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Modified H-Plane Sectoral Horn for FSS Sensing Applications

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Abstract— The use of frequency selective surfaces (FSSs) as sensors has found recent success in the structural health monitoring realm. FSS theory assumes infinite FSS dimensions and planewave illumination. However, in practice, an FSS sensor is finite, and the illuminating field varies across the plane of the sensor. As such, it is of interest to reduce the nonuniformity of the incident electromagnetic energy incident on the sensor. To this end, this work explores the modification of a standard H-plane sectoral horn through the addition of a ridge to generate a uniform electric field over a specified region of interest. In addition to this modified antenna, standard gain (pyramidal) and H-plane sectoral horns were also considered for comparison. The results show that variation in the electric field pattern is reduced for the modified sectoral horn but at the cost of matching properties.

Keywords—Electric Field Pattern, Frequency Selective Surfaces, H-Plane Sectoral Horn, Ridged Sectoral Horn

I. Introduction

Frequency selective surfaces (FSSs) are periodic arrays of elements that serve as spatial filters for incident electromagnetic (EM) energy. Patch and slot-based elements can be used to create FSS designs, as well as the inclusion of a conductive backplane. The particular response of a given FSS can be reflective, transmissive, or both, and is dictated by element type, shape, and dimensions as well as (physical and EM) substrate properties. Historically, FSSs have been applied as radomes, filters, and reflectors [1], and more recently, as sensors [2]. FSSs are uniquely well-suited for sensing applications due to the dependance of the EM response on environmental/external factors such as strain (i.e., applied physical load) or temperature [3]. The wireless nature and remote interrogation increases the attractiveness of such an approach for sensing applications. In addition, when designed to include a conductive backplane, these sensors are reflective in nature and therefore offer a one-sided interrogation. This is of interest in many practical sensing applications where access to both sides of a structure may be limited.

Generally, FSS analysis assumes infinite physical FSS dimensions and a uniform illuminating electromagnetic field (i.e., planewave excitation). However, in practice, the FSS sensor is dimensionally finite and is interrogated with a nonuniform electric field (E-field). Moreover, structures and/or materials in the near vicinity of a sensor under interrogation may contribute towards the overall detected (reflection or transmission) response. To this end, it is of interest to tailor the EM interrogation in such a way as to emphasize the sensor itself while reducing the impact of objects in the vicinity of the sensor. One such method by which this can be achieved is through the design of a radiating antenna with a specific E-field pattern that is commensurate with the sensor dimensions. As such, this work proposes a modified H-plane sectoral horn as an interrogating antenna for FSS-based sensing. This particular antenna offers a pattern that is narrow in one dimension and wide orthogonally and was designed for sensing applications that feature a rectangular-shaped sensor. In this way, sensing needs for geometries dimensionally similar to the pattern may be interrogated with a reduced impact on the sensor response due to nearby objects.

II. Simulations

To begin, full wave simulations of the E-field distribution 9.5 cm from the aperture of three different horn antennas were conducted using CST Microwave Studio™. Horn antennas were selected due to their well-known properties and common availability. The horns considered here are a standard gain (pyramidal), H-plane sectoral, and a modified H-plane sectoral that includes a ridged portion within the flared section. The ridge was added to the standard H-plane sectoral design to increase uniformity of the E-field [4]. Table 1 contains the dimensions for each antenna, where a and b are the broad and narrow dimensions of the waveguide feeding the horn, respectively, A and B are the broad and narrow dimensions of the aperture, respectively, and C is the length of the antenna from the waveguide feed to the aperture (from the center of the waveguide to the center of the aperture).

Table 1: Antenna dimensions.

Antenna	*a (mm)*	*b (mm)*	*A (mm)*	*B (mm)*	*C (mm)*
Pyramidal	10.668	4.318	54.102	39.624	101.6
Sectoral	10.668	4.318	70.104	4.318	150.876
Ridged	10.668	4.318	70.104	4.318	150.876

All simulations were completed in the K-band (18-26.5 GHz). Fig. 1 shows three-dimensional renderings of the three horns, where Fig. 1a illustrates the standard gain (pyramidal) horn and Fig. 1b illustrates the H-plane sectoral horn. The ridged H-plane sectoral has the same overall dimensions as the standard

H-plane sectoral with differences between the two (the ridged portion) is shown in Fig. 1c. This ridged portion has a length of *C*/2 in the flared section and tapers over a distance of *C*/8 starting from the end closest to the aperture. The ridge also has a width of 1 cm and is centered with respect to *a*.

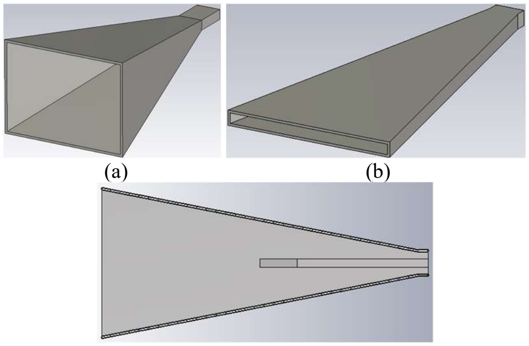

Fig. 1. Illustrations of pyramidal (a) and H-plane sectoral (b) horns, and a cutplane view of the ridged H-plane sectoral design (c).

The simulation result of interest is the magnitude of the 2D E-field distribution, comprised of all three orthogonal polarizations (*x*, *y*, and *z*), over a region with dimensions of 5 cm × 10 cm located 9.5 cm from and parallel to the horn aperture. These field patterns are shown in Fig. 2 for all three horns. As seen, the E-field distribution from the pyramidal horn (Fig. 2a) has a large amount of variation within the area of interest. As the goal is a uniform field to serve as an improved illumination for an FSS sensor, the H-plane sectoral horn shows improvement (Fig. 2b), but still has variation within the short dimension of the area of interest. Lastly, the ridged H-plane sectoral horn (Fig. 2c) has the least amount of variation throughout the area of interest (albeit with a reduced magnitude).

Since these antennas are under consideration for use with FSS-based sensing, the uniformity of E-field pattern is not the only parameter that must be considered. The return loss (RL) is also important, as the FSS response is often on the order of 0-15 dB. As such, the illuminating antenna should be well-matched (-20 dB or more for RL). To this end, Fig. 3 shows the RL for each horn. As seen, the RL for the pyramidal horn is less than -20 dB for essentially the entire frequency band. The standard and ridged sectoral horns, however, indicate a response that is ~10 dB higher than for the pyramidal horn. While a decrease in matching performance is evident in both sectoral designs, this is not unexpected as pyramidal horns are known for excellent matching properties [6]. As such, while both sectoral horns exhibit E-field characteristics that render them candidates for FSS sensing interrogation, further designed improvement is necessary to improve the matching characteristics.

III. Conclusion

In this work, a pyramidal, H-plane sectoral, and ridged H-plane horn antenna were considered as potential interrogators for FSS sensing. The pyramidal horn exhibited the most spatial variation in terms of E-field distribution, with improvement offered by both sectoral designs. The RL of the sectoral horns is greater than that of the pyramidal horn. The results presented suggest both sectoral horns may be suitable for FSS interrogation after designing to improve matching characteristics.

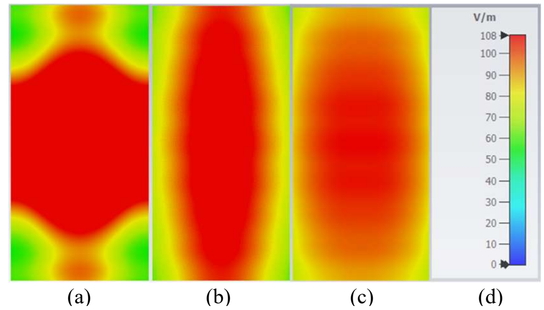

Fig. 2. E-field for pyramidal (a), h-plane (b), ridged (c), and scale (d).

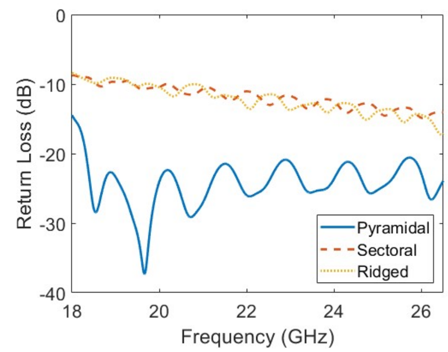

Fig. 3. RL for the pyramidal, h-plane sectoral, and ridged h-plane sectoral.

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