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# Design of Substrate Integrated Waveguide-based Metallic Strip Loaded Double Flared Horn Antenna

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## Abstract

Analysis of the double-flared metallic strips loaded synthetic artificial waveguide-based electromagnetic horn antenna for X-band applications is discussed here. The complete design procedure and field analysis within the horn are also presented to better understand the proposed horn antenna. The analysis is also applicable for more number of flaring. The results in the form of reflection coefficients and radiation patterns in the operating band are presented to support the idea of a horn antenna using the SIW domain. The impedance bandwidth of 20.43 % (from 9.05-11.11 GHz) with respect to the centre frequency of 10.08 GHz is achieved. The gain performance of the antenna at all the frequencies is seen to be consistent (avg. 8.23 dB) with a highest value of 9 dB.

## 1. Introduction

For the application of direction finding and obstacle location, electromagnetic horn having simple and solid geometry with a directive beam over a wide bandwidth, are used [1, 2]. Due to its bulky nature, the metallic waveguide-based horn antenna has limitations for the application in the miniaturized form.

The first development in horn antenna design using planar/or synthetic waveguide technology commonly investigated as substrate integrated waveguide (SIW) has been seen in 2004 by Z. Li [3]. After that various horn antennas using this planar waveguide have found their suitability for end-fire radiation applications [4, 5]. At frequencies of Ku-band and below, where most commercial substrates are used, suffer from performance degradation [6]. This deterioration in radiation performance arises due to low thickness of the substrate compared with the wavelength [7]. Due to this small substrate thickness, a mismatch between dielectric and air occurs at the interface. This mismatch is responsible for high back radiation and the narrow bandwidth of the horn antenna. Several different techniques to overcome this common problem have been addressed in the open literature. SIW-to-Stepped waveguide transition has been first proposed for wide impedance bandwidth [8]. After that, many methods like dielectric-metal lens [9, 10], perforated substrate [11], and elevated coplanar waveguide feeding [12] have been proposed. All the ideas as mentioned above are reported for thick (stacked) and extended substrates for the phase correction [13].

These ideas narrow the beam width but the length of the horn is compromised. In the design of horn, the most important idea behind the performance enhancement is to obtain a uniformly distributed phase at the aperture. One can easily get the directive beam at the aperture by making control over amplitude and phase of the current [14]. Several authors have discussed about the different idea for the accomplishment of unvarying amplitude and phase, such as an embedded array of metallic vias [15], grated metallic transition [16, 17], and gap SIW [18]. Although significant work has been proposed for the improvement of gain, directivity, and front-to-back ratio (FTBR) of the horn antenna, the optimum design of a thin substrate-based SIW horn antenna for lower frequency range (below Ku-band) is still missing.

Keeping the above discussions in our mind, we proposed a double-flared horn antenna for the application in X-band. By going through various literatures, we have found that this idea of horn design using artificial synthetic waveguide has not been reported yet. In this proposed model, we have used the double-flaring of waveguide for designing a horn antenna. Multiple flaring helps in reduction of cross-pol. level significantly. To match the impedance between horn aperture and free space two metallic strips is designed. This complete design using single substrate is advantageous for solving the common problem of high-cost non-planar integration. The designed simulation model is compact in size, simple to design, and easy to fabricate.

## 2. Horn Design and Analysis

The detailed geometry of the proposed horn with multiple flaring in the H-plane is shown in Fig. 1, with optimized geometrical parameter listed in Table I. As due to the planar nature of SIW, flaring of the walls is performed in H-plane using a single substrate.

### 2.1 Horn Design

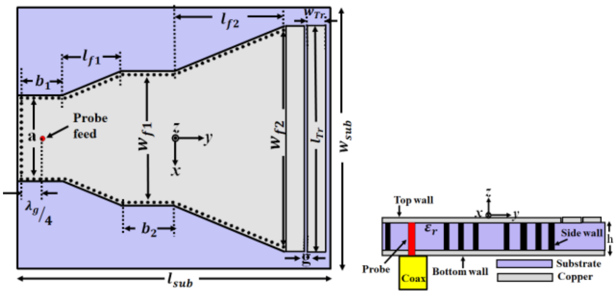
The first step towards designing the horn antenna is selection of appropriate substrate. The low loss thin substrate is chosen for better performance. The substrate is Rogers TMM3 having a height of 1.575 mm (62 mils), a permittivity of 3.27, and a dielectric loss tangent of 0.002. The complete horn design follows the same standards as mentioned in [19]. First, the waveguide with a cutoff frequency of 8 GHz to excite dominant ($TM_{11}$) mode is designed. After that, the first flaring is introduced and optimized for minimum electrical discontinuity at the throat. Similarly, another waveguide is designed to connect the first and second flaring at an appropriate angle. In this way, a complete planar integrated waveguide-based dual flared horn antenna is constructed. For feeding the entire structure SMA connector of 50Ω is design in the simulator. The feed is located at $\lambda_g/4$ distance from the vias array placed in the transverse plane. This feed positioning is associated with impedance matching, suppression of higher order modes, and reducing the phase error.

## 2.2 Design of Matching Unit

It is very well known that due to the thin substrate, the patterns and reflection coefficients behavior is inappropriate for horn applications. Therefore, for better performance in terms of radiation over a wide bandwidth, two metallic strips of equal length and width as a matching unit are loaded at the aperture of the grounded substrate. The gap between the two strips is considered for tuning the frequency of operation. The top and bottom copper-coated layers placed on the substrate are shorted through the metallic via arrays. These via arrays are designed as per SIW guidelines, which act as a metallic side wall of the horn antenna. Analysis of the both the E- and H-fields is carried out using 3D FEM-based EM simulator (ANSYS HFSS V.19.0).

## 3. Field Analysis

In the proposed design, we have optimized the structure so that only dominant ($TM_{11}$) mode gets excited. In this mode, the entire field component is independent of *z*; the electric field is everywhere parallel to the *z*-axis, whereas the magnetic field lies in the plane perpendicular to the *z*-axis. Therefore, the complete idea of fields can be derived from the *x-y* plane of the proposed antenna. The field distribution for $TM_{11}$mode for the proposed horn antenna with and without a matching unit is shown in Fig. 2 and 3, respectively. From Fig. 2(a) and 3(a), one can notice that the magnetic field vector at the throat region is more crowded than the horn's mouth. This is quite obvious because of the restriction in the passage of EM waves. As we move forward, we see the complete circulation of the field in the middle of the structure and the intensity decreases monotonically, as shown in [20]. From this important discussion, our electric and magnetic fields are orthogonal in the plane, similar to the plane wave in free space media. The big difference between Fig 2(a) and Fig. 3(a) is seen in the aperture region. In the first case, fields are directed along the x-axis, whereas in the second case, the magnetic field circulation can be seen. This difference clearly emphasizes the importance of the matching section (metallic strips) in the design horn antenna.




(a) (b)

**Figure 1.**Geometrical configuration of multi-flared horn (a) Top View (b) Side view

**TABLE I**
ANTENNA GEOMETRICAL PARAMETERS (UNIT IN MILLIMETERS)

| a | $b_1$ | $b_2$ | $l_{f1}$ | $w_{f1}$ | $l_{f2}$ |
|---|---|---|---|---|---|
| 19.4 | 9 | 12 | 14.94 | 30.67 | 27 |
| $w_{f2}$ | $l_{Tr}$ | $w_{Tr}$ | $l_{sub}$ | $w_{sub}$ | g |
| 51.98 | 54.45 | 4.57 | 75 | 62.78 | 0.45 |

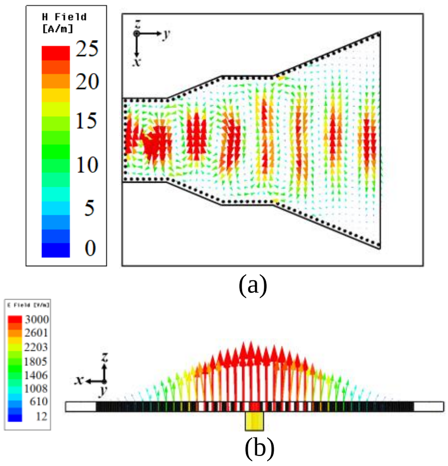



**Figure 2.**Vector form of field distribution for $TM_{11}$ mode in multiflared horn antenna without matching unit (a) magnetic field (b) electric field

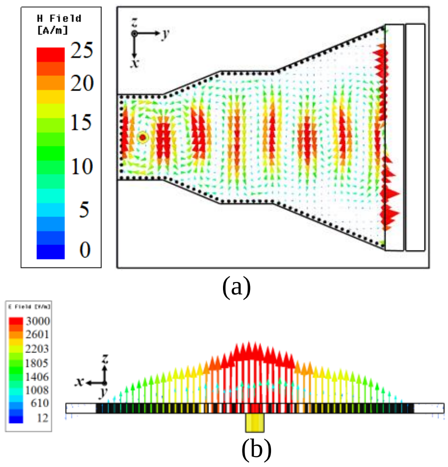



**Figure 3.**Vector form of field distribution $TM_{11}$mode in multiflared horn antenna with matching unit (a) magnetic field (b) electric field.

## 4. Results and Discussion

The standard design procedure proposes the simulation model of a double-flared SIW-based H-plane horn antenna. The design antenna is further loaded with metallic strips for unvarying phase and amplitude distribution at the aperture. The complete performance of the horn antenna is analyzed using HFSS simulator in terms of reflection coefficients and antenna radiation patterns.

### 4.1 Scattering Parameter

Figure 4 shows the reflection coefficients vs. freq. plot for both with and without matching unit. From Fig. 4, one can notice the importance of matching section in the antenna design. The dotted line represents the reflection coefficients without the metallic strips whereas the solid line represents the matched horn aperture and free space condition. Moreover, the width and the gap between the strips have its own importance in the impedance transformation of the proposed design. By optimizing the coupling space $(g)$ between the two strips, we can easily tune our frequency towards the high or low end of the operating band. Therefore we have a higher degree of freedom for adjusting our operational frequency and impedance bandwidth. The simulated reflection coefficients below -10 dB are between 9.05-11.11 GHz. The impedance bandwidth in the operating band is noted at 20.43 % with respect to the centre frequency of 10.08 GHz.

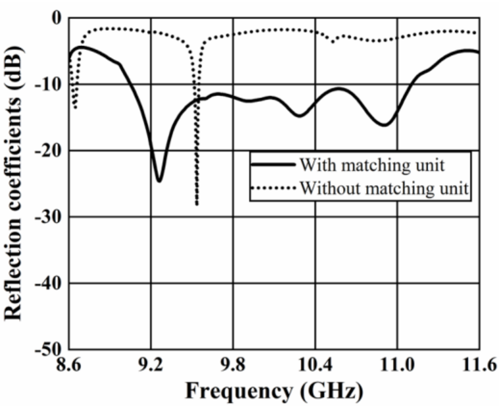
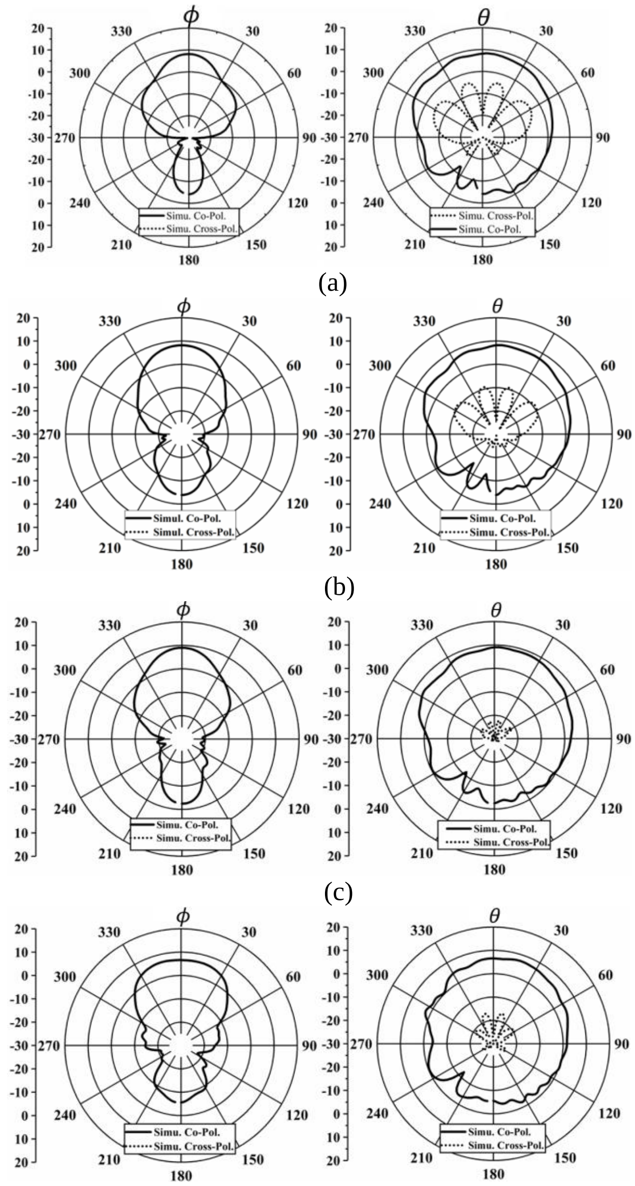



**Figure 4.** Reflection coefficients response of the double-flared horn.

### 4.2 Radiation Patterns

The field-pattern of the proposed horn at four different frequencies in the desired band is shown in Fig. 5. The field-pattern in both the *x-y* and *x-z* plane for a fixed flare angle shows stable radiation performance in all the mentioned frequencies. The cross-polarization in all the patterns is seen below -30 dB. The back radiation due to the small gap between the first metallic strip and horn aperture can be seen. At some frequencies, the beam is directive, whereas, at others, it is broad. The reason behind this pattern shape is that at some frequencies, the effective aperture area is less, and at others, it is more than the flare angle. It is required to optimize the flare angle so that more directive far field pattern in the *x-y* plane ($\phi = 90^0$) can be achieved in the entire frequency band.




*x-y* plane ($\phi = 90^o$) *x-z* plane ($\phi = 0^o$)

**Figure 5.** Radiation patterns of the double-flared horn. (a) at 9.26 GHz (b) at 9.68 GHz (c) 9.9 GHz (d) at 10.94 GHz

## 5. Conclusion

The simulation model of double-flared metallic strip loaded horn antenna for X-band applications is presented. Complete analysis in the form of far field patterns and mode study is carried out. The complete design is sketched on a grounded, thin substrate. Wide impedance bandwidth is achieved using two metallic strips at the mouth of the horn. The electric and magnetic field pattern show the clear idea of impedance transformation from SIW to free space. The far-field patterns in both the principal planes show stable performance having a maximum gain of 9 dB.

## 6. Acknowledgements

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