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A New-Fangled Gain Augmentation Technique by Using the Surface Mounted Short Horn

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Abstract

A microstrip antenna, also known as a patch antenna, consists of a metal patch on a substrate on a ground plane, The patch can take various forms to meet different design requirements. Typical shapes are rectangular, square, circular and circular ring. The microstrip antenna is low-profile, conformable to planar and nonplanar surfaces, simple and cheap to manufacture using modern printed-circuit technology, and mechanically robust.
The improvement of the microstrip antenna gain is the subject of this paper. We introduce a new gain enhancement technique by using the surface mounted short horn. We also introduces a new probe fed microstrip antenna element with the quasi-planar surface mount short horn.

Keywords: Microstrip Antenna, Planar Surface Mounted Horn.

1. Introduction

In this chapter, we introduce a new gain enhancement technique by using the surface mounted short horn. This new gain enhancement technique has been applied to aperture coupled microstrip antenna in [1] and also to probe feed microstrip antenna [2], [3]. A compact aperture coupled microstrip antenna with quasi-planar surface mounted horn of the slant-length, $l_S= \lambda_O/4$ has been investigated using the full wave 3-D Microwave Studio. The antenna is developed in the Ku-band i.e. 11.08 GHz – 12.5 GHz. The structure has bandwidth 12.4% and has gain 10 ±0.4 dB over the full bandwidth. This method provides improvement of both the bandwidth and gain. We could introduce the surface mounted horn as a gain improvement process through experimental investigations. A probe fed microstrip antenna was initially fabricated for measurement on the power meter. As the gain of the patch antenna was not enough our measurement was not satisfactory. At this moment, we thought about collection of more power around the patch using manually fabricated small copper horn. This arrangement provided 3 dB improvements in gain. Subsequently more investigations and optimization have been carried out through numerical investigations on the 3D-EM Simulator, Microwave studio.

The slant length of the horn is only $\lambda_o/4$ to achieve high gain i.e. 11 dBi. Bandwidth of 9.0 % has been obtained for the structure which can be further increased by use of thicker substrate [4]. A systematic numerical experimentation on a 3- D EM simulator [5] is presented to achieve high directivity. The microstrip antenna with a surface mounted horn is fabricated with plastic sheet. The horn surface is silver epoxy painted. Two element array has been fabricated and tested. An improvement of 10 dB isolation between the elements; as compared to the array without horn, is achieved by use of the surface mounted quasi-planar horn.

2. Numerical Experimentation

The proposed new structure is shown in Figure 1. At first, we have attempted to optimize size of a quasi-planar 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 =4.38. 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.

The total distance between center 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 optimize 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 [5].

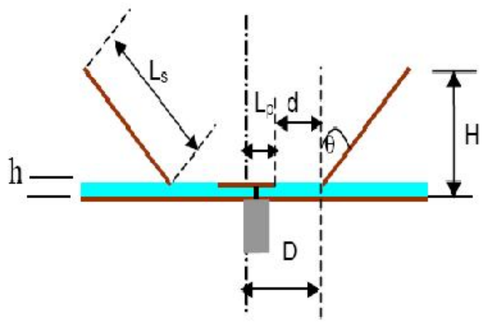

Figure 1: Microstrip patch antenna with quasi-planar surface mounted horn.

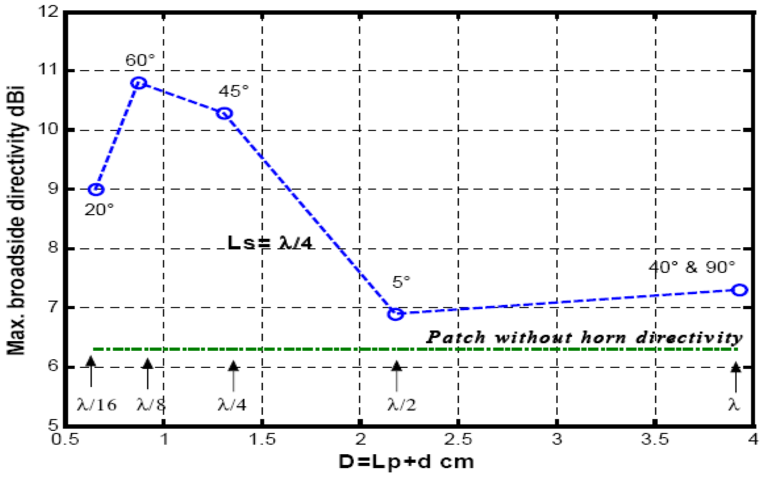

Figure 2: Position of Horn for Maximum Directivity at Different Slant Angle (□) of Horn.

The final results for horn of the slant length $L_S = \lambda_O/4$ is presented in the Figure 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.

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-planar 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-planar horn.

Table 1: Simulated results for slant angle □ = 60° and Ls= □o/4.

Substrate thickness. (h=0.081 cm)	Directivity without horn (dBi)	Directivity with horn d=□o/8 (dBi)	Directivity with horn d=□o/4 (dBi)	Band-Width No horn	Band-Width with horn d=□o/8	Band-Width with horn d=□o/4	Feed position without horn	Feed position with horn d=□o/8	Feed position with horn d=□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

3. Fabrication and Experimental Results

The patch antenna and patch antenna with qausi-planar 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 = 4.38 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-planar 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 metalized to achieve high gain.

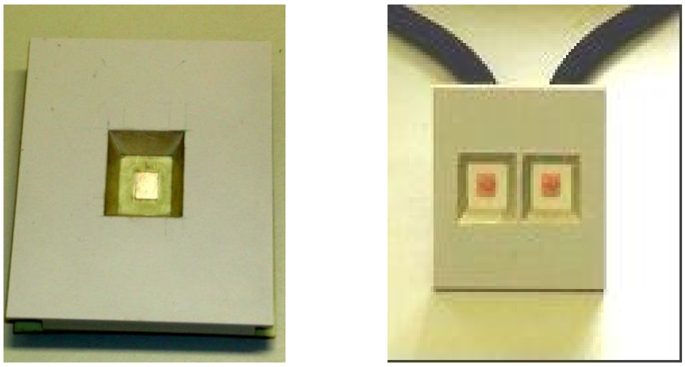

Figure 3: Fabricated Patch with Surface Mount Quasi-Planar.

Figure 4 and Figure 5 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.

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 4.5 also shows an improvement of 3.5 dB gain by use of the quasi-planar horn. As shown in Figure 4.20, 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.

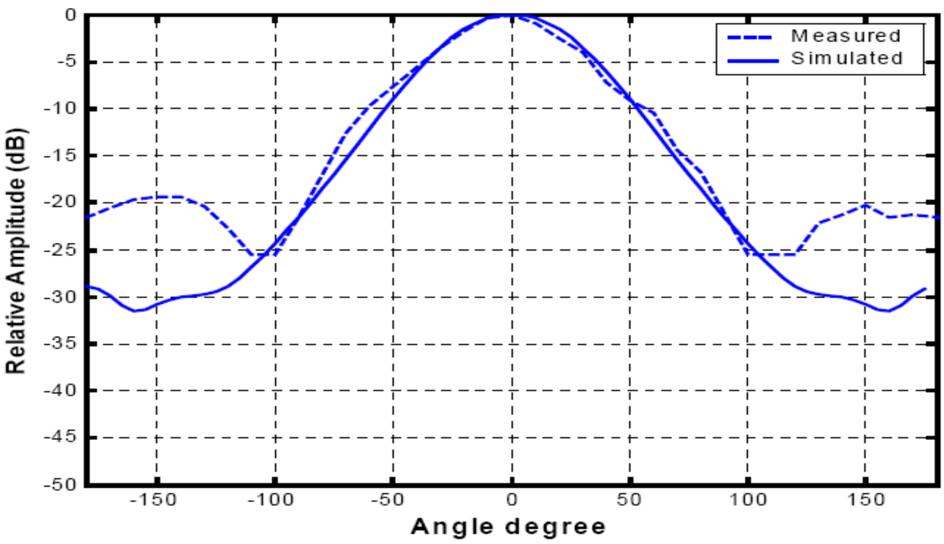

Figure 4: Measured and simulated E-plane field with horn.

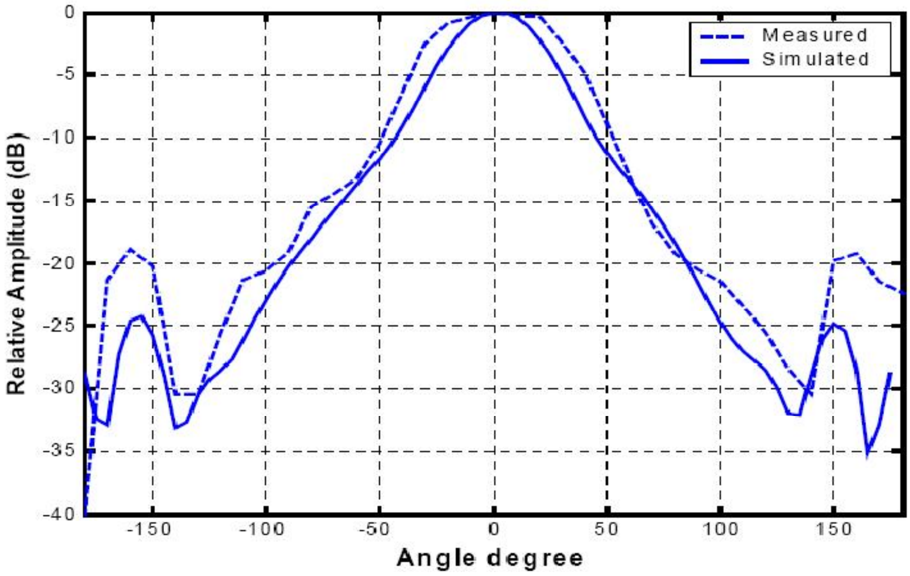

Figure 5: Measured and simulated H-plane field with horn.

Table 2: Experimental and Simulated Performance of Probe-fed Microstrip Antenna with and without Horn.

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°	44.5°	135°	120°
Beamwidth H-plane	57°	55.3°	74°	71°
Gain	9 dB	10 dB	5.5 dB	6 dB

Figure 7 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 the help of a standard horn. Fig.8 shows the measured isolation between the patches of two element array. The center to center distance between two patches is $0.82\lambda_O$.

The horn improves the isolation nearly by 10 dB.

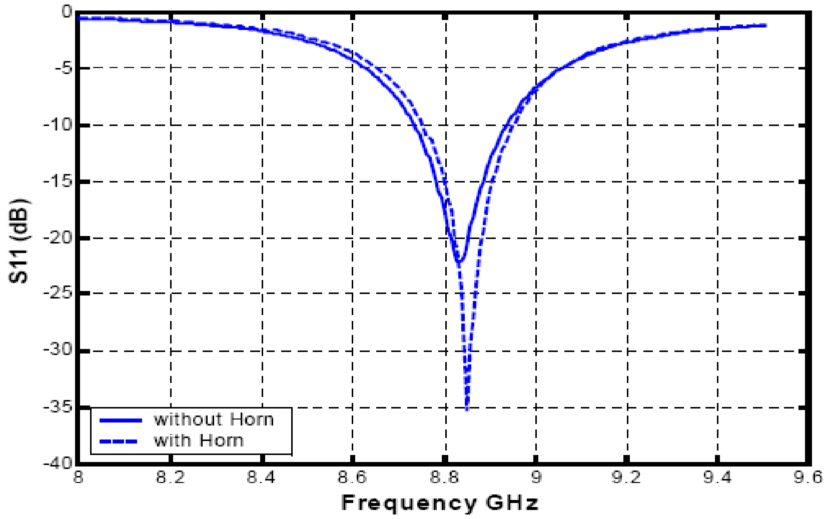

Figure 6: Measurement of return-loss with and without horn.

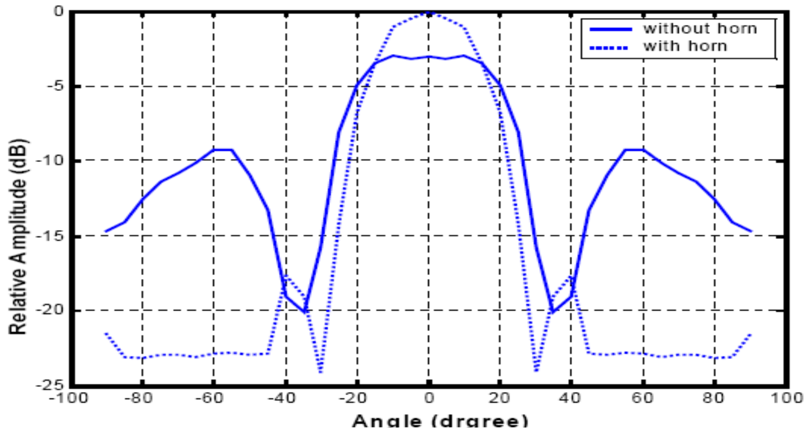

Figure 7: Two-Element measured E-plane field with and without horn.

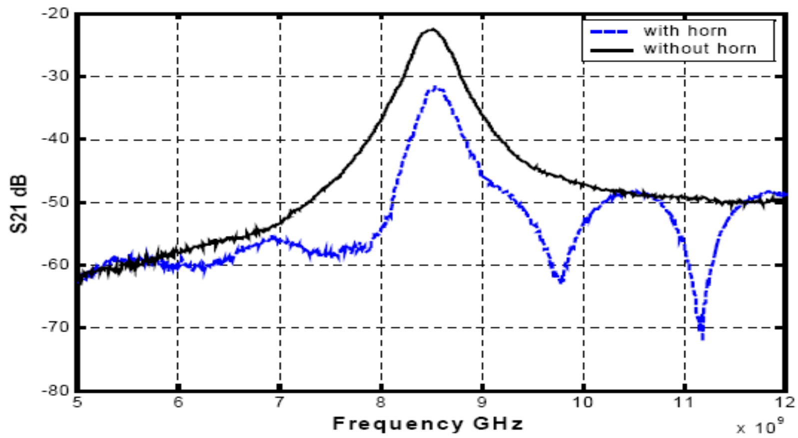

Figure 8: Measured coupling between two radiating elements with and without horn.

4. Gain Behavior of Inserted Horn

At certain substrate thickness, the surface mounted horn can not improve the gain much more as discussed in section .1 and Table 1.

By increasing the substrate thickness, the surface mounted horn is not able to trap the total power. Some of the power leaks through the substrate as a surface waves. To trap and guide this leaked power to the broadside direction, the horn has to be inserted into the substrate thickness till the ground plane. By inserting the horn into the substrate, the gain will increase by more than 1.5 dB as indicated in Table 3.

Table 3: Performance of Probe-fed Microstrip Antenna with Inserted and Surface Mounted Horn for Practical Substrates having Different Thickness and Relative Permittivity.

Substrate RT/duroid 6006						
hf	εrf	tanδf	tf (μm)	Broadside Gain (dB)		
				Patch without horn	Patch with surface mounted horn	Patch with inside mounted horn
0.0157 λ0	6.15	0.0019	17.5	5.1	10.1	10.49
0.0313 λ0	6.15	0.0019	17.5	5.3	10.3	10.89
0.0627 λ0	6.15	0.0019	17.5	5.9	9.7	11.18
Substrate RT/duroid 5880						
hf	εrf	tanδf	tf (μm)	Broadside gain (dB)		
				Patch without horn	Patch with surface mounted horn	Patch with inside mounted horn
0.0203 λ0	2.2	0.0009	35	6.7	10.9	11.4
0.0407 λ0	2.2	0.0009	35	6.57	10.6	11.7
0.082 λ0	2.2	0.0009	35	6.57	10.16	12.00

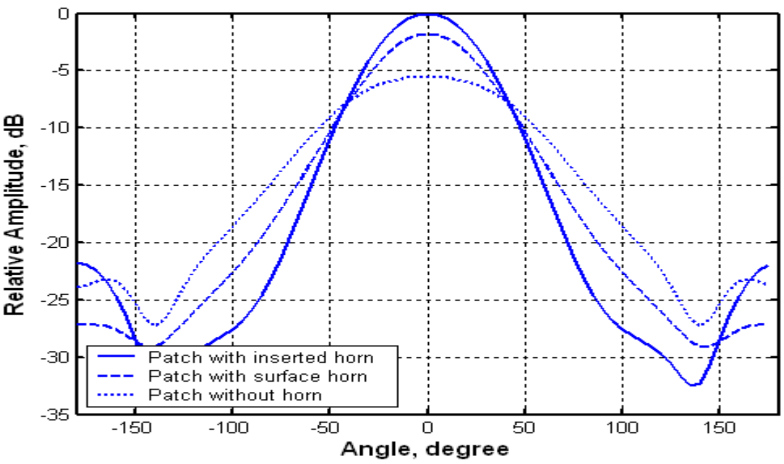

Figure 9: Simulated H-plane radiation patterns.

Two different substrates have been used to investigate the effect of the relative permittivity and the thickness on the behavior of the surface mounted and inserted horn. Less gain has been obtained in case of high relative permittivity materials due to the small dimension of the microstrip antenna as shown in Table 3.

Conclusion

We have introduced in this thesis a new combination of the aperture coupled microstrip antenna and a quasi-planner surface mounted short horn to increase the gain of the patch antenna by 4.5 dB. Horn has no significant effect on the resonance frequency, bandwidth and return loss. The combined structure has 12.4 % bandwidth. The presence of the quasi-planner horn has improved the back-lobe level by 5.4 dB.

At certain substrate thickness, the surface mounted horn can not improve the gain much more. By increasing the substrate thickness, the surface mounted horn is not able to trap the total power. Some of the power leaks through the substrate as a surface waves. To trap and guide this leaked power to the broadside direction.

By inserting the horn into the substrate, the gain of the patch antenna has been increased by more than 6 dB.

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