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A Conformal Cavity-Backed Supergain Slot Antenna

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Abstract—A conformal supergain slot antenna is presented in this paper, which comprises a thin substrate on the top broad wall of a shallow metallic cavity. Three slots with different lengths are etched out at suitable positions of the cavity wall to enhance the bandwidth as well as to achieve the supergain. A large ground is employed to obtain the near-end-fire radiation pattern. The proposed conformal antenna operates at the center frequency of 10 GHz. Simulated results show that a fractional bandwidth of 15% and maximum gain of 9.1 dB can be obtained for the three-slot conformal structure, the maximum radiation pattern tilts 38° from the end-fire direction. A prototype of the proposed antenna is fabricated and tested. Measured results are in good agreement with simulated ones.

I. INTRODUCTION

Conformal antennas can be flush-mounted on the curved surface for specific electromagnetic and mechanic requirements [1]. It is of great interest to design supergain and end-fire antennas for aircraft and missile applications. In principle, the end-fire gain can approach N^2 for a closely spaced N -element array of isotropic radiators [2]. However, the supergain antennas suffer from the low radiation efficiency, high mismatch loss, and narrow bandwidth [3]. Much work has been reported to overcome the limitations, most of which are related to dipole and monopole antennas. Folded arm technique [4], decoupling and matching networks [5], and bow-tie structures [6] were employed to improve the impedance matching, and to enhance the bandwidth. In [6], a compact three-element monopole Yagi supergain antenna with an element spacing of 0.053λ was designed, achieving a gain of above 9 dB over 10% fractional bandwidth.

In this paper, we propose a conformal cavity-backed supergain slot antenna, which can be mounted on the missile surface. Studies have been conducted to investigate the effects of the ground shape and size on the antenna's return loss and radiation pattern. A large ground is utilized to obtain the near-end-fire radiation pattern. The conformal antenna operates at the X-band and has the advantages of compact cavity size, enhanced bandwidth, and high radiation efficiency.

II. ANTENNA CONFIGURATION

The configuration of the proposed antenna is shown in Fig. 1. A curved Duroid RT 5880 substrate with permittivity of $\epsilon_r = 2.2$ and thickness of $h = 0.508$ mm is placed on the top broad wall of a shallow metallic cavity, whose inner dimension is 28 mm $\times$ 28 mm $\times$ 3 mm, and the wall thickness is $t = 5$ mm. Three slots are closely etched out in parallel on the inner layer of the substrate. The width of each slot is designed to be $W =$

Fig. 1. Configuration of the proposed cavity-backed slot supergain antenna, (a) 3D view, (b) top view, (c) side view. ($H_c = 3$ mm, $W_c = 28$ mm, $L_c = 28$ mm, $h = 0.508$ mm, $W = 2$ mm, $L_1 = 14.5$ mm, $L_2 = 10.6$ mm, $L_3 = 10.55$ mm, $d_s = 13$ mm, $d_l = 3.7$ mm, $d_r = 2.9$ mm, $d_f = 10.45$ mm, $t = 5$ mm, $W_f = 1.55$ mm, $W_s = 2.5$ mm, $L_s = 1.2$ mm, $P_s = 7.4$ mm, $a = 6.025$ mm, $b = 1$ mm).

2 mm, the length of three slots are $L_1 = 14.5$ mm, $L_2 = 10.6$ mm, and $L_3 = 10.55$ mm, respectively, which can achieve multi-resonance to broaden the bandwidth. The required magnitude and phase of the excited electric field along the slot surfaces to achieve supergain can be obtained by adjusting the positions of slots. Inter-element spacing values of d_l and d_r are optimized to be 3.7 mm ($0.12\lambda_0$) and 2.9 mm ($0.097\lambda_0$), respectively. An off-centered microstrip feed line with stubs is printed on the outer layer of the substrate. A large conformal ground with a radius of R and extra length of L_g is employed to push the radiation pattern closer to the end-fire direction. It should be mentioned that TE_{012} mode of the square cavity is excited by the feed line, through which the z-directed current flowing on the broad wall of the cavity can be disturbed by the slots. Resultantly, the transverse electric field across the slot surface can be properly excited for the radiation purpose.

III. ANTENNA PERFORMANCE

The proposed antenna is analyzed by ANSYS High Frequency Structure Simulator (HFSS). The performance of

Fig. 2. Prototype of the proposed conformal cavity-backed slot supergain antenna.

Fig. 3. Simulated and measured $|S_{11}|$ and gain of the proposed antenna with different ground shapes and sizes.

Fig. 4. Simulated and measured radiation pattern of the proposed antenna with different ground shapes and sizes (x-z plane, $f = 10$ GHz).

the antenna with different ground shapes and sizes are studied. The planar ground can be considered as the one with an infinite radius, which is denoted as $R = \infty$. The ground with a radius of $R = 200$ mm is considered as the conformal surface of a typical missile. In order to validate the performance, a prototype of the proposed antenna with $R = 200$ mm and $L_g = 3\lambda$ shown in Fig. 2 is measured.

The effects of ground shape and size on the return loss and realized gain of the proposed antenna are shown in Fig. 3. Measured results are also compared with simulated ones. Simulated results show that the -10 dB impedance bandwidth ranges from 9.21 GHz to 10.7 GHz for the planar ground and from 9.26 GHz to 10.76 GHz for the curved one, indicating

that a fractional bandwidth of 15% is obtained. Three resonant frequencies caused by different slot lengths are also displayed in Fig. 3. Since the electrical length of each slot slightly increases when the flat ground is changed to a curved one, the resonant frequencies of the bended structure are lower than those of the planar one. In addition, the gain slightly changes when the ground shape and size vary. However, the gain values remain above 8 dB, and gain ripples are less than 1 dB over the bandwidth. A maximum gain of 9.1 dB can be obtained for $R = 200$ mm and $L_g = 3\lambda$. The measured impedance bandwidth ranges from 9.2 GHz to 10.71 GHz, slightly lower than the simulated one, which maybe due to the fabrication and assembling tolerance. The maximum gain is measured to be 8.5 dB, which is 0.6 dB less than the simulated result, the discrepancy may be attributed to the loss introduced by the transition between SMA and microstrip feed line.

Fig. 4 shows the normalized radiation patterns in the x-z plane of the proposed antenna with different ground shapes and sizes. Due to the large radius of the missile, the curved ground can be approximately considered as flat. Therefore, the radiation patterns are almost invariable when the planar ground is replaced by a curved one. The beam-pointing angle is 58° from the end-fire direction for the ground with $L_g = 0$. As L_g increases to be 3λ , the offset angle shifts to be 38° . It should be mentioned that if L_g is infinite, an end-fire radiation pattern can be obtained. However, due to the cavity-backed structure and finite ground size, the maximum radiation unavoidably tilts away from the end-fire direction. The measured radiation pattern is also shown in Fig. 4, and it is in good agreement with the simulated one.

IV. CONCLUSION

In this paper, a conformal cavity-backed supergain slot antenna has been presented. The proposed antenna consists of a thin substrate and a shallow metallic cavity. With suitable positions and lengths of three slots, the antenna has achieved a maximum gain of 9.1 dB and a fractional bandwidth of 15%. It has been shown that the main beam of the proposed antenna tilts toward the end-fire direction when a large ground is employed. Therefore, the proposed conformal antenna can be a promising candidate to be embedded into missile systems.

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