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Cavity-Backed Dumbbell-Shaped Slot Antenna for C-Band Application

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ABSTRACT: In this paper, a novel dumbbell-shaped slot along with thin substrate integrated waveguide (SIW) cavity backing is used to design dumbbell-shaped slot antenna. The design in this paper has unidirectional radiation pattern, high gain, high (FTBR) at resonant frequency while having low profile, planar configuration. The unique slot shape creates complex current distribution at resonant frequency that results in simultaneous excitation of hybrid mode at higher frequency along with conventional TE_{120} mode in the cavity. Both conventional mode and the hybrid mode helps the modified slot to radiate at the corresponding resonant frequency resulting in compact, cavity-backed dumbbell-shaped slot antenna. This designed antenna resonates at 7.1 GHz with gain of 5.8 dB respectively. The FTBR of the antenna are above 10 dB at operating frequency.

KEYWORDS: Cavity-backed antenna; dumbbell slot; hybrid mode; slot antenna; substrate integrated waveguide (SIW).Ene

I. INTRODUCTION

Since the authorization of the unlicensed use of C frequency band from 4–8 GHz for commercial application, the C-Band has become one of the most promising band for short range high-rate indoor wireless communications. In recent years.In recent years, slot antennas have been used extensively as one of the popular choice for realization of low profile, conformal antennas in radar, telemetry systems and maritime applications [1]–[3].Recently, the increasing application in mobile communication and radar systems has increased the demand for low profile, compact, multiband antennas [7]. Several studies on multi frequency slot antenna have been reported in recent years [8], [9].However, all these designs have one major drawback of producing bidirectional radiation pattern which limits its performance in several applications. The front -to -back ratio (FTBR) of the slot antenna can be improved by using a metallic cavity backing behind the slot but the system becomes bulky.

Recently Substrate Integrated Waveguide (SIW) has emerged as an attractive alternative which incorporates non planar waveguide structures in planar substrate by the use of rows of metallic vias implementing the side wall of the waveguide based circuits in planar substrate [11].Substrate integrated waveguide cavity-backed antenna was first proposed by Luo. *et al.* [12]. Several techniques to improve the bandwidth of SIW cavity-backed slot antenna are reported in recent years [13]. Excitation of hybrid modes to enhance the bandwidth performance of the antenna is also reported [14], [15].

However, not so many designs have been found so far to implement SIW cavity- backed slot antenna with high gain, high FTBR performance. Recently, SIW cavity-backed dumbbell-shaped slot antenna is reported to implement active antenna oscillator [20],tunable antenna [21] in X-band.

In this paper, a novel technique to design cavity-backed dumbbell shaped slot antenna is demonstrated. The proposed antenna replaces rectangular slot by a modified dumbbell-shaped slot which creates an additional hybrid current distribution in the cavity at higher frequency along with conventional TE_{120} mode distribution. Both these modes excite the unique slot structure to radiate at resonant frequency resulting in compact,cavity-backed slot antenna. One attractive feature of the proposed antenna is that the frequency ratio (FR) of the resonant frequency can be tuned by simply changing the slot antenna dimension while retaining same cavity dimensions. The fabricated prototype shows high gain, high FTBR with moderate bandwidth at resonant frequency while maintaining low profile, planar configuration.

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II. Principle of Operartion

The geometry of the proposed antenna is shown in Fig. 1. The dumbbell-shaped slot is etched at top metallic plate and placed at a distance of 'd' from one sidewall of the cavity. The SIW cavity in this design is manufactured on a single substrate by four rows of metallic vias making four sidewalls of the cavity. The diameter ( ) and pitch ( ) of the via holes can be adjusted while maintaining the conditions $d/s \geq 0.5$ and $d/\lambda_o \leq 0.1$ to ensure minimum leakage of energy [12].
To implement dual-frequency slot antenna, the simple dumbbell- shaped slot, as shown in Fig. 2(b), is modified by placing a circular patch inside the slot along with a pair of strips connecting inner circular patch and outer conductor separated by a slot arc of length of $\varphi = 90^{o}$ as shown in Fig. 1 and 2(c). The working principle of the antenna is explained with the help of real (Z_{11}) plot in Fig. 2(d) extracted using Ansoft HFSS after de-embedding the feeding line. The length and width of the cavity is chosen to keep the resonant frequency in C band The placement of the dumbbell-shaped slot disturbs the current path of TE_{120} mode.

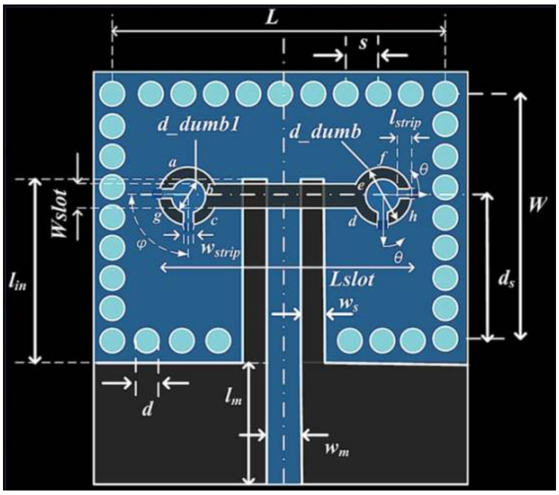
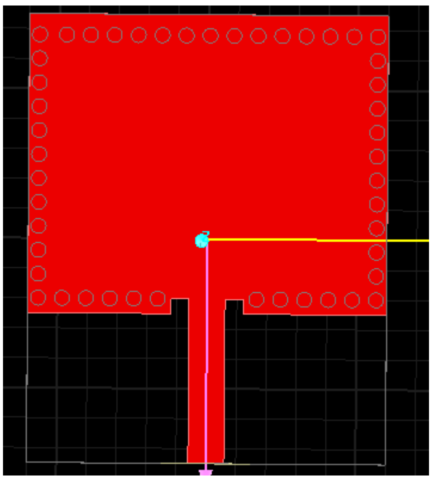


Fig. 1. Geometry of the Proposed Design (L= 24 mm , W= 20 mm , d=1 mm , s =1.6 mm , W_m = 2.4 mm , W_s = 1.2 mm , Lslot = 12 mm , Wslot = 1 mm , d_dumb= 4 mm , d_dumb1= 2.6 mm , l_{strip} = 0.7 mm , W_{strip} = 0.5 mm , d_s = 11.7 mm , l_{in} = 12.2 mm , l_m = 15 mm , $\theta = 0^{0}$, $\varphi = 90^{0}$)



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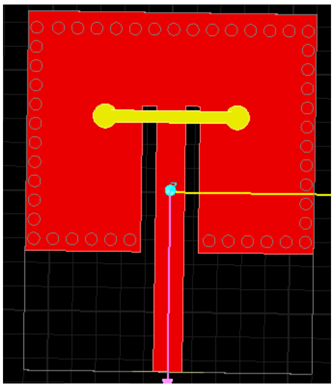

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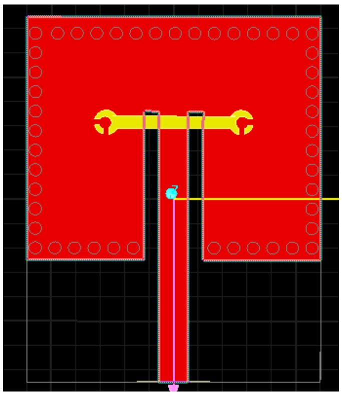

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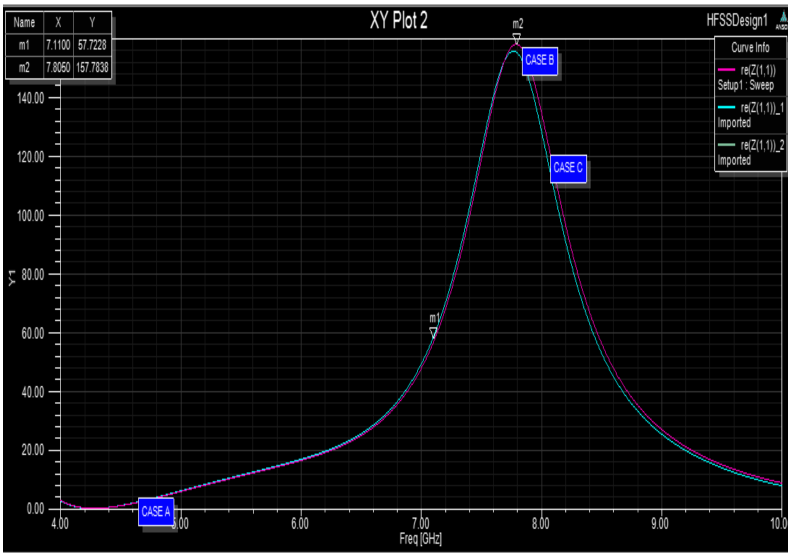

(d)

Fig. 2. (a) Cavity without slot (Case A); (b) single frequency design (Case B);(c) dual-frequency design (Case C), (d) real (Z) plot of the cavity without(Case A) and with slot loading (simple dumbbell slot (Case B) and modified dumbbell slot (Case C)).

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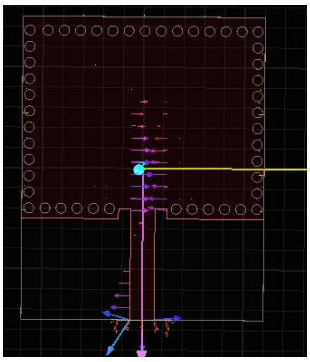
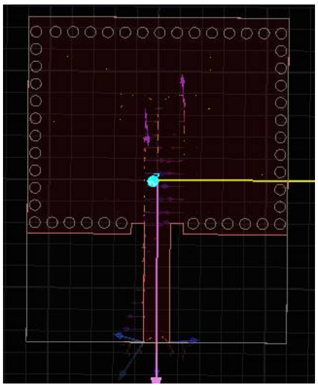
The electric field and surface current distribution of the simple slot is shown in Fig. 3(a) and (b), respectively and that of simple dumbbell slot loaded cavity is shown in Fig. 3(c) and (d), respectively and that of the proposed design at resonant frequency is shown in Fig. 3 (e) and Fig. 3 (f) respectively. The electric field distribution of the proposed antenna at the resonant frequency(f_R =7.1 GHz) is quite similar to that of the TE $_{120}$ mode of SIW cavity loaded with simple dumbbell slot antenna (Case B).The surface current distribution at this frequency follows the outer boundary of the slot along the path '*agcdhfa* ',as referred in Fig. 1, with negligible amount of current in the inner circular patch. The electric field distribution at this frequency is out of phase the opposite sides of the slot as shown in Fig. 3(e) which excites the slot to radiate.



(a)



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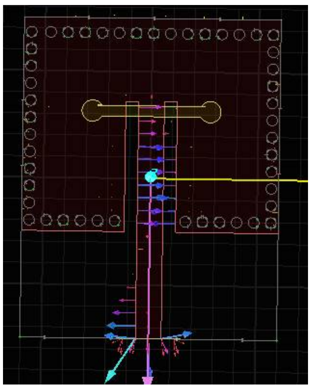

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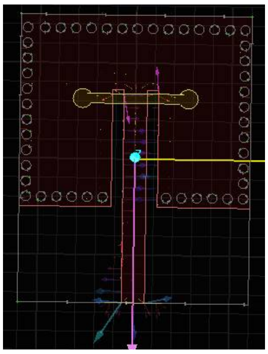

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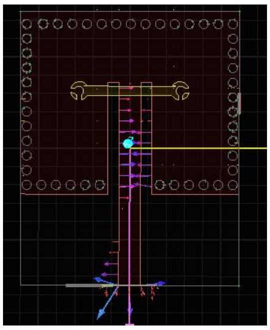
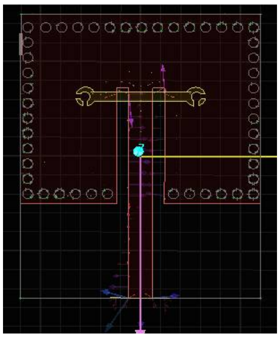


(e)



(f)

Fig. 3. Electric field vector and surface current density vector at top metallic plate (a), (b) with simple slot (Case A); (c), (d) with dumbbell-shaped slot (Case B); (e), (f) with modified dumbbell-shaped slot (Case C) at 7.1 GHz.

The surface current at resonant frequency (f_R =7.1 GHz) is a hybrid distribution as it follows the path '*abcdefa*', as referred in Fig. 1.Hence a significant amount of current flows into the inner patch of the modified slot through the pair of connecting strips as shown in Fig. 3(f).This modified current path creates a complex field distribution in the cavity and introduces an additional hybrid mode resonance. This can also be seen in the real (Z_{11}) plot in Fig. 2(d) where placement of modified slot (Case C) creates the hybrid mode resonance at 7.1 GHz which is not present in the previous cases (Case A and B).The electric field distribution at this frequency is also out of phase at the opposite side of the slot as shown in Fig. 3(e). Therefore by using modified dumbbell slot , Cavity-backed Dumbbell-Shaped slot antenna can be achieved without further modification in cavity dimensions.
A simple feeding technique similar to conventional SIW cavity-backed slot antenna is used in the current design

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without much difficulty to get impedance matching at both resonance. As shown in Fig 1, a 50-Ω grounded coplanar waveguide (GCPW) line followed by a 50 -Ω microstrip line of same width is used to feed the antenna. The inset of the feeding line 'l_{in}' is optimized to excite corresponding modes of the cavity *and hence to get good frequency response. The optimum dimensions of the design are given in Fig. 1.*

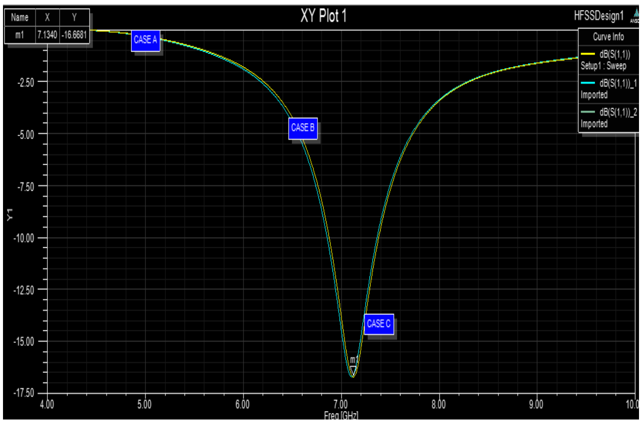

Fig. 4. Comparative study between simulated reflection coefficient of the antenna.

III. Experimental Results

The proposed design is fabricated on Rogers RT Duroid5880 with the substrate thickness of 0.787 mm which is less than $0.036\lambda_0$ for operating frequency. The comparative study between simulated reflection coefficient of the antenna shown in Fig. 4.The simulation of the designed structure shows that the modified slot resonates at resonates frequency i.e. ,7.1 GHz impedance bandwidth (- 10 dB) of 279 MHz (3.9%) at resonance. The simulated gain and radiation pattern of the antenna is also shown in Fig. 5.The simulated gain of the antenna at resonant frequency is 6.8 dB. However, the gain of the antenna can be improved by increasing the height of the substrate as it approaches the optimum distance of one fourth of guided wavelength between slot antenna and reflector behind it. The proposed antenna produces unidirectional radiation pattern at both frequencies due to SIW cavity backing. The measured radiation pattern almost follows the simulated pattern with maximum radiation in broadside direction. The simulated FTBR of the antenna is 14 dB at resonant frequency. The VSWR of the antenna is 1.3 at 7.1 GHz respectively. There is a little discrepancy between simulated and measured results which may have caused due to limitation in the fabrication process. The proposed antenna exhibits flexibility in tuning frequency ratio and better out-of band performance with a compact slot antenna configuration and a simple feeding technique as compared to other antennas.

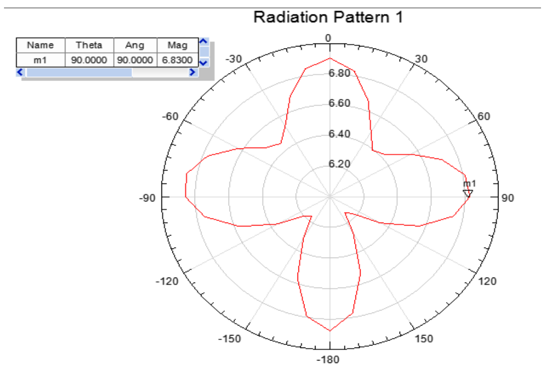

Fig. 5. Study of radiation pattern and gain of the antenna at 7.1 GHz

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IV. CONCLUSION

A brief analysis of a cavity-backed dumbbell shaped slot antenna for C-Band methodology is presented in this paper. The proposed design uses a modified dumbbell-shaped slot to introduce additional hybrid mode resonance without affecting the conventional cavity modes. The use of single slot structure to excite frequency resonance increases the compactness of the antenna. The frequency ratio of the antenna can be tuned to certain extent by changing the dimensions of the slot. The proposed design is fabricated in a single layer substrate and thus maintains low profile, planar configuration. The fabricated prototype shows unidirectional radiation pattern with high gain and moderate bandwidth at resonant frequency which makes it suitable for practical applications in C-band of EM spectrum.This helps to reduce the effect of bi-directional patterns.

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