High Gain Wideband Compact Microstrip Antenna With Quasi-Planner Surface Mount Horn

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Abstract **– We report a new compact square microstrip antenna with surface mounted quasi-planner horn. Horn is made of plastic sheet and painted with silver epoxy. Horn improves gain of patch by 3 dB-4.5 dB without adversely affecting bandwidth which is 2.3% -9%.. Horn also improves isolation between array elements by 10 dB. Total thickness of antenna, including horn is only 6.94 mm.**

I. INTRODUCTION

The modern broadband communication systems and radars require light weight compact antenna with high gain and larger bandwidth. Such antenna are also needed for the wireless and phased array applications. The traditional microstrip antenna has typical gain between 6dBi – 8dBi and narrow bandwidth around 2 %. There is need to improve the performance of microstrip antenna to achieve larger gain and wider bandwidth without disturbing the planar nature of the microstrip radiating element. The bandwidth is normally improved by using a thick substrate [1].

Some schemes have been suggested to enhance gain of the microstrip radiator . The single superstrate and the multiple superstrate have been examined for this purpose. [2,3]. However, for significant improvement in gain, use of very high permittivity and permeability superstrate is suggested. Usually such superstrates are not practical. Moreover, they result in further reduction of the limited bandwidth available with the microstrip antenna. The cavity-backed microstrip antenna with superstrates of both dielectric and magnetic properties has also been suggested for high gain microstrip antenna [4]. This method also suffers the same practical problem of materials and also radius of the cavity is usually more than λ_o , which is large. The structure becomes bulky and unattractive in array application. Lee et al. [5] have experimentally examined a two-layer electromagnetically coupled rectangular patch antenna to obtain 9.2 dB gain with but only 1.3 % bandwidth.

This paper reports a new microstrip antenna element with the quasi-planner surface mount short horn. The slant length of the horn is only $\lambda_o/4$ to achieve high gain i.e. 11 dBi. We obtained 9.0 % bandwidth for the structure which can be further increased by use of thicker substrate [1]. The paper presents a systematic numerical experimentation on a 3 D EM simulator, MICROWAVE STUDIO™, Version -3 [6] to achieve high directivity. The microstrip antenna with a surface mounted horn is fabricated with plastic sheet. The horn surface is silver epoxy painted. We have also fabricated and tested a two element array. An improvement of 10 dB isolation between the elements; as compared to the array without horn, is achieved by use of the surface mount quasi-planner horn.

II. NUMERICAL EXPERIMENTATION

Our proposed new structure is shown in Fig. 1. At the first, we have attempted to optimise size of a quasi-planner short horn and its placement with respect to the patch in order to obtain the maximum possible gain for the compact structure. A probe-fed square microstrip antenna, with dimension, 0.857cmx0.857cm is designed on a square dielectric substrate of size, 8.0 cm x 8.0 cm x 0.081cm and relative dielectric constant ε_r =3.38. The patch antenna resonates at 8.77 GHz. A short horn of slant length, $L_s = \lambda_o/4 = 0.875$ cm is selected in this work. λ_o is the wavelength at the resonance frequency.

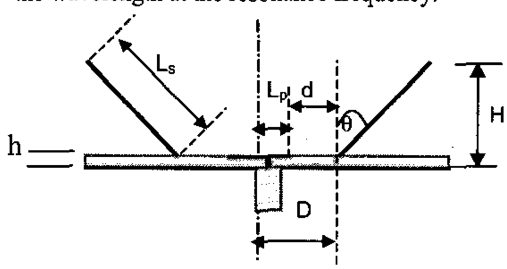

Fig. 1 Microstrip patch antenna with quasi-planner surface mount horn

The total distance between centre of the patch and inner edge of the horn is, $D=L_p+d$. Where $2L_p$ is the dimension of square patch and d is the distance between edge of the patch and inner edge of the horn. The patch has 6.27 dBi directivity without horn. The slant length of horn makes θ ° angle with respect to the vertical axis to the patch. Through numerical experimentation we optimise horn position, d and slant angle θ ° to achieve the maximum gain. For several horn position, d between $\lambda_o/16$ to λ_o, we compute broadside directivity of the patch radiator at slant angles between θ ° =0 ° and 90 ° with help the 3D- EM simulator [6]. The final results for horn of the slant length $L_s = \lambda_o/4$ is presented in the Fig 2. The θ for maximum directivity is shown in the figure and the corresponding position, d in wavelength is also shown. Thus we can achieve the high directivity at the horn position, d $=\lambda_o/8$ and $\lambda_o/4$ for the horn slant angle, θ= 60 ° and 45°. While maintaining nearly high gain, distance, d and slant angle, θ can be adjusted to meet requirement of an array arrangement.

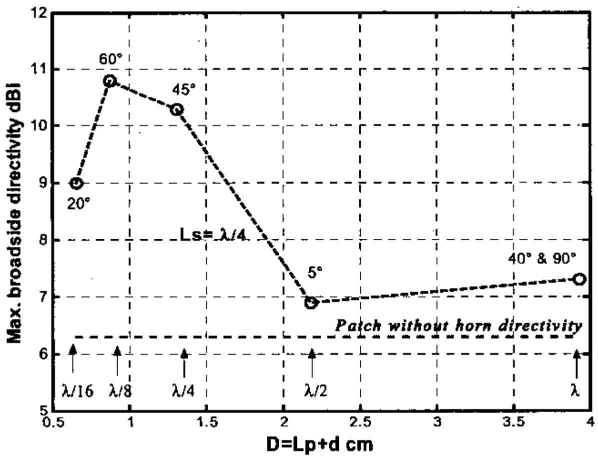

Fig. 2 Position of horn for maximum directivity at different slant angle (θ) of horn.

A microstrip antenna on the thin substrate provides narrow bandwidth, typically about 2%. Therefore, we examined the microstrip antenna with and without horn on the thick substrates also. The numerical investigation is carried out for the qusi-planner horn of slant length, $L_s = \lambda_o/4$, slant angle, θ = 60 ° and horn position, d $=\lambda_o/8$ and $\lambda_o/4$. The thickness of substrate, h is 0.081 cm and thick substrates are taken in multiple of this basic thickness. The results of numerical investigation is shown in Table-1. The table shows that for the horn position, d $=\lambda_o/8$, directivity of the antenna with horn decreases from 10.7 dBi to 7.8 dBi with the increase in the substrate thickness from h to 4h. There is only a marginal increase in directivity of the simple patch from 6.23 dBi to 6.9 dBi for 4h thick substrate. The degradation in directivity of the patch antenna with horn is due to leakage of power from the thick radiating aperture of the patch. The leaked power does not reach to the horn for sufficient radiation. Table-1 further shows that for the horn position, d $=\lambda_o/4$ the directivity is increased to 11 dBi. The enlarged dimension, d of base of the horn helps to collect more power to the horn. This makes size of the radiating element large and may not be suitable for an array application. Therefore, for an array application we can restrict ourselves for 3h thick substrate and accept 9.7 dBi directivity with some reduced bandwidth around 7.82 %.

Table-1 further shows that with increase in thickness of the substrate from h to 4h, the bandwidth of the patch radiator increases from 2.67 % to 11.8%. For the horn placed at d $=\lambda_o/8$, the bandwidth is reduced a little. However, it increases from 2.30 % to 11.6 % with increase in substrate thickness from h to 4h.The bandwidth shows improvement for the horn position, d $=\lambda_o/4$. Table-1 shows that the feed position for the proper matching changes with thickness of the substrate and also by presence of the horn. This should be taken care of to design the microstrip antenna with surface mounted qausi-planner horn.

III. FABRICATION AND EXPERIMENTAL RESULTS

The patch antenna and patch antenna with qausi-planner short horn is fabricated for the experimental investigation. One set of patch antenna is fabricated on the thin substrate, h = 0.081 cm, ε_r = 3.38 and the square patch length $2L_p$ = 0.857 cm to resonate at f_r = 8.77 GHz. The horn has a slant angle θ = 30 ° and slant length, L_s =0.875 cm. Length of square base of the horn is 2.2 cm. Another set of square patch antenna is fabricated on the thick substrate, 3h = 0.243 cm, ε_r = 3.38 and the square patch length L_p = 8.44 cm to resonate at f_r = 9.2 GHz. The horn has slant angle θ = 60 ° and slant length, $L_s = \lambda_0/4$. The slant angle is changed to confirm high gain obtained through simulation for θ between 30 ° and 60 °. The horn is placed at $d=\lambda_0/4$. For light weight antenna structure, the short quasi-planner horn structure is fabricated from a thick sheet of PVC. The total thickness of the antenna structure with horn (H) is only 6.94mm. The conducting surface of the horn is painted with silver epoxy paint. An array of two elements on the thin substrate is also fabricated to test the radiation property, bandwidth and isolation between the radiating elements for large array application. The fabricated patch element and two element array with the surface mounted plastic horn is shown in Fig.3. We note that for the array both horns are made in one plastic block. For a large array also the horns could be cut in one plastic sheet and inner surfaces could be properly metallized to achieve high gain

Table-1
Simulated results for slant angle $\theta = 60°$ and $L_s = \lambda_o/4$

Substrate thickness (h=0.081 cm)	Directivity without horn (dB_i)	Directivity with horn $d=\lambda_o/8$ (dB_i)	Directivity with horn $d=\lambda_o/4$ (dB_i)	Band-Width No horn	Band-Width with horn $d=\lambda_o/8$	Band-Width with horn $d=\lambda_o/4$	Feed position without horn	Feed position with horn $d=\lambda_o/8$	Feed position with horn $d=\lambda_o/4$
1	6.27	10.7	10.1	2.67%	2.3%	2.63%	0.12	0.105	0.115
2	6.47	10.5	11.0	6.58%	4.48%	5.58%	0.17	0.14	0.150
3	6.70	9.70	11.0	10.5%	7.82%	9.2%	0.27	0.23	0.250
4	6.90	7.80	10.7	11.8%	11.6%	10.93%	0.40	0.39	0. 400

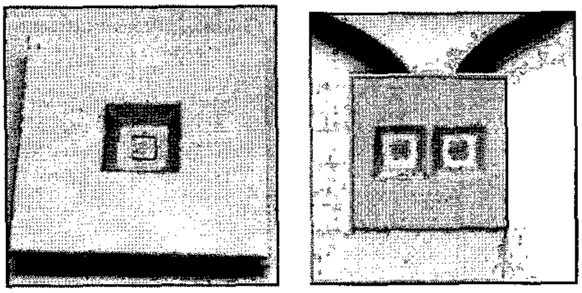

Fig. 3. Fabricated patch with surface mount quasi-planner horn

Fig.4(a) and Fig.4(b) show radiation patterns of the patch antenna in the E-plane and H-plane respectively for the patch with horn on the thin substrate, h= 0.081 cm. The experimental results validates the simulation. The deviation in the back-lobe is due to measurement condition, and point to point manual measurement.

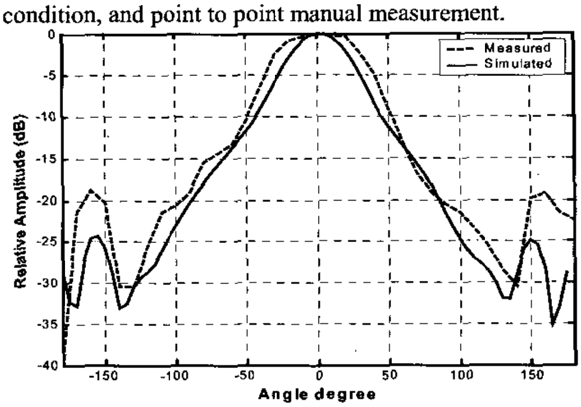

Fig. 4(a) . Measured and simulated E-plane field with horn

We make a detail comparison between the measured performance and the simulation of the patch antenna, with and without horn in the Table-(2). We obtain 9.0 dBi gain as compared to the standard horn. We get 9.2 dBi directivity from the measured beam-widths. The Table-(2) also shows an improvement of 3.5 dB gain by use of the quasi-planner horn. As shown in Fig.(5), the horn reduces the bandwidth slightly, from 2.4% to 2.3%.However, it has improved the return loss from –22 dB to –35 dB. Similar results are obtained for the patch on thicker substrate, h=0.243 cm. For this case we obtained 11.0 dBi gain with 9.0% bandwidth.

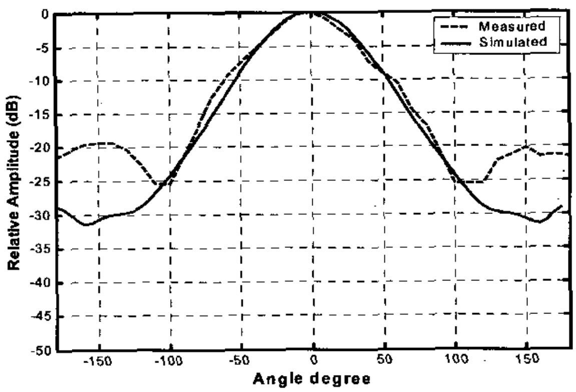

Fig. 4(b) Measured and simulated H-plane field with horn

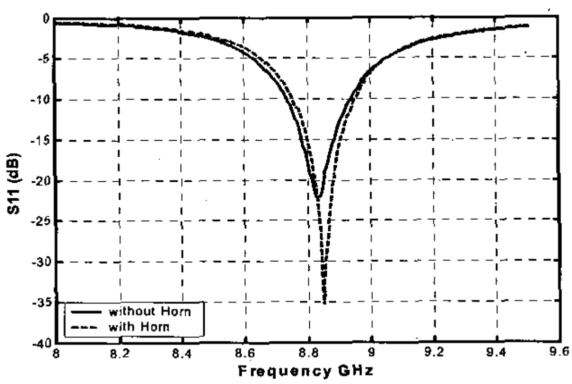

Fig. 5. Measurement of return-loss with and without horn

Table-2
Performance of antenna element

parameter	With horn		Without horn	
	Experiment	Simulation	Experiment	Simulation
S_{11}(dB)	-35	-40	-22	-25
Bandwidth	2.3%	2.3%	2.4%	2.67%
Resonance frequency	8.85 GHz	8.77 GHz	8.832 GHz	8.75 GHz
Beamwidth E-plane	55°	43.5°	135°	120°
Beamwidth H-plane	57°	55.3°	74°	71°
Gain	9 dB	10 dB	5.5 dB	6 dB

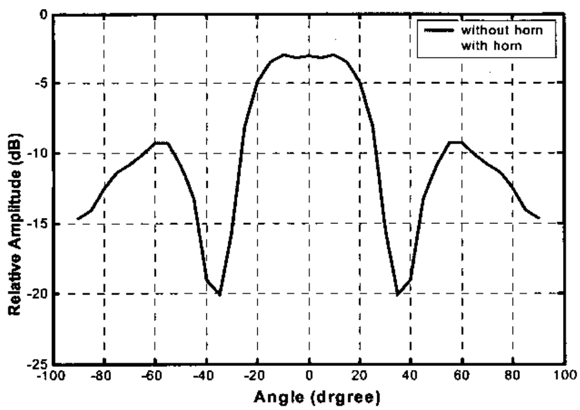

Fig. 6. Two-Element measured E-plane field with and without horn

Fig. 6 shows the measured radiation patterns in the E-plane for a two element array with and without horn. The horn improves the gain of two element array by 3 dB. There is also a significant improvement in the side lobe level due to presence of the horn. We obtained 11.5 dBi gain of the two element array with horn and 8.5 dBi gain of the array without horn with help of a standard horn. Fig.7 shows the measured isolation between the patches of two element array. The centre to centre distance between two patches is $0.82\lambda_o$. The horn improves the isolation nearly by 10 dB.

IV. Conclusion

The new square microstrip antenna with surface mounted quasi-planner horn can improve gain of the patch antenna by 3 dB-4.5 dB without adversely affecting the bandwidth. The horn is made of the plastic sheet and painted with silver epoxy. For a large array application the horn can be cut in a plastic sheet and surface of the horn can be properly metallized. We obtained 9 dBi- 11 dBi gain with bandwidth 2.3 % - 9.0 % for an individual patch element with the horn. The horn also improves the isolation between array elements by 10 dB for the centre to centre distance between two patches, $0.82\lambda_o$ which is important for an array application.

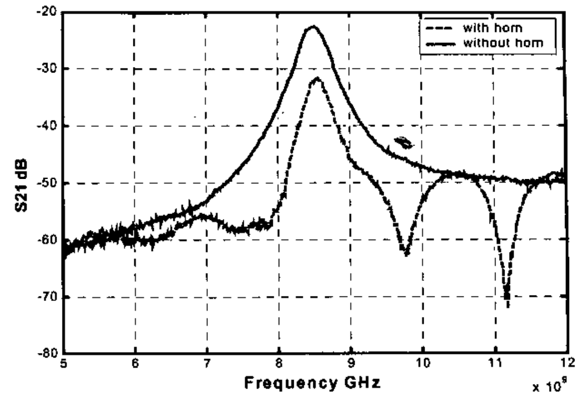

Fig. 7. Measured coupling between two radiating elements with and without horn

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