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Cavity Backed Circular Half Mode SIW Array for Microwave Communications

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***Abstract:** A two element array of circular shaped cavity backed substrate integrated waveguide (SIW) based antenna is proposed in this work. The elements are backed by a dielectric cavity of FR4 epoxy and fed by SIW slot coupling mechanism. Keeping the advantages of the conventional waveguides, the bandwidth of the radiation can be increased by choosing proper dimensions to the slots and circular patches. The two element array configuration in the design contributed to the comfortable uplift of the gain. The impedance matching is achieved by inserting a two arm power divider with pre-calculated dimensions. The accurate formulation of the electromagnetic problem of analyzing the SIW antenna is achieved by using integral equation based methods which can be solved numerically. The designed top layer of the antenna is analyzed with well known Method of Moments (MoM) and the results are compared. The functioning of the antenna is compared in terms of Return losses, radiation pattern and gain. The antenna exhibits 72% of bandwidth with peak gain of 4.2dB in the range of 4.4GHz to9.9GHz with the resonating frequency of 7.54GHz and well suited for C-band microwave communication applications.*

***Keywords:** Substrate Integrated Waveguide, Circular HMSIW, Cavity backed, Method of Moments, Metallic vias, HFSS Software.*

I. INTRODUCTION

Substrate Integrated Waveguide (SIW) technology is the most promising technology for the realization of effective radiating systems for the future microwave communication systems. It is a synthetic rectangular waveguide formed using a dielectric substrate by tightly arraying metalized via-holes which connect the upper and lower metal layers to form an effective radiating structure. SIW antennas are useful in many applications in the microwave communication systems including C and X-band applications owing to several advantages such as high power handling capacity, low cost, compact profile, high quality factor and integration with MMIC devices. However, the limitation in bandwidth is a never ending issue in the design of microstrip SIW antennas. Many bandwidth enhancement methods have been suggested by the researchers including hybrid mode excitation and exciting the antenna with the slots of duel and multi-resonance characteristics.

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Cavity backed SIW construction is one of the most promising and attractive option in antenna design due to its promising wideband characteristics. This paper proposes a novel two layer cavity backed circular SIW radiator for microwave communication technologies, highlights some of the most important advantages including bandwidth enhancement, gain uplift to the desired levels. The design of the circular array requires different steps including optimization of the radiator dimensions together with the HMSIW cavity, the organization of the coupling between the array elements, and the efficient design of the feed network to energize both the elements. A substrate integrated waveguide (SIW) antenna array consisting two SIW phase shifter sections with two inserted metallic posts operating at 10 GHz is presented in [3]. The phase shift is obtained by changing the positions of two reactive posts inside each element of the array. An ultra wideband and elevated gain cavity-backed square 4X4 array antenna is designed [4] by highlighting the higher-order SIW structure with slot elements in the bottom layer of the antenna. To advance the aperture efficiency, several bowtie and planar slot cavity-backed antennas have been designed [5]-[7]. A Dielectric resonating antenna (DRA) array fed by a cavity-backed SIW is designed and analyzed to radiate in desired directions [8].

A compact monopulse array with double-layer 8-cells SIW antenna has been developed using optimum feed networks with enhanced microstrip to SIW transitions [9]. A phased slot array antenna with wide angle scanning has been demonstrated with decreased gain fluctuation in the microwave operating band [10][11]. Two QMSIW antennas have been proposed for WLAN and WBAN applications [12] and performance of the antennas are successfully tested on a human body.

The design of HMSIW based dual-band antennas are demonstrated in [13 − 15], which has good antenna performance characteristics. Considering all the advantages of Cavity backed radiating structures, the present paper demonstrates the design and analysis of a two element half circular shaped antenna array fed by using slot coupling mechanism. The proposed antenna is simulated by using Full-wave based High Frequency Structure Simulator (HFSS) software.

This paper is prearranged as follows. Section II describes methodology followed for design of cavity backed circular half mode SIW array. Section III describes the fullwave analysis of the upper layer of the proposed radiating structure. Section IV demonstrates the results elucidating antenna radiation characteristics and finally Section V is conclusion.

II. DESIGN OF CAVITY BACKED ANTENNA ARRAY

The implementation of the active array consisting different steps including optimization of the dimensions of the cavity elements design and realization of feed network with SIW bottom layer for desired impedance matching.

A. Cavity Design

The upper layer of the antenna consists of two half circular patches backed by SIW cavity with two rectangular slots placed on the ground plane. The dielectric substrate material chosen for effective implementation of this structure is FR4 epoxy with dielectric constant ϵ_r = 4.4 with loss tangent tanδ=0.02. The dimensions of the circular patch can be calculated by [16]

$$f_r = \frac{K_{mn}C}{2\pi r\sqrt{\mu_r \epsilon_r}} \tag{1}$$

Where f_r is resonant frequency, K_{mn} is Bessel's function coefficient and r is the radius of the patch. The resonance frequency is chosen to be in the microwave C-band with 7.5GHz.The upper layer of the proposed array is shown in Figure 1.

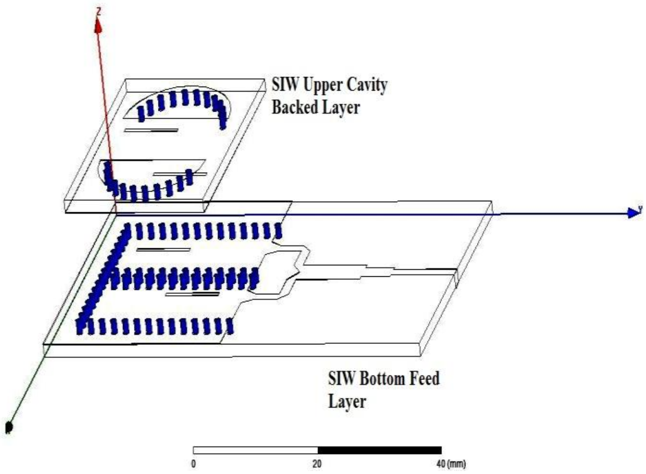

Fig.1. Two layer architecture of the Cavity backed antenna.

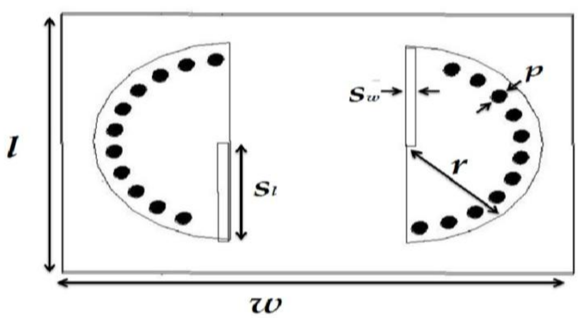

Fig.2. Upper layer architecture

B. SIW Feed Network Design

The bottom layer of the antenna consists of two segments including SIW waveguide section connected with two arm power divider with pre-calculated dimensions[2]. The dimensions of the power divider are chosen to achieve perfect impedance matching for transition between waveguide and microstrip line. A quarter wave transformer is used to connect the waveguide to the input microstrip feed line. LineCalc of Agilent is used to determine the widths and lengths of the lines and transformer. The architecture of the SIW and feed network of the bottom layer is shown in Figure 3.

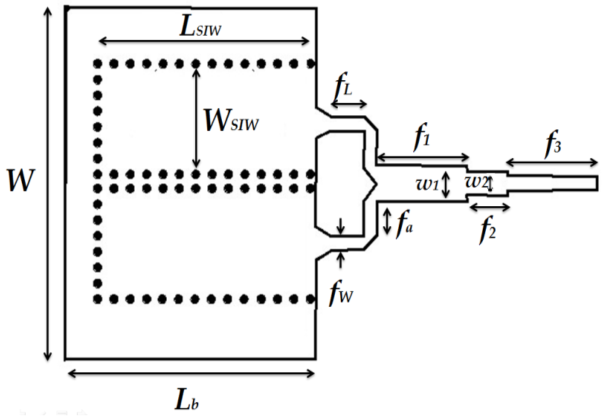

Fig.3. Bottom layer architecture

The two layer cavity backed SIW based antenna is designed and optimized using Finite Element Method (FEM) based commercial HFSS software. The overall architecture of the antenna in HFSS platform is shown in Figure 4. The antenna occupies an area of 40X30 mm^2 and the optimized dimensions are tabulated in Table-I.

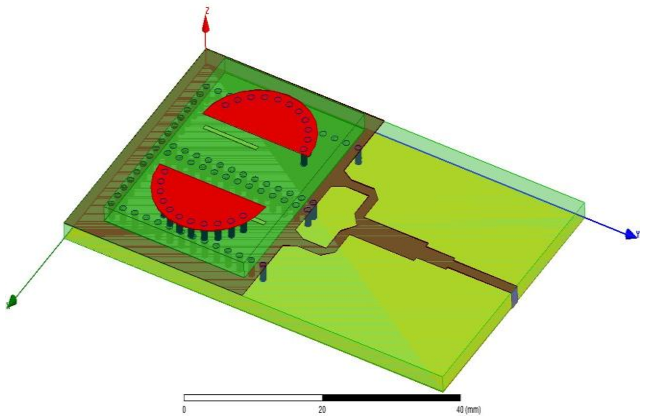

Fig.4. Architecture of the proposed Antenna

Table-I: Design parameters of the two layer antenna

Parameter	Value in mm	Parameter	Value in mm	Parameter	Value in mm
L	73	S_l	9.1	f_3	1.57
W	30	S_w	0.7	f_w	1.57
l	40	r	9.4	w_1	4
w	30	p	1	w_2	2.56
L_{SIW}	35.6	fl	4	h	1.6
W_{SIW}	12.6	f_1	10.88	s	2
L_b	34	f_2	5.35	t	0.03

III. FULL-WAVE ANALYSIS OF CAVITY BACKED ANTENNA ARRAY

The full-wave analysis of SIW structure can be done by considering the upper layer as a circular assembly of conducting posts placed in a parallel plate waveguide and formulated using the effect of the cavities formed by the upper and lower conducting plates.

The standard dyadic Green's function approach is proposed to analyze the SIW cavity backed structures in [17]. The cavities are enclosed by top and bottom conducing plates and circularly shaped fences of vias. The excitation is done by waveguide slots under the cavity.

The ports are located by replacing the equivalent magnetic current sources and the matrix for admittance can be calculated with the help of pre-determined Green's function.

A procedure using Method of Moments (MOM) analysis is clearly demonstrated in [18] to determine the fields inside the Substrate Integrated Waveguide arrays. The derivation of SIW dyadic Green's function, analysis of radiating slots and the formation of the moment method are evidently discussed.

The EM fields generated by a magnetic current source within the waveguide is numerically computed by taking Green's function of the parallel plates into consideration, expressed in terms of eigen functions in vector form, and including the scattered fields by the metallic vias.

The resultant fields are the summation of the contribution of the fields due to parallel plates, the fields scattered by the metallic holes and the slots on the waveguide walls.

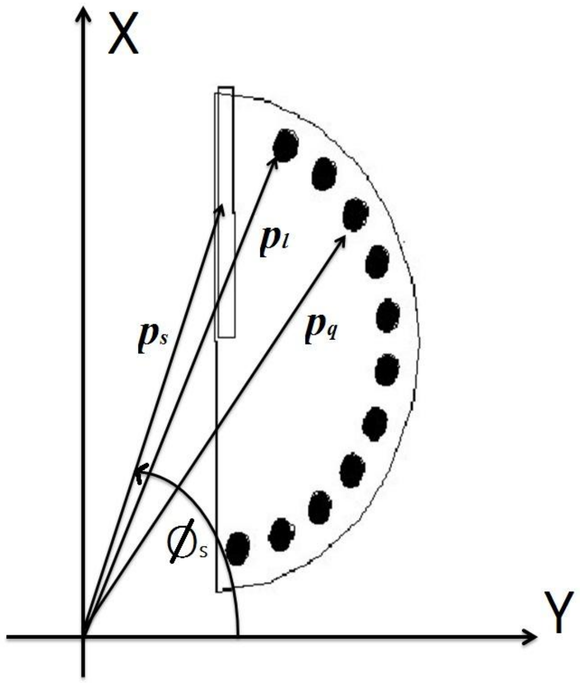

Fig.5. Single Circular HMSIW

The single element of the proposed antenna is considered and analyzed. The analysis is done by the considering the single element as the combination of parallel plates with metallic vias, the slots are considered as the magnetic current source within the waveguide. The analytical diagram is shown in Figure 5 in which the location of the slots and vias are represented with the $\boldsymbol{\rho_s}$ and $\boldsymbol{\rho_l}$ respectively. The azimuth indicating the location of the source points are represented with $\boldsymbol{\varnothing_s}$. The overall upper layer is considered as the array of two elements fed out of phase with proper spacing between elements. The upper layer of the cavity backed antenna is shown in Figure 6, analysed by the MoM method and MATLAB code is implemented to find the required responses.

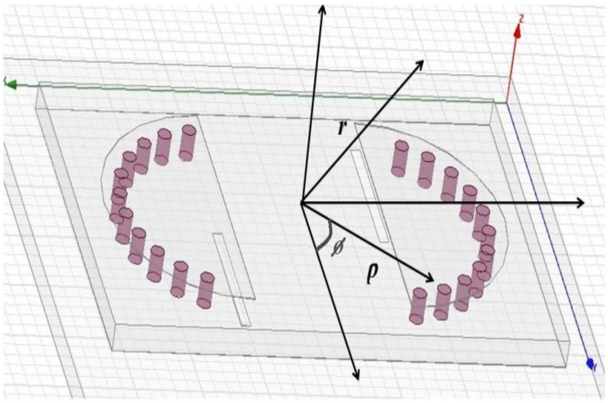

Fig.6. SIW structure with slots

The field scattered by the top and bottom plates is expressed in terms of Green's function as an expansion in terms of vector wave functions

$$\boldsymbol{G_s}(\boldsymbol{\rho}) = \frac{j}{2\pi}\sum_n \int_0^\infty dk_\rho \left[M_n\left(k_\rho, k_{0z}, \rho, z\right)E_1 + M_n\left(k_\rho, -k_{0z}, \rho, z\right)E_2 + N_n\left(k_\rho, k_{0z}, \rho, z\right)F_1 + N_n\left(k_\rho, -k_{0z}, \rho, z\right)F_2\right. \quad (2)$$

Where E_1, E_2, F_1 *and* F_2 are unknown vector functions which has to be determined depends on the characteristics of the structure and medium. $M_n\left(k_\rho, k_{0z}, \rho, z\right)$, $N_n\left(k_\rho, k_{0z}, \rho, z\right)F_1$ are cylindrical vector eigen functions.

and $k_0 = \omega\sqrt{\mu_0\epsilon}$, $k_{0z} = \sqrt{{k_0}^2 - {k_\rho}^2}$.

The field scattered by the cylindrical via is expressed as the following series of out coming EM waves

$$\boldsymbol{H_s}(\boldsymbol{\rho}) = \sum_l^m \sum_{n,m} \left[M_n\left(k_\rho, k_z, \rho - \rho_l, h - z\right)A + N_n\left(k_\rho, k_{0z}, \rho, h - z\right)B \right] \quad (3)$$

Where $\boldsymbol{l}$ is a spanning index of the cylinders, $\boldsymbol{m}$ and $\boldsymbol{n}$ are angular dependences and *A*, *B* are unknown coefficients to be determined.[19].

IV. RESULTS & DISCUSSION

A. Return loss

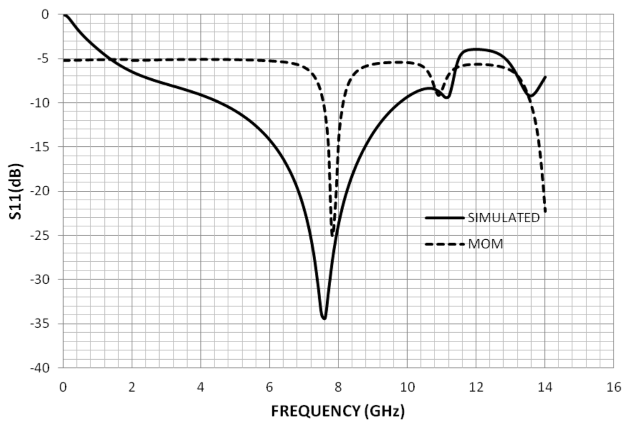

Fig.7. Reflection Characteristics

The return loss can be obtained by taking reflection characteristics of the slot located back to the cavity with the half mode SIW structure. It is given by

$$S_{11} = 20\log_{10}[\Gamma]\ \text{dB} \quad (4)$$

where Γ is the coefficient of reflection and it is the ratio of the incident electric field to the reflected at the cavity of SIW antenna. The Return loss is directly related to the VSWR and frequency. The S_{11} parameters are computed with the help of the admittance matrix obtained for the input slot connected back to the cavity through the bottom SIW waveguide pair. The results show that the proposed antenna is resonating at 7.54GHz with wide 72.8% of bandwidth.

B. Radiation Pattern

The radiation pattern of the proposed antenna is taken as the variation of field as a function of space around the structure. The 2-D and 3-D radiation patterns are shown in Figure 9 and 10 respectively. It is observed that the maximum gain of the antenna is 4.2dB and the maximum radiation is in broadside direction.

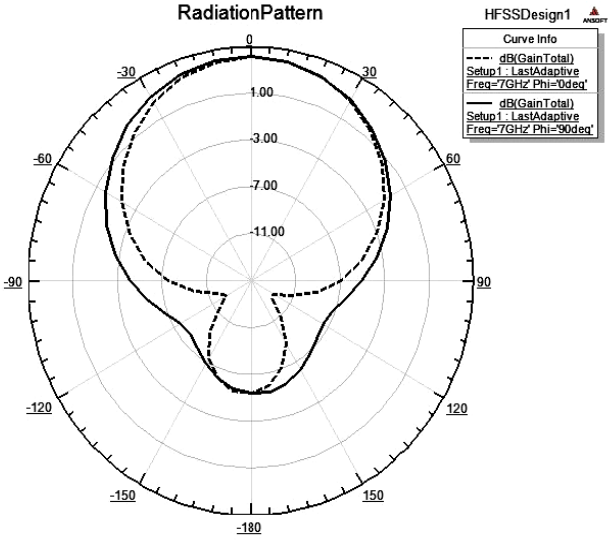

Fig.8. Radiation Pattern of the cavity backed antenna

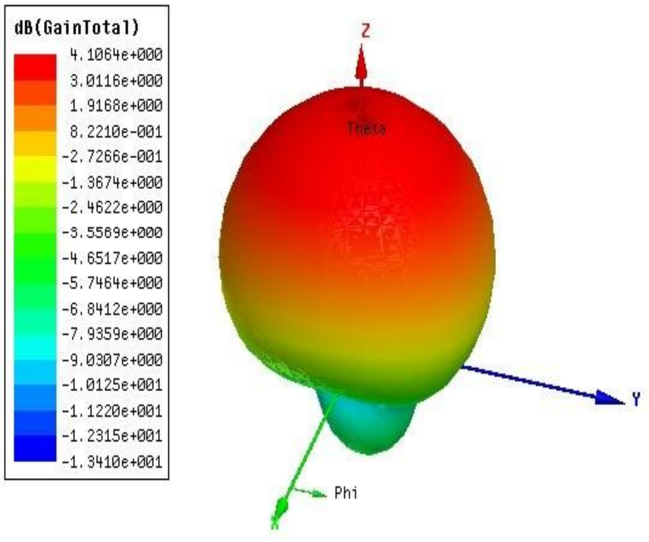

Fig.9. 3D Radiation Pattern of the antenna

The simulated results of the antenna radiation characteristics are observed in terms of Radiation efficiency, Gain, Impedance bandwidth and Front-to-back ratio. The proposed antenna exhibits the satisfied radiation characteristics that can be used for the given broadband applications in C-band. The efficiency of the antenna is observed to be nearly 90% with good reflection characteristics. The overall summary of the performance of the proposed antenna is tabulated in Table-II.

C. Performance characteristics

Table-II: The Radiation characteristics

ANTENNA PARAMETER	VALUE
Frequency(GHz)	7.54
Gain (dB)	4.2
Radiation Efficiency (%)	89.49
Radiated Power(W)	0.000251285
Accepted Power(W)	0.000280773
FBR	16.8835
Return loss (S_{11})(dB)	-34.24

V. CONCLUSION

A novel two layer cavity backed half mode circular SIW array antenna is proposed in this paper. The two elements of the antenna are excited with a pair of SIW structures matched with a multistep two way power divider. The array antenna exhibits broadband characteristics with 89.5% of efficiency and 72% of bandwidth with peak gain of 4.2dB. The mathematical formulation of the upper layer of the antenna is implemented using well known integral equation based MoM method. The reflection characteristics of the proposed antenna array realized mathematically and compared with the simulated results. The results show that the SIW cavity backed antenna simulated in HFSS and the MoM based mathematical modelling exhibit similar reflection characteristics with optimum resonance frequency of 7.54GHz, which can be effectively used in C-band microwave applications.

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