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Ruggedized Surface-mount Omni-directional Antenna for Supersonic Aerial Platforms

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Abstract— A rugged metal protected antenna that produces an omnidirectional radiation pattern is proposed in this letter. The omnidirectionality is achieved by using a cavity enclosed PCB (Printed Circuit Board) with $\lambda/4$ transformers and ground shortening pins combination. The slotted cavity filled with ablative material is designed to maintain the radiation characteristics of the enclosed PCB and provide strength for the antenna arrangement, which can be effectively used on high-speed aerial platforms. The simulated and measured results demonstrate that the proposed antenna possesses a stable omnidirectional radiation pattern, its horizontal gain is higher than -1.5 dB, the azimuthal gain ripple is within ± 0.7 dB, and the antenna efficiency exceeds 85%, over the entire operational frequency band. In addition, the conformal, tapered, non-protruding, low-profile and DC-grounded design makes winged antennas superior candidate for supersonic (Mach > 1) airborne applications.

Index Terms— Airborne antenna, conformal antenna, aerodynamically stable, cavity enclosed radiator, high-speed platforms

I. INTRODUCTION

On high-speed aerial platforms, blade and stub antennas are generally deployed, because of their omnidirectional radiation characteristics and uniform horizontal gain with vertical polarization [1, 2]. Nevertheless, such antennas protrude from aerial platforms, which enhances the radar-cross-section (RCS). Reduced RCS is critical and vital for stealth and defense applications [3, 4]. Moreover, the protruding structure increases air resistance, increases cabin noise, and is more susceptible to damage and corrosion, due to high-speed mobility or high aero-heating environment [5-7].

Surface-mounted or flush-mounted conformal antennas are the focus of high-speed platforms for reliable aerodynamic performance. These configurations can be designed using the concept of shunt fed antennas, available in classical literature [8, 9], whose variants lead to recent innovations, like the one in [10]. Airborne communication systems require omnidirectional antennas with good horizontal gain and low azimuth gain ripple to achieve stable discontinuous coverage at all yaw angles [11, 12]. An omnidirectional conformal on-glass antenna with coupled-feed was presented in [13], targeting durability and to minimize weight and wind resistance. But its azimuth gain is very low, below -10 dB at several angles. In [14], a conformal antenna using an L-shaped monopole configuration was exhibited, but with a quasi-omnidirectional horizontal pattern, having gain ripple of 6dB in azimuth plane. In [15], an inverted L-shaped aircraft antenna using ground edge current was proposed.

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Nevertheless, with the high azimuth gain ripple of 10 dB. A conformal sabre-like structure with an omnidirectional radiation pattern, having the yaw plane gain change of 3.45 dB was proposed in [16] for airborne applications.

On the other hand, with the development of technology, kinetic kill weapons and ultra-high-speed vehicles have become technically and economically feasible [17]. Such platforms have to face extreme aerodynamic circumstances, which will put more pressure on the PCB materials/printed antennas than they can handle. Therefore, in addition to low-profile and surface-mount antennas, closed antennas based on metal alloys or metal cavities must also be used to provide shielding for vulnerable components to withstand harsh conditions and to have better heat and damage resistance [18].

In this letter, for targeting the beam-pattern and aerodynamic requirements of high-speed aviation platform applications, a metal cavity embedded, DC grounded, surface-mounted antenna is proposed, which has an omnidirectional radiation pattern with good uniform horizontal gain and low azimuth gain ripple. Section II describes the structure and principle of the proposed antenna arrangement. Section III discusses the simulated and measured results, while the conclusions are in section IV.

II. ANTENNA FORMULATION

The surface-mounted omnidirectional antenna, illustrated in Figure 1, consists of a slotted-metallic cavity enclosed, planar center-fed configuration designed using Roger RT/duroid 5880 ($\epsilon_r = 2.2$), with a thickness of 4.71mm.

Fig. 1. Proposed tapered metal cavity embedded omnidirectional antenna formulation (with dimensions in mm)

The embedded configuration comprises of a radiating patch engraved with four $\lambda/4$ transformers and ground shortening pins. The length of the square-shaped radiating patch mainly defines the operational frequency of the proposed antenna, in correlation with the shortening pins. This can be approximated by first analyzing the resonance of a periodic substrate integrated structure [19]. The width of pin short area of the antenna can be given by

$$W_{eff} = W - \frac{d^2}{0.95s}, \quad (1)$$

where d is the diameter of the pin-short. The fundamental resonance frequency and $TE_{m,n}$ electric field of the substrate integrated waveguide surrounded by the pin-short was given in [20] as

$$f_{m,n} = \frac{c}{2\sqrt{\epsilon_r\mu_r}} \sqrt{\left(\frac{m}{W_{eff}}\right)^2 + \left(\frac{n}{W_{eff}}\right)^2}, \quad (2)$$

$$E_z = A_{m,n} \sin\left(\frac{m\pi x}{W_{eff}}\right) \sin\left(\frac{n\pi y}{W_{eff}}\right). \quad (3)$$

While m and n are the mode numbers. Equation (1) to (3) can be used to engineer the four resonant areas within the resonator integrated with shortening pin walls. The transformers having an impedance of 200Ω each are designed using slots, to attain perfect impedance matching of 50Ω at the center of the radiator (fed-point) [21]. A center-fed symmetric structure contributes to achieve better radiation pattern symmetry in the azimuth plane, to avoid coverage fluctuation. Pin shortenings descending from the patch to the full ground bottom layer, establishing a loop like formation, leads to realizing an omnidirectional pattern by making all the four sides of the patch to radiate with maximum field intensity. Figure 2 exhibits that the electric field intensity is minimum at the points where the grounded pin shorts are used, whereas all sides of the patch contain well-distributed main propagation energy. A layer of Roger RT/duroid 5880 with a thickness of 1.575mm is placed over the patch to provide insulation between the radiator and the DC grounded cavity. The DC grounding of an antenna is an efficient and effective method to avoid ESD (Electrostatic discharge) issues and to provide lightning protection for evading malfunctioning and damages [22].

Fig. 2. Electric field behavior over the patch radiator

In the metal structure, aperture slots are formed on the edges of the embedded radiation patch to generate coupling and let energy to be radiated effectively in an omnidirectional manner. Narrowing the width of cavity aperture slots will reduce the horizontal gain and antenna efficiency, so the appropriate slot width is set to obtain good azimuth radiation performance. Figure 3 shows that the antenna

efficiency varies with the change in width of the slots. The efficiency of the proposed antenna formulation increases with the increase in metallic slot width, till slot width reaches 2.6mm. With further increase in width of aperture slot, the antenna efficiency remains stable. To provide optimal strength to the antenna structure, the minimum slot width at which optimum efficiency can be achieved is used. The results show that, under the adjusted slot width, the antenna efficiency of the proposed antenna is greater than 85% over the whole operational frequency band.

Fig. 3. Antenna efficiency of the designed formulation at different values of the metal cavity aperture slot width (dimension in mm)

Fig. 4. Field behavior of the proposed antenna arrangement at 2.65 GHz, (a) Electric (b) Magnetic

The aperture slots of the metal structure are filled using ablative epoxy ($\epsilon_r = 3$), to maintain physical strength and aerodynamic robustness of the designed antenna arrangement. Ablative epoxy is filled in a way, not only can cover the aperture slots, but can fill even the minor air gaps within the metal cavity, and avoid oxidation and

ionization at extreme temperature conditions. Electric and magnetic fields distributions of the proposed antenna are viewable in Figure 4, demonstrating the operational mechanism and realization of omnidirectional radiation characteristics.

III. SIMULATED AND MEASURED RESULTS

S-parameter simulations are performed using CST (Computer Software Technology), whereas measurements of the prototype are carried-out using Agilent Vector Network Analyzer. Simulated and measured reflection co-efficient contours along with the fabricated antenna picture are viewable in Figure 5. Simulated and measured results are well in harmony. Measured results show that the proposed antenna is effectively operational over the frequency band ranging from 2.63 GHz to 2.67 GHz.

Fig. 5. Reflection co-efficient of the proposed Omni-directional antenna

Figure 6 displays the simulated and measured radiation patterns of the proposed antenna arrangement at 2.64 GHz. Simulated results are taken using CST software, whereas antenna measurements are conducted at NSI anechoic chamber. Radiation characteristics are analyzed along yz and xy planes, representing vertical and horizontal planes, respectively. Both the simulated and measured beam-patterns are in very good agreement and flaunts good omnidirectional radiation characteristics. Achieved omnidirectional radiation patterns are worthy of having placement liberty and large coverage area, along with having unwavering and steady communication during mobility and maneuvering of portable aerial platform.

Fig. 6. Simulated (blue dashed) and Measured (red solid) radiation patterns of the demonstrated antenna in E-plane and H-plane at 2.64 GHz

Minimum horizontal gain and peak gain over the entire functional frequency band of the proposed ruggedized omnidirectional antenna are illustrated in Figure 7. Results depict that the proposed cavity embedded arrangement possesses good horizontal gain (more than -1.5 dB) and low azimuth gain ripple of ± 0.7 dB through-out the operational bandwidth. Moreover, Figure 6 and Figure 7 shows that the radiation pattern characteristics remain stable and similar over

the whole functional frequency band. Thus, the proposed antenna arrangement demonstrates very promising and commendable radiation characteristics, making antenna prospective candidate for airborne applications.

Fig. 7. Simulated (blue dashed) and Measured (red solid) minimum horizontal gain (cross) and peak gain (circle) of the proposed antenna

The proposed omnidirectional antenna formulation offers better radiation characteristics in comparison with several previously presented research efforts for airborne applications in-terms of horizontal gain and azimuth gain ripple, as can be seen from Table 1. At the same time tapered cavity enclosed surface-mount antenna provide better robustness and aerodynamic stability being more ruggedized and metallic cavity protected / enclosed. Though, [12] presents a radome enclosed structure, but has air-gaps within a radome, which reduces the aerodynamic strength. Thus, the proposed formulation tends to be a superior option, especially for supersonic airborne platforms.

TABLE I. COMPARISON WITH PREVIOUS WORK

Ref.	Durability / Conformal Technique	Max. Ant. Dim. (mm)	Lowest Functional Freq. (MHz)	Min. Az. Gain (dB)	Horizontal Gain Ripple (dB)	Radome or Metal Protected
[13]	On-Glass antenna	1972*	30	-14	> 10	No
[14]	L-shaped monopole loaded design	130*	807	-6	6	No
[15]	Inverted L with one folding	1510*	20	-11.5	10	Yes
[16]	Sabre-like structure	42*	2400	-2	3.45	No
This work	Tapered Surface-mount cavity	57*	2630	-1.4	1.4	Yes

* excluding ground plane, being part of the aircraft

IV. CONCLUSION

A sturdy surface-mounted omnidirectional antenna is proposed, where the antenna consists of a cavity enclosed PCB configuration having $\lambda/4$ transformers and ground shortening pins to generate omnidirectional beam-pattern. DC grounded, tapered, slotted cavity covers the PCB configuration to offer strength and protection against severe aerodynamic conditions. The proposed antenna arrangement possesses good linear yaw-plane gain, low horizontal gain ripple, symmetric azimuth pattern, decent antenna efficiency and stable omnidirectional radiation characteristics all over the operational frequency band. Furthermore, being non-protruding and having a

simple feeding mechanism with the full ground plane, the proposed antenna does not have extravagant RCS and provide ease of mounting over the aerial vehicle.

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