A Wideband Annular Ring Radiator with Polygonal Ground Plane

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***Abstract*—Vivaldi radiators and its variants have been extensively used for wideband single antenna and array applications. The Vivaldi radiator and other radiators such as spirals, log periodic, ridged gap wave guides are predominantly 3D antennas. There has been a need for a truly planar antenna for antenna array applications in the Communications, EW and Radar band of 6-18 GHz. In this paper a wideband radiator covering 6-22GHz is designed and analyzed using HFSS simulations. The popularly known UWB antenna technology is now quite matured leading to effective coverage of the communication band of frequencies from 3.1 to 10.6 GHz. This technology is adapted to design, analyze and implement a planar element radiator for array applications covering the 6-18GHz band. The antenna is realized in hardware with a return loss of less than -10dB over 7.2GHz to 22 GHz and good radiation patterns from 6.0 to 15 GHz.**

***Index Terms*—Wide Band; Communications; EW; Printed Antennas.**

I. INTRODUCTION

Wide band (WB) microstrip antennas have been used extensively in communications in recent times. An excellent survey of microstrip antennas is given literature [1-2]. The communication band of 3.1-10.6GHz has been allocated for commercial use in 2001 and since then extensive research has been carried out and number of publications have come out on very wide band antennas [3]. In this huge effort two approaches have been followed, the inherent enhancement of bandwidth of radiators and the wide slot approach. The bowtie antenna is a broad band antenna covering a frequency range of 2.0 to 18GHz [4]. The Vivaldi radiator is a 3D antenna and has been extensively studied and some of its variants have yielded a very wide band width of 1-40 GHz [5]. Very wide band phased array antennas covering the communication band have also been found in literature. While the Vivaldi, log periodic, spirals and its variants are some of the elegant solutions to the multi octave band width requirement, extensive research has been directed towards development of planar wide band antennas in the last decade. In the planar antenna category, the exploitation of the technique of enhancement of bandwidth through loaded slots of various shapes have been extensively reported. Particularly, the wide slot antenna (WSA) approach has yielded bandwidths of more than 172% [6].

As already pointed out, the UWB antennas have been implemented with various slot shapes such as square [7], circular / elliptical [8], Rhombic [9], Hexagonal [10], etc. and using feeding techniques with microstrip line feed and coplanar waveguide feed. Also the most effective bandwidth enhancement technique is to use parasitic elements in the feed in the microstrip portion as well as in the radiating portion. One such technique is the tuning fork feed [11]. This technique has been taken as a guide in our paper combined with shaping of the ground plane. In another paper, elliptical slot with fork and parasitic driven antenna has been reported with a VSWR bandwidth of 2.0-22.0 GHz [12]. In this paper, beyond 9GHz, undesirable nulls are seen in the patterns which have some disadvantages with regard to spatial coverage in communications and EW. The endeavor here has been to extend the frequency coverage to 6-18GHz as regards VSWR (or return loss) and pattern bandwidth to cover Communications, Radar and EW band.

Through simulations using HFSS software, a return loss of less than -10 dB has been achieved over the frequency of 7.2-22GHz. The radiation pattern nulls have been improved by shaping the ground plane in the form of polygon encircling the entire radiating annular portion. Extensive parameter studies have been carried out to optimize dimensions for maximum VSWR bandwidth and improvement of nulls in radiation patterns. With the optimized dimensions, the antenna has been fabricated on a substrate of dielectric constant ε_r =2.2 and return loss, patterns and gain have been measured and results are given.

II. THE ANTENNA DESCRIPTION

In the antenna design, UWB wide slot antenna approach has been followed. The antenna consists of a circular wide slot surrounded by a semicircular ring on the top portion and a three sided polygon at the bottom portion. This is further surrounded by a ground plane with an inner edge consisting of a decagon and an outer periphery of an unequal sided octagon as given in Figure 1. This antenna is fed by a microstrip line printed on the back of the substrate with tuning fork lines as given in Figure 2. The fabricated antenna is given in Figure 3.The tuning fork lines deliver the feed power through electromagnetic coupling. This has been optimized through systematic simulations. Two circular patches have been included at the end of the tuning fork lines to increase the number of resonant modes from three to five which resulted in better VSWR bandwidth. The antenna is printed on a substrate of ε_r = 2.2 and thickness h_1=0.8mm. Various dimensions have been optimized to yield maximum VSWR bandwidth and acceptable radiation patterns.

III. PARAMETRIC ANALYSIS

For obtaining large bandwidth, one of the methods is to excite multi resonant modes. Referring to Figures 1-2, various parameters such as microstrip line feed length 'L1', Tuning fork length 'L2', circular parasitic patch radius ‘R’, distance'd' at the end of tuning fork lines, position of parasitic patches 'D', wide slot shape, position of coupled patch 'P', substrate thickness 'h', substrate dielectric constant 'ε_r' and other parameters have been varied in extensive simulations for obtaining optimum values for maximum bandwidth. The fabricated antenna is given in Figure3.

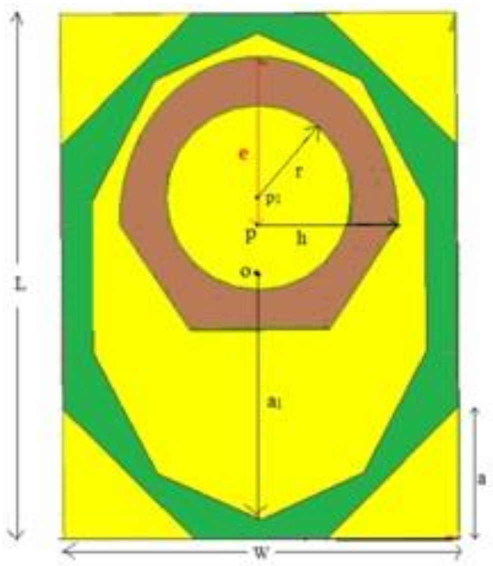

Figure 1: The antenna substrate top view with dimensions

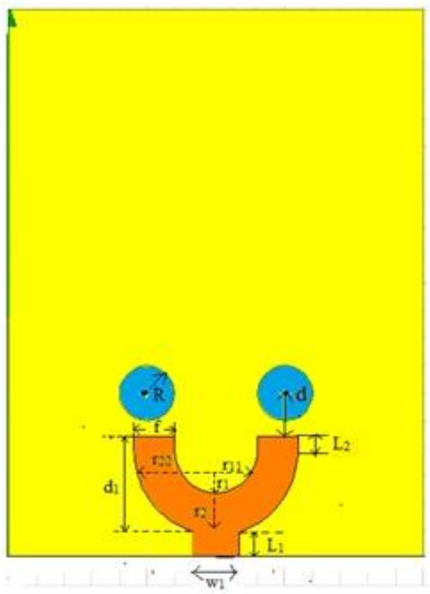

Figure 2: The antenna substrate back view with dimensions

A. Effect of Circular Patch and Stub

The effect of parasitic circular patch (introduced for creating more resonant modes) and the variation of parameter L2 on VSWR bandwidth are given in Figures 4-5. It can be seen from Figure 4 that without circular parasitic patches there are three resonances occurring at 7.7GHz, 10.4GHz, 13.8GHz, with these patches additional resonances at 17.8GHz and 20.2GHz are created. This has led to a return loss reduction at higher frequencies. There is a significant effect of changing stub length 'L2' at the end of the tuning fork feed. Referring to Figure 5 by reducing the stub length there is an improvement in return loss from 10GHz-22GHz. L2=0.5mm gives the desired return loss characteristics. The mode resonances are clearly brought out and for L2=1.5mm they are distinct and deep with respect to return loss.

Figure 3: Fabricated antenna-top and bottom view

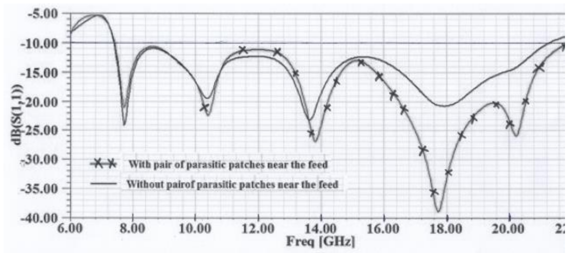

Figure 4: Return loss with and without circular parasitic patches

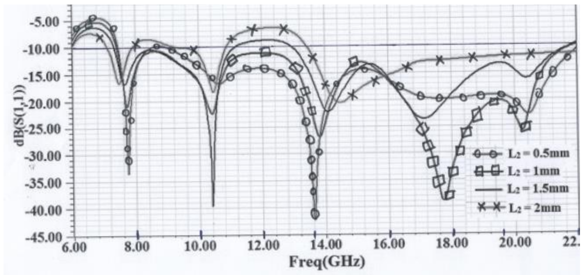

Figure 5: Return loss with varying 'L2'

B. Effect of Variation Of 'd' and Position of Top Patch 'p'

The parameter variation in 'd' is given in Figure 6. As 'd' decreases resonances become distinct and deeper. d=5.127mm gives the best performance. Another significant parameter variation is with respect to position of the coupled patch on the topside of substrate as given in Figure 7 As displacement of center of circular slot 'p' from the central symmetric position is studied and this has got significant effect in the lower frequency portion. As 'p' is increased the return loss increases between 8 and 10GHz.

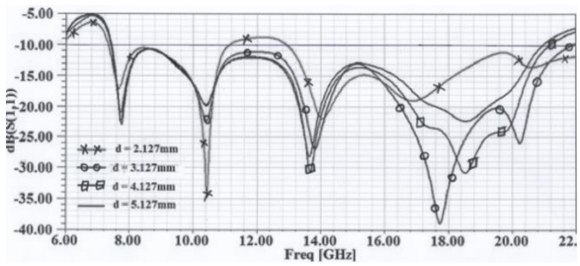

Figure 6: Return loss with varying parasitic patches 'd'

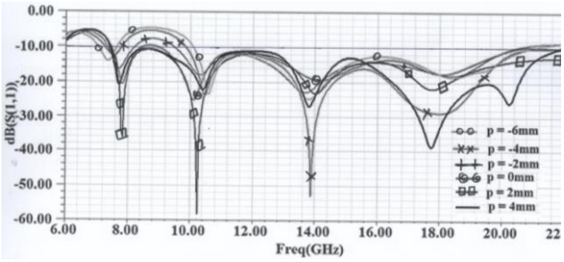

Figure 7: Return loss with varying position of coupled patch on top of substrate 'p'

C. *Effect of Substrate Thickness 'h_1' and Dielectric Constant*

Return loss plot with respect to substrate thickness 'h_1' is given in Figure 8. As the thickness is increased the resonances are found to reduce and the curves become rather flat. h_1=0.8mm gives the desired characteristics. For higher values, return loss increases beyond -10dB across the band. Another parametric variation studied is the substrate dielectric constant given in Figure 9. As dielectric constant of substrate is increased from 2.2 to 6.15, the return loss increases and goes up to -2dB.

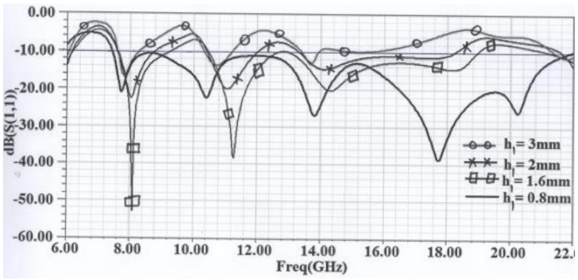

Figure 8: Return loss with varying substrate thickness 'h_1'

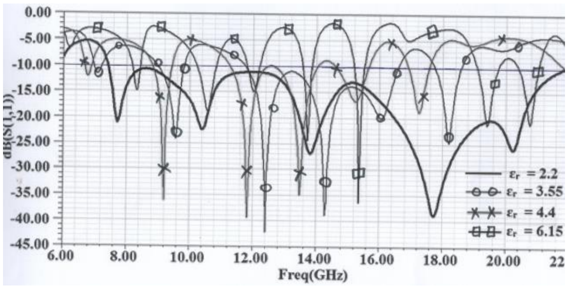

Figure 9: Return loss with varying dielectric constant of substrate 'ε_r'

D. *Effect of Slot Shape*

Three types of patches for the ground plane around the semicircular patch has been studied with various shapes namely elliptical, octagonal and decagonal and the variation of return loss is given in Figure 10. The decagonal shape gives best return loss performance. In all these cases the parameters that are studied are for minimizing the return loss and improvement of radiation patterns.

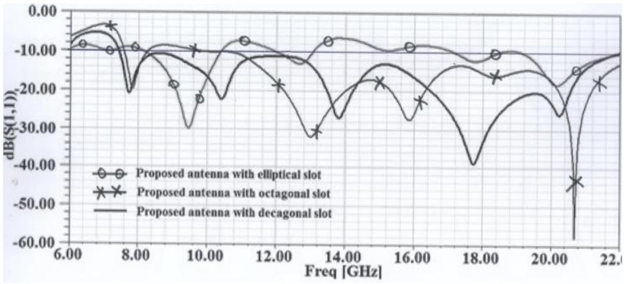

Figure 10: Return loss with varying ground plane and slot shape

IV. RESULTS

Return loss plot obtained through HFSS simulations is given for the optimized dimensions given in Table 1 is given in Figure 11. The return loss is below -10db over the frequency range of 7.2-22GHz. The simulated radiation patters are not given here but are good without nulls from 6.0 GHz to 18 GHz.

The antenna is printed on an RT Duroid 5880 substrate with ε_r = 2.2 and thickness 0.8mm. The measured return loss is below -10db from 2-22GHz and beyond as given in Figure 12. The measured one is much better than the simulated case. This has been our observation with consistency. Radiation patterns have been measured only in the frequency range of 6-18 GHz. which is our range of interest for communications and tactical EW applications and are given in Figure 13. It can be seen that there is a significant improvement in patterns with regard to nulls up to 15GHz compared to the paper cited above. Both E and H plane patterns are given in the same polar graph at each frequency. E plane (Vertical plane) is represented by solid line and H plane (Horizontal plane) is represented by chain line. Improvements are required in patterns in the frequency range from 15GHz to 18GHz. The gain varies from -4.2dB at 7.2GHz to +5.0 GHz at 18 GHZ. The optimum dimensions given in Table 1 have been used for fabrication of the antenna.

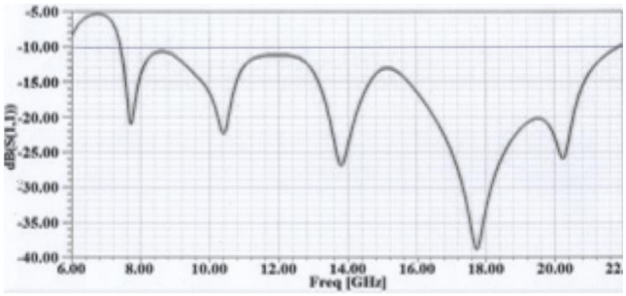

Figure 11: Return loss of antenna (simulated)

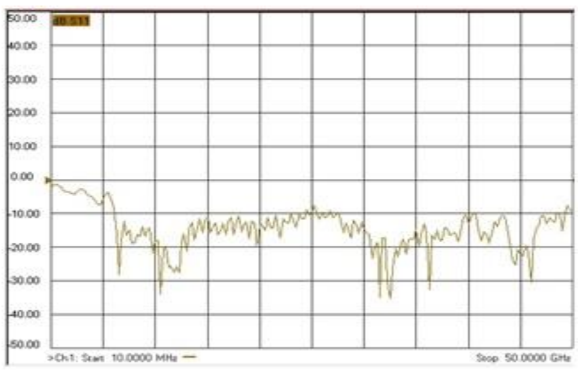

Figure 12: Return loss (measured) 10MHz to 50GHz

Table 1
Antenna Dimensions

Symbol	Dimensions	Symbol	Dimensions
L1	2.34mm	*L*	40.00mm
W1	3.35mm	*W*	30.00mm
L2	1.00mm	h_1	0.80mm
d	3.12mm	*A*	10.00mm
d1	8.87mm	*O*	20.00mm
r1	3.14mm	*a1*	18.50mm
r11	2.98mm	*P*	24.00mm
r2	0.88mm	*E*	12.72mm
r22	5.93mm	*p1*	6.00mm
R	2.00mm	*r*	7.00mm
f	2.95mm		

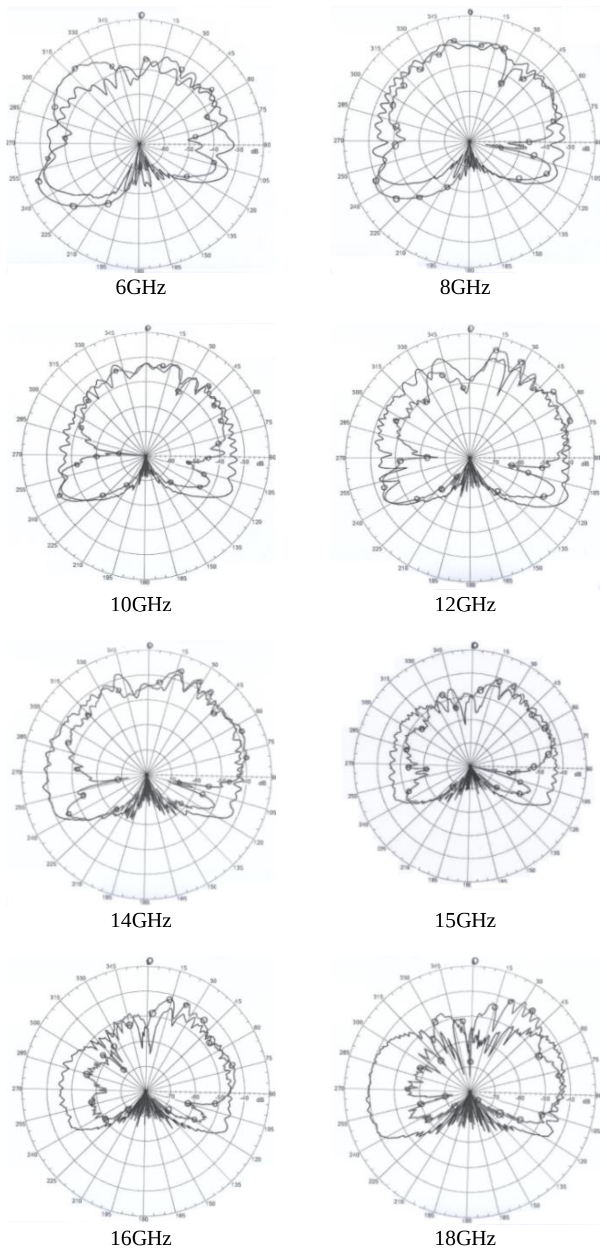

Figure 13: Radiation patterns (measured)

V. CONCLUSION

A wide band antenna has been designed and analyzed through HFSS simulations and implemented in hardware. The antenna is fabricated on a substrate with $\varepsilon_r = 2.2$ and thickness of 0.8mm. In simulations, parametric studies of various parameters have been carried out and optimum values have been arrived at. Circular patches at the end of tuning fork microstrip feed and a decagonal ground plane patch surrounding the elliptical slot are specific contributions made in this paper to achieve large bandwidth. These novel features have given improved simulated and measured patterns over 6GHz-15GHz. In simulations, a return loss of less than -10 dB over 7.2 to 22GHz has been obtained. The return loss (measured) is below -10 dB over 2GHz to 22GHz. The measured gain of the antenna varies from - 4.2dB at 7.2GHz to +5.0 GHz at 18 GHZ. The antenna finds applications in communications, radar and EW.

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