513λ          | 4.8λ              | 7.43λ             | 3.73λ             |
| Bandwidth             | 66%             | 20%               | 10%               | 60%               |
| Directivity           | 15-18dBi        | 20dBi             | 20-22dBi          | −                 |
| Cross Polarization    | <20dB           | <20dB             | <20dB             | <20dB             |
| Beam symmetry         | ±48° (96°)      | ±35° (70°)        | ±20° (40°)        | ±40° (80°)        |

4. Conclusion

The paper has presented miniaturization of asymmetrical Gaussian profiled corrugated horn. The miniaturized GPCH has an aperture diameter of 1.708λ, and the length of the horn is 3.513λ long only. The $S_{11}$ parameter and Cross Polarization value for the whole S-band remain below -20dB and -25 dB shown in Figure 6 and Figure 7. At Design frequency, the value of directivity is 17 dBi and cross-polarization of -29.8614 dB with the beam symmetry of ±48° shown in Figure 4. From Figure 3, the value of gain, cross-polarization, and beam symmetry at 2 GHz is 15.5 dBi, -22.8870 dB, and ±50°. The value of directivity, cross-polarization, and beam symmetry for 4 GHz frequency is 16.9 dBi, -36.4512dB, ±48° shown in Figure 5. The presented GPCH gives a 66% wide-band performance with the optimum value of co-polarization.
and cross-polarization with good beam symmetry. A comparison of different designs of the Gaussian profiled horn is presented in Table 4. The proposed GPCH has a size compactness and wide bandwidth performance with respected to different Gaussian Profiled Corrugated Horn Antenna.

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References
[1] P. J. B. Clariccoats and A. D. Olver, Corrugated Horns for Microwave Antennas, London, IEE, 1984.
[2] A. D. Olver, P. J. B. Clariccoats, A. A. Kishk, and L. Shafai, Microwave Horns and Feeds, London, IEE, 1994, Chapter 9.
[3] A. W. Love, Electromagnetic Horn Antennas, New York, IEEE Press, 1976.
[4] T. Chu and W. E. Legg, "Gain of Corrugated Conical Horns," IEEE Transactions on Antennas and Propagation, AP-30, July 1982, pp. 698-703.
[5] C. Granet and G. L. James, "Design of Corrugated Horns: A Primer," IEEE Antennas and Propagation Magazine, 47, April 2005, pp. 76-84.
[6] T. A. Milligan, Modern Antenna Design, Second Edition, New Jersey, IEEE Press/John Wiley, 2005, Chapter 7.
[7] G. L. James, "Analysis and Design of TE11-to-HE11 Corrugated Cylindrical Waveguide Mode Converters," IEEE Transactions on Microwave Theory and Techniques, MTT-29, 1981, pp. 1059-1066.
[8] Mun Seok Choe, Kwang Hoon Kim EunMi Choi (2013) A comprehensive analysis of a TE11 to HE11 mode converter for an oversized F-band corrugated waveguide, Journal of Electromagnetic Waves and Applications, 27:17, 2221-2238.
[9] Salimi, Tohid, Amir Maghoul, and Ali A. Abbasid. "Design of a compact Gaussian profiled corrugated horn antenna for low sidelobe level applications." International Journal of Computer Theory and Engineering 5.2 (2013): 223.
[10] D. Olver, P. J. B. Clariccoats, A. A. Kishk, and L. Shafai, Microwave P. J. B. Clariccoats and A. D. Olver, Corrugated Horns for Microwave Antennas, London, IEE Electromagnetic Wave Series 18,1984, ISBN 86341 0030.
[11] Mac A. Thomas B., "Design of Corrugated Conical Horns," IEEE Transactions on Antennas and Propagation, AP-26, 2, March 1978, pp. 367-372.
[12] Modern Antenna handbook by Constantine A. Balanis Copyright. 2008 John Wiley and Sons, Inc. page 126
[13] Mun Seok Choe, Kwang Hoon Kim and EunMi Choi (2013) A comprehensive analysis of a TE11 to HE11 mode converter for an oversized F-band corrugated waveguide, Journal of Electromagnetic Waves and Applications, 27:17, 2221-2238.
[14] Wang, Hai Lu, Zejian Liu, Ying Yu, Junsheng Yao, Yuan Liu, Xiaoqing Chen, Xiaodong. "Design of a tanh profiled compact Gaussian corrugated horn for Cassegrain antenna application." 2015 Asia-Pacific Microwave Conference (APMC). Vol. 2. IEEE, 2015.
[15] Zhao, Qiuying He, Huiwen Xi, Leilei Shao, Wenbo. "Miniaturization design of dual-slot corrugated horn antenna on Ka-band." 2014 IEEE International Conference on Communication Problem-solving. IEEE, 2014.
[16] Abbas-Azimi, Majid, Farhad Mazlumi, and Fereidoon Behnia. "Design of broadband constant-beamwidth conical corrugated-horn antennas [Antenna designer's notebook]." IEEE Antennas and Propagation Magazine 51.5 (2009): 109-114.
[17] Mckay, Johannes Robertson, Duncan Speirs, Peter Hunter, Robert Wylde, Richard Smith, Graham. "Compact Corrugated Feedhorns With High Gaussian Coupling Efficiency and -60 dB Sidelobes." IEEE Transactions on Antennas and Propagation 64.6 (2016): 2518-2522.
[18] Soares, Pedro AG, Pedro Pinho, and C. A. Wuensche. "High performance corrugated horn antennas for CosmoGAL satellite." Procedia Technology 17 (2014): 667-673.
[19] Teniente, Jorge, Ramon Gonzalo, and Carlos del Rio. "Gaussian profiled horn antenna for hispasat 1C satellite." International journal of infrared and millimeter waves 20.10 (1999): 1809-1815.
[20] McElhinney, Paul Donaldson, C.R. He, W. Zhang, Liang Phelps, A.D.R. Cross, A.W."A high directivity broadband corrugated horn for W-band gyro-devices." IEEE transactions on antennas and propagation 61.3 (2012): 1453-1456.