Ultrawideband Flush-Mounted Antenna

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***Abstract*— A wideband compact antenna which can be flush mounted on a platform for high-power broadside transmitting applications is introduced. The proposed design comprises a TEM horn embedded in a shaped rectangular cavity. The detrimental interaction with the lossless cavity is mitigated by properly integrating the TEM horn inside the cavity. This approach allows the antenna to radiate as an aperture antenna at low frequencies while maintaining good radiation features from the TEM horn at higher frequencies. Elliptically-shaped ridges are also added inside the cavity to improve gain and the quality of radiation patterns at the high frequency end. The proposed antenna has electrical size of ~ $0.28\lambda \times 0.54\lambda \times 0.3\lambda$ (length × width × depth) at the turn-on frequency and has VSWR<2, gain>5dBi, and good radiation patterns with low cross polarization from 2 to 7GHz.**

***Index Terms*— Cavity backing, flush mounting, ultrawideband antennas, TEM horn**

I. INTRODUCTION

THE demand for ultrawideband (UWB) broadside, high-power, and flush mountable antennas is growing; particularly for unmanned aerial vehicle (UAV), aircrafts, and electronic warfare applications [1]. Typically, these antennas should be compact, lightweight, and axially short (shallow) with high power handling to comply with the size, weight, and power (SWAP) requirements of the intended applications [2]. In contrast to the low-profile end-fire antennas [1], not many compact and short wideband broadside antennas are available. Cavity-backed planar spiral [3] and log periodic [4] antennas are often utilized for wideband airborne and automotive applications. However, the limited power handling and the need for a deep cavity to achieve good impedance match and gain restrict the applications thereof. The wideband cavity-backed magneto-electric dipole has a low profile [5]; however, it has relatively large aperture and its patterns have some deficiencies at high end. Ridged waveguide horn antennas [6]-[9] have wide bandwidth, high power handling, and they can be flush-mounted on the platform surface. However, their large size and profile limit their use in the considered systems. Transvers electromagnetic (TEM) horn is another candidate that can be designed to meet SWAP requirements [10]-[11]. As demonstrated in [11], this antenna can be miniaturized about three times by simple geometrical modifications while improving its far-field performance and maintaining its high power handling capability. Yet, the antenna still needs to be recessed in a metallic cavity without significantly compromising the size and overall performance.

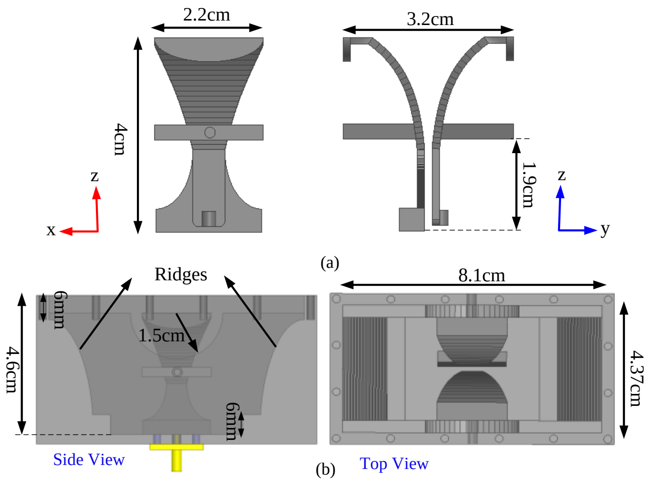

Fig.1. (a) Designed TEM horn antenna and (b) TEM horn as recessed and connected to the cavity.

This paper discusses the design of a TEM horn antenna embedded in a metallic cavity (Fig. 1) for performance in 2-7GHz range. The antenna is physically integrated with enclosure to achieve desired interaction with the cavity and good performance without the negative impact of inherent resonances. The cavity size and shape are modified to achieve desired impedance match at the low end and preserve pattern integrity at the high end. Compact size is maintained and decent performance is demonstrated computationally and experimentally.

II. ANTENNA DESIGN

The initial design of a compact combined TEM horn-loop antenna is based on the procedures given in [11]. The antenna, shown in the inset of Fig. 2(a), combines an exponential TEM horn and a metallic loop routed along the back of the antenna. Crescent slots and bow-tie shaped plates are added along the loop to simultaneously lower the turn-on frequency and improve the gain at the low frequency end while maintaining decent performance at higher frequencies.

The free-standing antenna operates with good impedance match (VSWR<2) and stable gain (>4dBi) along the antenna

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axis (Fig. 2). The antenna is then enclosed in a 8cm × 8cm × 4cm metallic cavity as shown in the inset of Fig. 2(b). The utilized cavity supports multiple modes or resonances over the considered frequency band. The excitation of the TEM horn induces currents on the cavity walls and consequently excites several undesired resonances which negatively impact the VSWR, gain, and the quality of the radiation patterns. The VSWR spikes and gain dips, shown in Fig. 2, around 2.03GHz and 3.85GHz demonstrate the deleterious impact due to the establishment of high Q-factor cavity modes. The conventional approach to dampen these resonances and mitigate the undesired interaction is to load the cavity with magnetic absorber (e.g. silicone rubber loaded with ferrites or iron) which has high permittivity, permeability, and magnetic loss [12]. The performance of the antenna in an absorber-loaded cavity is also shown in Fig. 2. As seen, good and stable VSWR and gain are restored at the expense of antenna efficiency (radiation efficiency ~ 60% at the low end) which is not desired for the considered high-power applications.

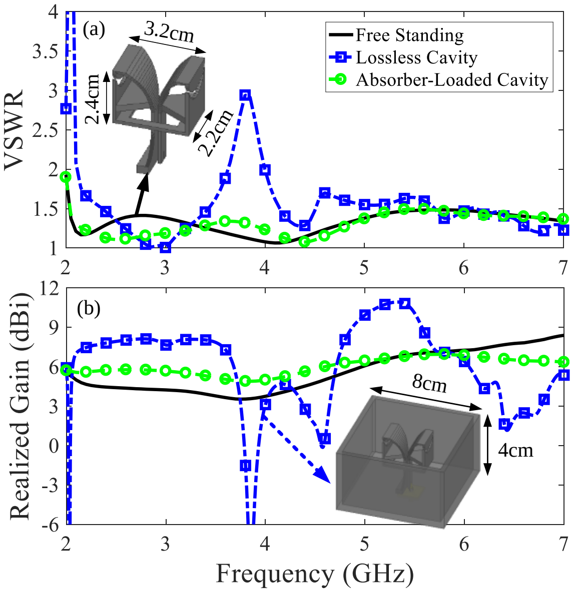

Fig.2. (a) VSWR and (b) realized gain of TEM horn in the free standing case and when it is recessed in lossless and absorber-loaded cavities.

It is well-known that the cavity size and shape play important role in the excitation of its modes. Smaller shaped cavity may have the undesired modes excited outside the operational bandwidth. However, in this design, the cavity depth is limited by the antenna height and it cannot be further reduced. Also, the cavity width (in H-plane) needs to be sufficiently large not to affect the TEM horn performance. To maintain good impedance match at 2GHz, the minimum width is found to be 8cm. The impact of the cavity length (in E-plane) and shape is studied for the selected cavity width and depth. For different cylindrical, rectangular, and polygon cavity shapes, it is found that the cavity resonances are still excited over the considered frequency range which limits the applications of this approach.

Another effective approach to eliminate cavity resonances is based on properly positioning and integrating antenna inside the cavity. For instance, in [13], a resonant-free cavity-backed Vivaldi array is realized by connecting the array's edge elements in E-plane to the cavity walls. Therein, the direct electrical connection eliminates the undesired resonances and aids exciting the radiating modes of a rectangular aperture antenna formed by the cavity. Herein, when the TEM horn is connected directly to the cavity walls in E-plane, the (VSWR=2) turn-on frequency increases ~1.4 times from 2GHz to 2.8GHz as shown in Fig. 3(a). The traveling wave current reaching the TEM horn aperture does not radiate efficiently or transit smoothly to the cavity walls; instead it reflects back toward the feed causing impedance match degradation at the low end. Notice that the integration of the loop part, shown in inset of Fig. 2(a), is not necessary in the direct connection case since the antenna is shorted to the cavity. The cavity walls are supposed to have the loop functionality of decreasing the reflections from the horn's aperture and reducing the capacitive reactive energy around the TEM horn which is not fully achieved in this case.

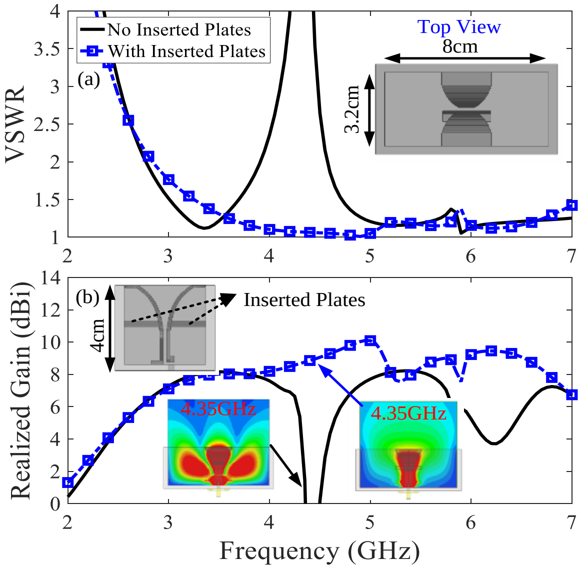

Fig.3. (a) VSWR and (b) realized gain when the TEM horn is connected to the cavity walls with and without the inserted plates. Also, H-plane electric field distributions at 4.35GHz are shown in the inset.

Another important observation from Fig. 3 is the effect of the inserted plates (inset of Fig. 3(b)). As seen, connecting the antenna only at the aperture does not fully eliminate the cavity resonance which still occurs around 4.35GHz. The elimination of the resonance is achieved by connecting the plates to the cavity. This connection eliminates the establishment of the standing-wave currents on the E-plane walls leading to stable gain and VSWR performance as shown in Fig. 3. The electric field distributions, shown in the inset of Fig. 3, demonstrate the impact of the inserted plates on eliminating the undesired cavity modes. In this design, the plates are inserted at 1.9cm from the cavity bottom.

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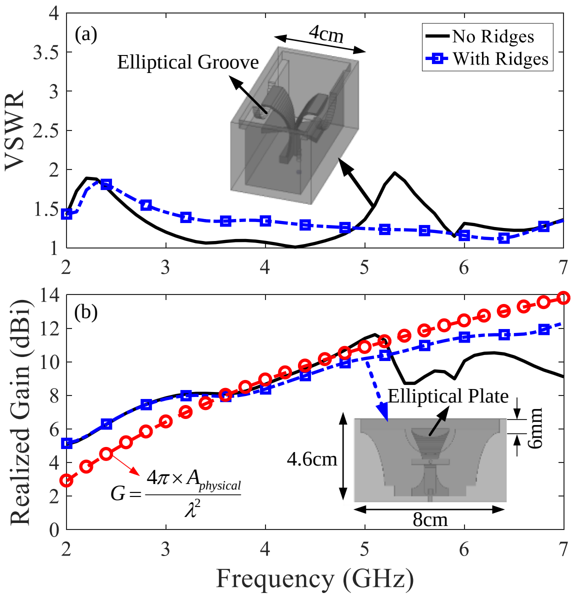

Fig.4. (a) VSWR and (b) realized gain of the TEM horn with and without the cavity ridges. The theoretical gain of an aperture antenna with the same size is also depicted.

Although the undesired resonances are avoided using the discussed approach, two issues still exist: the impedance match degradation at the low end and the gain drop at higher frequencies around 5GHz. The impedance match issue is mitigated by eliminating the discussed direct electrical connection and establishing instead a proper capacitive coupling between the cavity and the TEM horn aperture. This coupling helps reduce the aperture reflection and tune the TEM horn input impedance at the low frequency-end, and can be controlled by modifying the TEM horn and the cavity shapes near the aperture. A good performance is achieved with a configuration adopted from the combined antenna geometry [11]. As depicted in the inset of Fig. 4(a), half elliptical plates and grooves are added to the TEM horn and E-plane cavity walls; respectively. The dimensions of these additions are tuned to facilitate the desired coupling at the low frequency end without affecting antenna performance at higher frequencies. Herein, the major and minor radii of the half elliptical plates are 22mm and 4.6mm; whereas, they are 30mm and 15mm for the grooves. The thickness of the groove (in E-plane) is 4.16mm. Also it is found that slightly recessing the antenna inside the cavity helps the impedance match at the turn-on frequency without any noticeable effect on its gain. Herein the TEM horn is recessed 6mm as shown in the inset of Fig. 4(b). VSWR< 2 is achieved over the operating bandwidth using the proposed method. The gain issue at higher frequencies is mitigated by adding elliptically-shaped ridges in the H-plane cavity walls. The added ridges help forming a constructive radiation from the TEM horn and the cavity and suppress the radiation of undesired higher order modes as shown in Fig. 5. As seen, the ridges slightly affect the field distribution and thus the overall performance at the low and mid bands while improving gain, and radiation patterns at higher frequencies (above 5GHz). The theoretical gain of a uniformly-excited rectangular aperture of identical aperture size as the cavity is also plotted in Fig. 4(b). It can be observed that the designed antenna has higher gain at the low frequencies due to the fringing fields at the aperture which contribute to the increased electrical size [13]. As the frequency increases, less uniform illumination occurs due to the more directive radiation from the TEM horn and impact of cavity ridges at higher frequencies; therefore lower gain and aperture efficiency are observed.

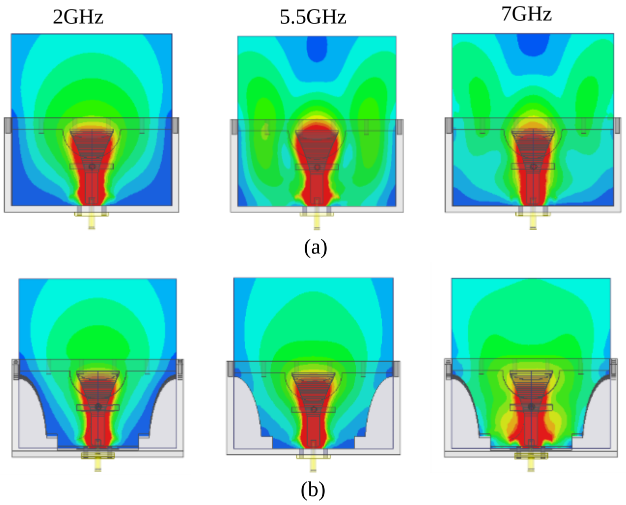

Fig.5. H-plane electric field distribution of the proposed design (a) without and (b) with the cavity ridges at 2GHz, 5.5GHz, and 7GHz.

III. FABRICATION AND MEASUREMENTS

After straightforward parametric studies aimed to improve the design shown in the inset of Fig. 4(b); specifically, the VSWR at the low frequency end, the final design is built from three CNC machined parts (rectangular cavity and TEM horn top and bottom plates). The geometry of the fabricated antenna and its dimensions are shown in Fig. 1. A short balun that transforms a 50Ω microstrip line to 65Ω parallel plate transmission line at the input of the TEM horn is integrated as shown in Fig. 1(a). The inserted plates are machined with the TEM horn plates and are attached to the cavity walls as shown in Fig. 1(b). N-type coaxial connector is attached to the balun and the bottom of the cavity.

Good impedance match with VSWR <1.5 over most of the band is measured as shown in Fig. 6. The measured realized gain is above 5dBi and it consistently increases with frequency. Excellent agreement is achieved between measurements and full-wave simulations. Measured and simulated E- and H-plane radiation patterns are shown in Fig. 7. Symmetric radiation patterns with low cross-polarized level (cross-polarization discrimination (XPD) is >20dB over most of the band) are obtained in both planes. H-plane patterns are more directive as expected since the aperture has larger dimension in this plane. The antenna is measured at the Naval

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Research Laboratory with input power >200W without any issues [14]. Comparison with several compact flush-mounted antennas in terms of electrical size at the turn-on frequency defined at VSWR=2 and gain over 3.5:1 bandwidth (BW) is presented in Table I. The compactness and good electrical features including decent gain and high aperture efficiency of the proposed design can be easily observed.

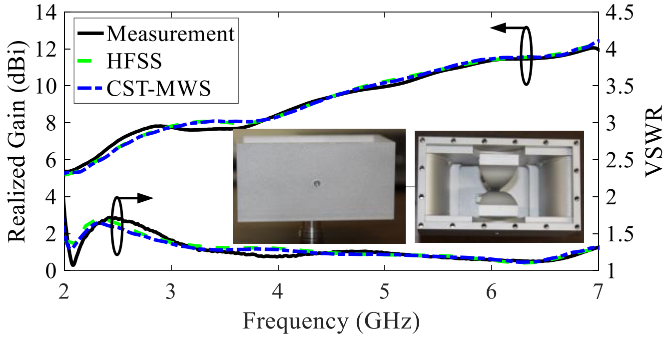
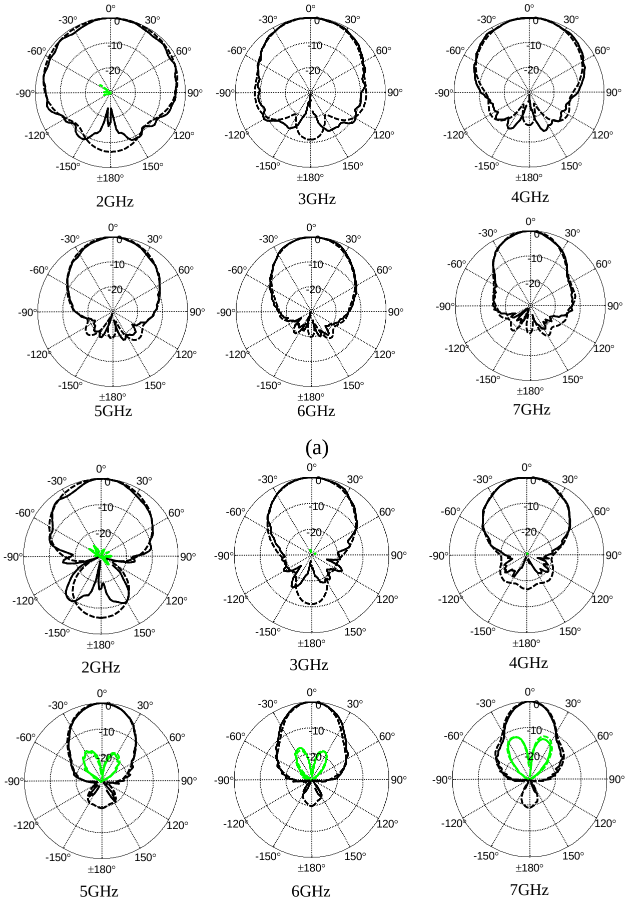


Fig.6. Measured and simulated VSWR and realized gain of the fabricated antenna shown in the inset.



(a)

(b)

Fig.7. Measured (solid) and simulated (dashed) (a) E- and (b) H-plane co- (dark) and cross-polarized (light) radiation patterns of the fabricated antenna.

IV. CONCLUSION

Wideband flush-mounted TEM horn antenna is introduced. The flush-mounting is realized by recessing the antenna in a metallic cavity and integrating it with the walls to eliminate cavity modes over the operating bandwidth. Design procedure and various theoretical considerations are discussed. The fabricated antenna has compact size, VSWR < 2, gain > 5dBi, and high quality radiation patterns over 3.5:1 bandwidth. The bandwidth of operation can be further extended by better balun design and few geometrical adjustments including the cavity size, ridges shape, and TEM horn height.

Table I: Comparison with existing flush-mounted antennas.

Design	**Size (W×L×H)**	**Gain (3.5:1 BW)**
This work	$0.28\lambda \times 0.54\lambda \times 0.30\lambda$	5.3-12.2dBi
[4]	$0.54\lambda \times 0.54\lambda \times 0.12\lambda$	0.10-7.5dBi
[5]	$0.64\lambda \times 0.64\lambda \times 0.155\lambda$	5.0-9.5dBi
[6]	$0.55\lambda \times 0.84\lambda \times 0.66\lambda$	6.0-9.70dBi
[7]	$0.46\lambda \times 0.80\lambda \times 0.61\lambda$	6.0-11.7dBi
[8]	$0.45\lambda \times 0.91\lambda \times 0.33\lambda$	6.0-10.0dBi
[9]	$1.42\lambda \times 1.42\lambda \times 0.37\lambda$	9.15-11.6dBi

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