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Plate-Laminated Slotted-Waveguide Fed 2×3 Planar Inverted F Antenna Array

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***Abstract*—**Substrate Integrated waveguide based 6-element array of Planar Inverted F antenna (PIFA) has been presented and analyzed parametrically in this paper. The antenna is fed with coupled transverse slots on a plate laminated waveguide cavity to ensure wide bandwidth and simplicity of feeding network. The two-layer structure has one layer dedicated for feeding network and the top layer dedicated for radiating elements. It has been demonstrated that the presented feeding technique for feeding such class of array antennas can be far simple in structure and miniaturized in size when it comes to designing large phased array antenna systems. A good return loss and standing wave ratio of 2:1 has been achieved while maintaining properties of typical PIFA.

***Keywords*—**Feeding network, laminated waveguide, PIFA, transverse slots.

I. Introduction

THE increased demand of compact and high bandwidth antennas since last decade has forced researchers to move towards higher band of frequencies. In this regard, PIFA can be considered as a good candidate at lower microwave frequencies due to its reduced size, low profile and higher radiating efficiency. However, at higher microwave band of frequencies radiating efficiency of PIFA is degraded due to feeding pin used to excite PIFA and feeding pin also requires to be soldered with antenna radiating plate [1] leading to structural deformities and excess losses.

In past few years, various feeding techniques have been proposed and analyzed to increase the radiating efficiency of PIFA. In order to obtain wider bandwidth PIFA has been fed by an open-ended coplanar waveguide [2]. An aperture coupled PIFA excited through micro-strip transmission line has been proposed by [3]. A multilayer folded feeding structure have been proposed [11] and an edge feeding technique have been proposed by [12]. Multiple antenna designers have used capacitive plate to feed radiating plate and achieve higher impedance bandwidth [4]-[6].

In this paper, a feeding technique has been presented based on the idea of feeding the radiating elements via transverse slots in a waveguide cavity published in [8]-[10]. As a result, a 6-element PIFA with conformal feeding network has been designed and analyzed in this paper to demonstrate their use in design of complex and large phased array radars and multi-element beam forming antenna systems. Owing to the low leakage an absorption losses of Substrate Integrated Waveguides (SIW) at higher frequencies, the layer-1 consists of SIW cavity backed transverse slots for feeding the 6-element PIFA array at layer-2. The layer-2 consists of radiating patches and shortening plate to connect the patch to ground. High Frequency Structural Simulator (HFSS) has been used as simulating tool that uses Finite Element Method (FEM) as numerical technique.

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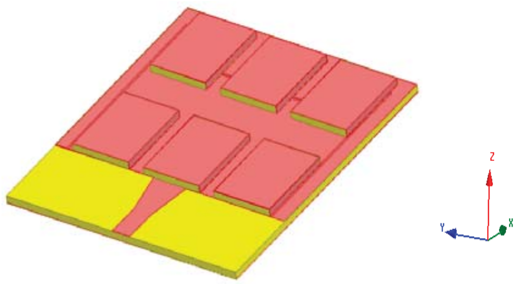

Fig. 1 3-D View of 2x3 array

II. Antenna Physical Configuration

Three-dimensional view of proposed design is given in Fig. 1. Design consists of two layers which are discussed separately. Substrate material used for both layers is FR-4 epoxy with relative permittivity of $\varepsilon_r = 4.4$, dielectric loss tangent of 0.02 and thickness of 1.60 mm. Each PIFA element is composed of a radiating patch and a shorting plate that connects radiating patch and upper copper surface of layer-1. The upper copper surface of layer-1 acts as ground plane for radiating elements on layer-2.

A. Layer-1

The top view of layer-1 is given in Fig. 2. A cavity using the SIW structure at Layer-1 has been formed, the six transverse slots present at a calculated displacement act as power coupling structure to PIFA elements on top layer. Positions and dimensions of slots are optimized using HFSS simulator. The dimensions of Layer-1 are given in Table I. The transition between laminated waveguide and microstrip transmission line is designed by using (1) as given in [7].

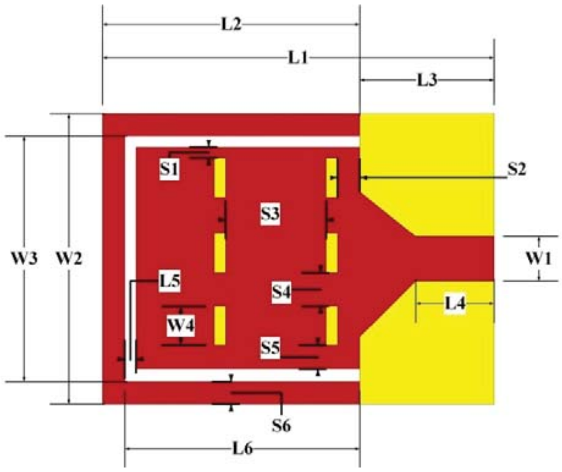

Fig. 2 Top View of Layer-1

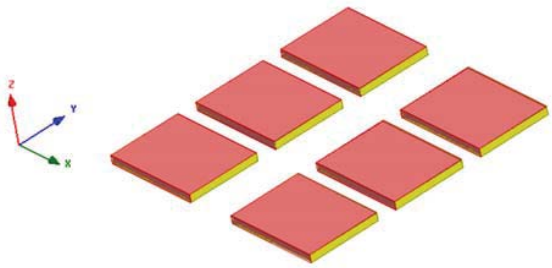

Fig. 3 Single element PIFA short circuited from one end

$$\frac{a_e}{w_e} = (4.38)e^{-0.627\left(\varepsilon_r/\varepsilon_e\right)} \quad (1)$$

TABLE I
DIMENSIONS OF TWO-LAYER ANTENNA STRUCTURE (MM)

L_1	72	S_1	0.5	W_1	4.8
L_2	52.5	S_2	3.5	W_2	62
L_3	19.5	S_3	29	W_3	54.5
L_4	8.5	S_4	5	W_4	14
L_5	0.5	S_5	2		
L_6	37	S_6	3		

B. Layer-2

The layer-2 is composed of six PIFA elements along with shorting plates, the dimensions and spacing of elements is shown in the 3D diagram given in Fig. 3. Radiating patch has dimensions of 20x15 mm^2 and length of shorting plate is kept 20 mm. Separation between each PIFA element along x-axis and y-axis is 33.5% λ and 12.9% λ respectively.

III. OPERATION PRINCIPAL

Energy enters the antenna though the 50Ω port at layer-1 and a microstrip transmission line section. The tapered waveguide to microstrip line transition has been used to transport the maximum power to the laminated waveguide cavity section. Six transverse slots are specifically designed and positioned to couple maximum amount of power to the top layer, thanks to the transverse slot coupling technique explained in detail in [8]-[10]. The energy is efficiently coupled to the top layer as can be seen in the fields and surface current simulation on the antenna surface shown in Figs. 4 and 5. Positions and dimensions of slots are optimized to couple maximum amount of power to upper layer. These coupled slots serve as the feed point to the planar F antennas on the top layer, the displacement between slot and the shorting plate used to short circuit the antenna to the ground plane can be used to match the impedance of antenna to the slot, this distance is altered to obtain the optimum power coupling and maximum radiation efficiency using HFSS parametric tools.

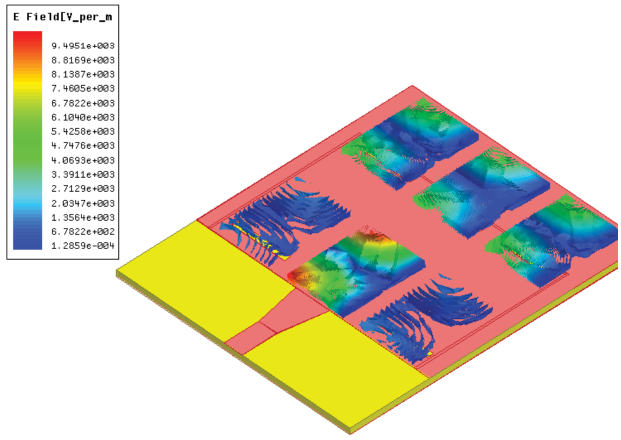

Fig. 4 E-Field magnitude simulated on Layer-1

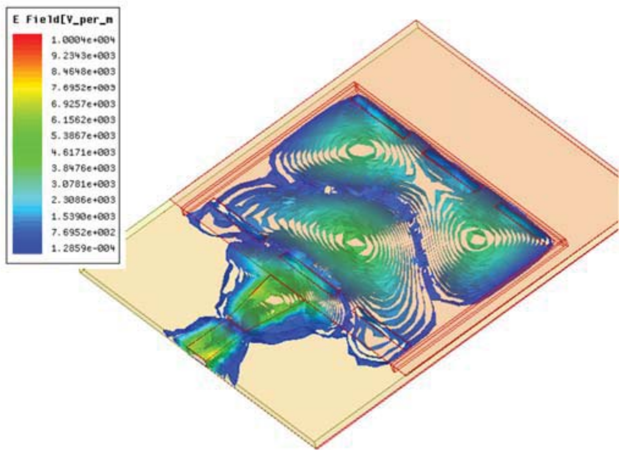

Fig. 5 E-Field magnitude pattern on Layer-2

IV. RESULTS AND DISCUSSION

Impedance matching between 50 Ω lumped port and radiating elements is controlled by changing the position of slot along x-axis. A good return loss of 40 dB is achieved by optimizing slot position while maintaining properties of conventional PIFA antenna as shown in Fig. 6 (a). Fig. 6 (b) gives the parametric analysis of changing the length of integrated waveguide cavity (L2 dimension in Fig. 2). It has been analyzed from Fig. 6 (b) that the return loss improves as cavity dimension along x-axis is increasing. The optimum return loss performance is achieved when the cavity length is set to 58 mm. The optimized 2D radiation pattern plots in all three planes are shown in Fig. 7. It can be seen from Fig. 7 that a radiation pattern of six element arrays in its natural form is achieved with approximately 30º of half power beam width.

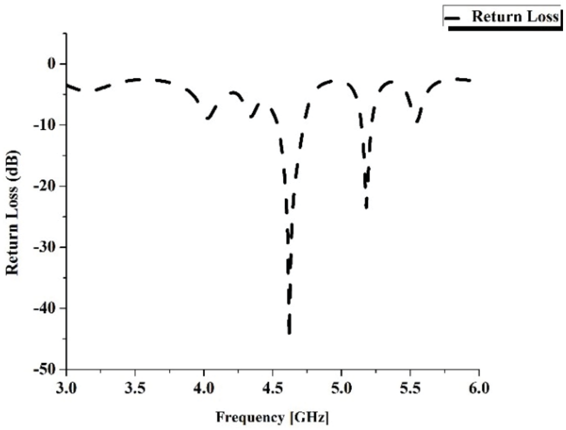

Fig. 6 (a) Return Loss at operating frequency

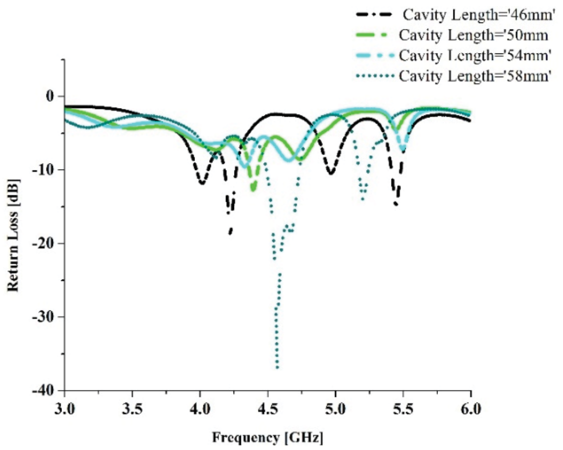

Fig. 6 (b) Effect of changing cavity dimensions along x-axis

The waveguide cavity-backed transverse slot coupled feeding technique is promising to reduce the complexities involved in designing feeding networks for large phased array and beamforming systems where it sometimes even becomes impossible or infeasible to develop such systems with traditional feeding techniques. This has been demonstrated that this technique may be suitable for applications where large antenna gains are expected (that involves a lot of array elements) without the added space, complexity and cost, whereas maintaining the optimum performance and efficiency of array networks. On the other hand, the loss inserted by the power dividing network for such large arrays make the design impractical in modern day in demanding applications. Increasing the number of elements by any number does not introduce any significant loss in the system, this makes it possible to design loss-loss, miniaturized and simple array networks. As proposed in [8], it is also possible to control the phase of these transverse slots by means of PIN diodes. This leads to the possibility of an extremely simple design of high-gain electronically controllable phased array antenna without the need of designing power dividing and phase shifting networks separately, thus saving lots of hassles involved in realizing such systems.

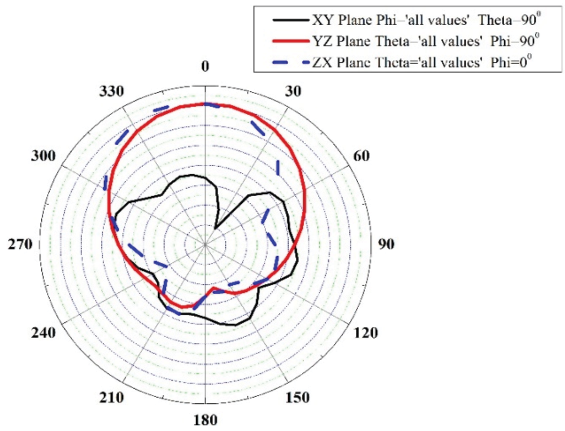

Fig. 7 Radiation pattern in three planes

V. Conclusion

A feeding technique has been presented and analyzed while maintaining properties of conventional PIFA. The presented design offers advantages of being easy to design, low losses and most importantly reduced complexity. Especially when it comes to designing a feeding network for large antenna arrays the proposed feeding using transverse slot coupling offers optimum performance without surplus complexity in the design.

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