Gain Enhancement of a 94GHz LTCC Integrated Horn Antenna Using High Impedance Periphery

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***Abstract*—There is a growing interest to implement antenna-in-package (AiP) systems for a variety of applications such as imaging, beamforming, integrated transceivers, and radars. Substrate integrated pyramidal antennas are valuable AiP candidates owing to their small form factor, integration ease, and high gain. However, height reduction, dielectric losses and integration of the latter can drastically degrade their gain pattern and limit their applications. This degradation is mainly due to undesired excitations on the surface of the dielectric. For the first time in this paper, we present a Grounded Co-Planar Waveguide-fed (GCPW) 94GHz low temperature cofired ceramic (LTCC) pyramidal horn antenna. To prevent parasitic TE excitations, a mushroom type High Impedance Surface (HIS) periphery is implemented. The combined antenna with HIS surrounding leads to approximately 2.3dB improvement in gain. Concurrently, the 3dB beamwidth is reduced by 26° in both E-Plane and H-Plane.**

***Index Terms*—94GHz, Antenna in Package,High Impedance Surface (HIS), Low Temperature Co-fired Ceramic (LTCC),**

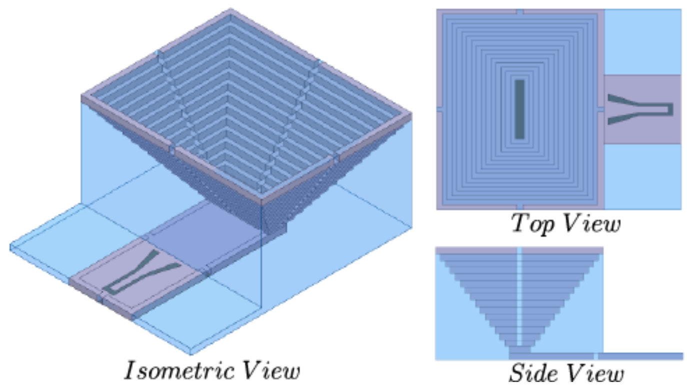

Fig. 1. Substrate Integrated Horn Antenna on LTCC.

I. Introduction

Low temperature co-fired ceramic (LTCC) is a low cost and high density integration packaging technology. LTCC also enables multilayer antenna fabrication and offers better control on the number of layers as compared to classical printed circuit boards (PCB) [1]. Nevertheless, LTCC fabrication suffers from a number of drawbacks. For instance, a commonly used substrate, the DuPont 9K7 Tape ($\epsilon_r = 7.1$), imposes stringent limitations on the fabrication which can drastically impact the performance of horns and leads to parasitic excitations. Also, the layer-by-layer implementation is done using laser etched via walls technology to create the integrated structure. These imperfect walls cause leakage that can potentially excite parasitic fields on the dielectric and lead to back radiation and directivity loss.

In this paper, we present the fabrication process analysis of a novel substrate integrated pyramidal horn antenna operating at 94GHz. To reduce the parasitic excitations on the surface of the dielectric, we place a high impedance surface ring around the aperture periphery using mushroom structures [2]. The latter were chosen for their design simplicity.

II. Design and Fabrication Process Consideration

A. Integrated Horn Antenna

Fig. 1 presents the rendering an integrated pyramidal horn antenna operating at 94GHz. The walls of the metallic horn were discretized according to the *fired* thickness of the LTCC layers. That is, the integrated horn is a stepped version of the smooth surface horn. Few gaps of material are kept on the center of every frame for fabrication purpose. These gaps are carefully chosen to minimize leakage and the current flow inside and outside the antenna. This leakage can excite undesired diffracted fields that may lead to directivity loss and deformation of the radiation pattern.

As depicted on Fig. 1, the antenna is fed by a grounded co-planar waveguide designed to match a 50Ω W-Band probe. Fig. 2 depicts a side view of the horn antenna showing the etched walls at every layer with respect to two slopes P_x and P_y along the x and y axis, respectively :

$$P_x = \frac{2Nh}{A-a} \text{ and } P_y = \frac{2Nh}{B-b} \tag{1}$$

In the above, A and B refer to the horn's aperture size along the x and y direction respectively, h is the height of one ceramic layer and N is the number of layers comprising the horn. In our case, we use $N = 15$.

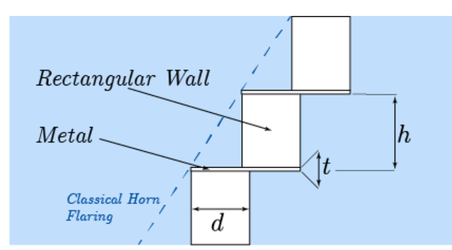

Fig. 2. Integrated horn using rectangular walls to create the inner surface.

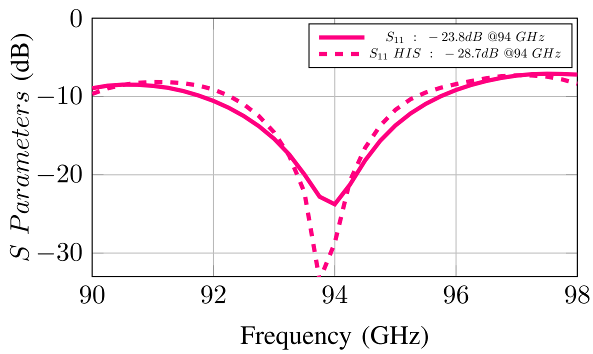

Fig. 3. Reflection coefficient of the GCPW-fed horn, with and without its HIS periphery.

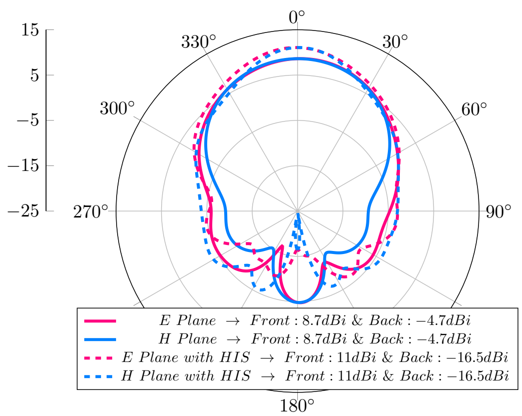

Fig. 4. GCPW-fed pyramidal horn realized gain at 94GHz, with and without its HIS periphery

The radiation pattern, presented in Fig. 4, shows a considerable back radiation with a main back lobe located at $\theta = 180°$. Notably, the front-to-back ratio is slightly higher than 13dB and the 3dB beamwidth in both planes is approximately 62°. An attractive solution to improve the performance of the antenna is using HIS periphery to suppress surface currents and prevent edge diffraction along the aperture's periphery. This is discussed below.

B. High Impedance Surface (HIS)

HIS structures are periodic and frequency selective structures. One of the earliest periodic surfaces is that of the mushroom structure [3], as depicted in Fig. 5. This structure is equivalent to a LC circuit. Notably, it was designed to have a resonance frequency and a maximum impedance at 94GHz. The subject resonance frequency of the HIS is given by:

$$f_r = \frac{1}{2\pi\sqrt{LC}}, \tag{2}$$

where L and C are the equivalent inductance and capacitance, respectively. Here :

$$L = \mu_0 h_e \quad \text{and} \quad C = \epsilon_0 \frac{1+\epsilon_r}{\pi}.W_e.cosh^{-1}(\frac{W_e}{g_e}+1) \tag{3}$$

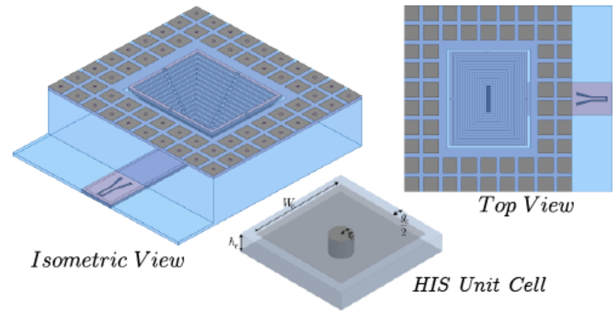

Fig. 5. Integrated Horn Antenna with its HIS Periphery

where μ_0 is the free space permeability, h_e the height of the substrate, W_e the width of the patch forming the mushroom and g_e is the gap between two successive HIS cells.

III. Simulated Performances

The HIS structure is then integrated around the horn antenna. We use two rows of unit cells to ensure efficiency in the suppression of undesired TE excitations from the horn aperture's periphery. As depicted in Figs. 5 the HIS cells are located at the top of the 15 layer structure horn antenna.

The radiation pattern of the horn with the HIS periphery is depicted in Fig. 4. As seen, back radiation is significantly reduced by 11.8dB in both E and H-Planes. The 3dB beamwidth is also reduced and is around 36° for both E and H-planes. This is a reduction of the beamwidth of about 26° as compared to the case without the HIS ribbons around the aperture. The resulting gain improvement is about 1.8dB.

IV. Conclusion and Remark

We presented a 94GHz LTCC approach to fabricate an integrated pyramidal horn antenna with integrated HIS ribbons around its aperture to suppress undesired diffraction. The HIS ribbons around the LTCC pyramidal horn led to significant reduction of the backward radiations lobes. As a result, the realized gain increased by 2.3dB at 94GHz. During the meeting, we will present fabrication details and challenges.

References

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