VOL. 9, NO. 6, JUNE 2014 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

ANALYSIS OF HYBRID SLOT ANTENNA BASED ON SUBSTRATE PERMITTIVITY

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ABSTRACT

Most of the microstrip patch antennas are constructed on thin substrates with low dielectric constant. The demand of millimeter wave and monolithic fabrication increased the interest of thick substrates with high dielectric constant. The efficiency of the antenna will decreases with increase in substrate permittivity but size of the antenna also decreases. When substrate permittivity is decreased, then performance can be improved. The thicker substrates will increase the bandwidth but if it exceeds some point then surface wave losses will be affected. Thinner substrates will not give bandwidth enhancement but surface wave losses can be decreased. There is tradeoff between substrate material selection and the performance of the antenna and the size. Without changing the substrate material, the size reduction can be achieved by employing slots in the model. The purpose of this paper is to provide a set of output parameters of hybrid slot antenna with change in substrate permittivity. The performance evaluation of hybrid slot antenna is carried out by changing the dielectric constant of the materials by maintaining the constant thickness of 1.6mm.

Keywords: dielectric constant, hybrid slot, substrate permittivity, monolithic fabrication, size reduction.

1. INTRODUCTION

Microstrip patch antennas offer an attractive solution to compact, conformal and low-cost designs of many wireless application systems. Most of the microstrip antenna work in the past has employed electrically thin, low permittivity substrates. For this case, a variety of theoretical models has been formulated, and appears to give good results in terms of resonant frequency and input impedance. Recent interest in millimeter wave systems and monolithic fabrication, however, has created a need for substrates that are electrically thicker, and/or have high permittivity [1-3]. Increased bandwidth is another reason for interest in electrically thicker substrates. Anomalous results have been previously observed for printed antennas on such substrates [4-5].

Many of the theoretical models, which worked well for thin, low dielectric constant substrates, fail to give good results for thicker or higher permittivity substrates. In order to determine the range of validity of these models, and to provide a database of measured data for the testing of improved models, this paper describes the results of a comprehensive set of measurements of hybrid slot microstrip antenna. The hybrid slot model shown in Figure-1 is having different models of slot shapes placed on the patch surface. Six substrate materials are taken in this work including air. Different slots and their dimensions are shown in Figure-2.

2. ANTENNA MODEL AND DIMENSIONS

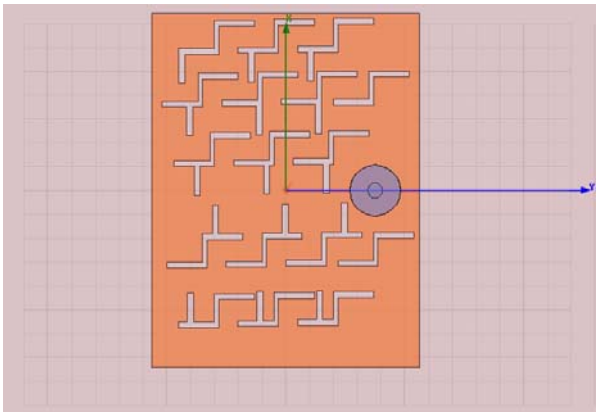

Figure-1. Hybrid slot MSPA.

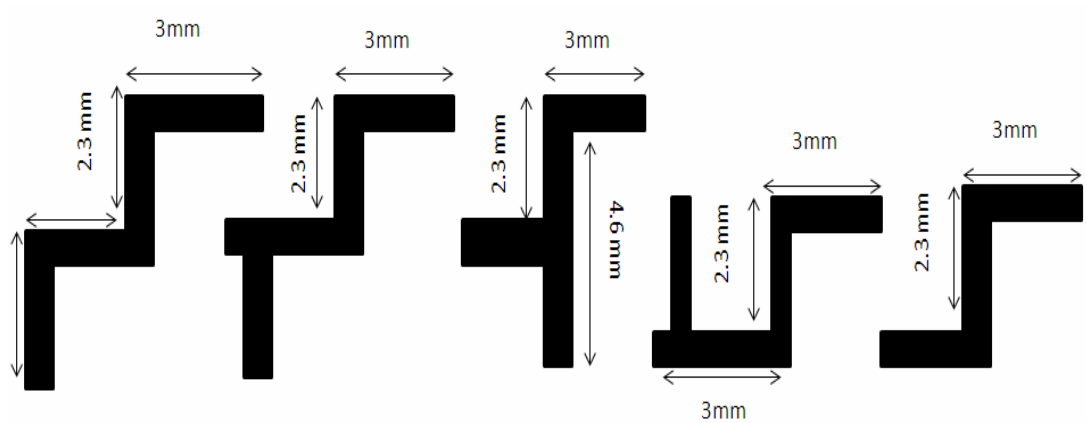

Figure-2. Different shapes of slots and their dimensions.

Different types of slot models are placed on single patch element [6-10]. The slots are placed in a fashion that each slot is having different shape, but vertical slots are having dimension of 2.3 mm and horizontal slots having 3 mm. Slots are placed all over the patch with uniform distance between them.

3. MATHEMATICAL ANALYSIS

Each slot of Hybrid slot pattern is divided into number of rectangular apertures. For an aperture in an infinite ground plane, the Fourier transform relations are given as below:

$$\vec{E}(x,y,z) = \frac{1}{4\pi^2}\iint_{-\infty}^{+\infty} \vec{\varphi}(k_x,k_y,z)e^{+j(k_x x + k_y y)}\, dk_x dk_y$$

$$\vec{\varphi}(k_x,k_y,z) = \iint_{-\infty}^{+\infty} \vec{E}(x,y,z)\, e^{+j(k_x x + k_y y)}\, dk_x dk_y$$

Where, $\vec{\varphi}(k_x,k_y,z) = \vec{f}(k_x,k_y)\, e^{-j(k_z z)}$

Here $\vec{f}$ is a generating function and $\vec{\varphi}(k_x,k_y,z)$ is the Fourier transform of the electric field generated by each rectangular aperture.

For the slot pattern 1, assume the thickness is't'. The entire pattern is divided into four rectangular apertures. The Fourier transform of electric field of each aperture is as shown below:

$$\vec{\varphi_{11}} = \vec{f_{11}}(k_x,k_y)e^{-j(k_z z)}$$
$$\vec{\varphi_{12}} = \vec{f_{12}}(k_x,k_y)e^{-j(k_z z)}$$
$$\vec{\varphi_{13}} = \vec{f_{13}}(k_x,k_y)e^{-j(k_z z)}$$
$$\vec{\varphi_{14}} = \vec{f_{14}}(k_x,k_y)e^{-j(k_z z)}$$

The generalized equation is,

$$\vec{\varphi_1}(k_x,k_y,z) = \sum_{i=1}^{4} \vec{f_i}(k_x,k_y)e^{-j(k_z z)}$$

Here $\vec{f_i}(k_x,k_y)$ is a generating function which depends on the shape of the slot i.e., rectangular in the present case

By applying the inverse Fourier transform to $\vec{\varphi_1}$ we get the original electric field as,

$$\vec{E_1}(x,y,z) = \frac{1}{4\pi^2}\iint_{-\infty}^{+\infty} \vec{\varphi_1}(k_x,k_y,z)e^{+j(k_x x + k_y y)}\, dk_x dk_y$$

For the slot pattern 2, the original electric field is given as below:

$$\vec{E_2}(x,y,z) = \frac{1}{4\pi^2}\iint_{-\infty}^{+\infty} \vec{\varphi_2}(k_x,k_y,z)e^{+j(k_x x + k_y y)}\, dk_x dk_y$$

Similarly for the slot pattern 3, 4, 5 the original electric field is given as below:

$$\vec{E_3}(x,y,z) = \frac{1}{4\pi^2}\iint_{-\infty}^{+\infty} \vec{\varphi_3}(k_x,k_y,z)e^{+j(k_x x + k_y y)}\, dk_x dk_y$$

$$\vec{E_4}(x,y,z) = \frac{1}{4\pi^2}\iint_{-\infty}^{+\infty} \vec{\varphi_4}(k_x,k_y,z)e^{+j(k_x x + k_y y)}\, dk_x dk_y$$

$$\vec{E_5}(x,y,z) = \frac{1}{4\pi^2}\iint_{-\infty}^{+\infty} \vec{\varphi_5}(k_x,k_y,z)e^{+j(k_x x + k_y y)}\, dk_x dk_y$$

These slots are cut on the patch at different locations to form a random fractal pattern [10]. The total electric field generated by the entire pattern is the sum (superposition) of the individual electric fields.

Table-1. Antenna dimensions.

S. No.	Input parameters	Dimension in mm
1	Patch length	29.7 mm
2	Patch width	22.5 mm
3	Substrate length	80 mm
4	Substrate length	80 mm
5	Substrate height	1.6 mm
6	Feed position along y-axis	7.5 mm
7	Coaxial inner radius	0.6 mm
8	Coaxial outer radius	2.1 mm
9	Feed length	6.3 mm
10	Antenna dimension	80x80x1.6

4. RESULTS AND DISCUSSIONS

Table-2. Antenna output parameters for different substrate materials.

S. No.	Substrate material	Resonant frequency	Return loss in dB	Bandwidth enhancement in %	Gain in dB
1	Air	5.2 GHz	-16.35 dB	0.3%	8.33 dB
2	RT-Duroid	3.8, 5.9 GHz	-15.28, -19.14 dB	0.6%, 0.5%	8.44 dB
3	Benzocyclobuten	3.5, 5.5 GHz	-12.56, -38.38 dB	0.2%, 0.3%	7.56 dB
4	FR4	2.7, 4.2 GHz	-10.01, -16.35 dB	0.1%, 0.3%	4.5 dB
5	Plexiglass	4.8 GHz	-19.14 dB	0.3%	5.4 dB
6	Polyster	3.2, 4.9 GHz	-10.71, -24.51 dB	0.2%, 0.3%	6.2 dB

Different substrate materials are used in this analytical study. Air and plexiglass based antenna is resonating at single frequency, whereas other materials used are resonating at dual band. Table-2 shows the return loss, bandwidth enhancement and gain of the antenna for different substrate materials. By keeping the antenna dimension at fixed values, an analytical study is done by changing the dielectric constant values of the substrate materials and the antenna performance characterization is presented in this work. Figure-3 shows the return loss Vs Frequency curve for different materials and we attained return loss less than -10 dB and VSWR<2 at all resonating frequencies.

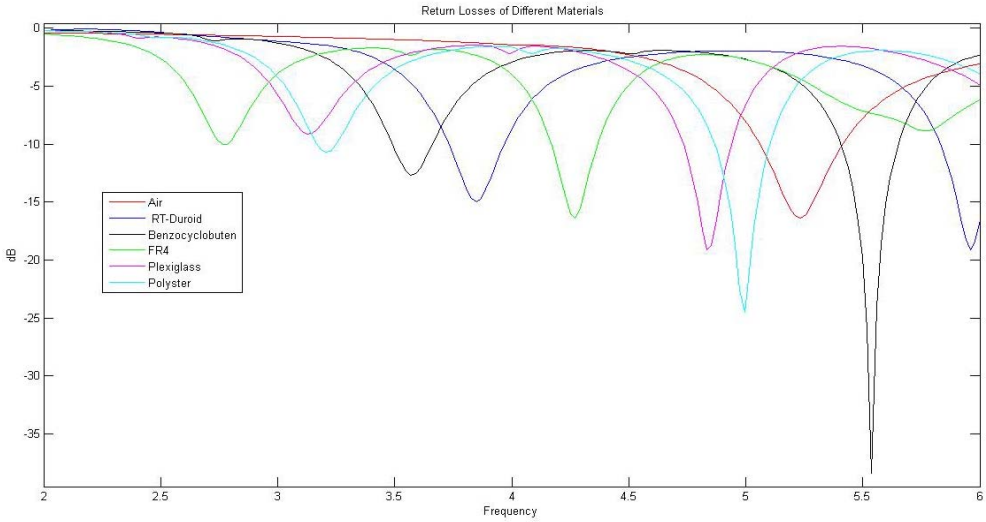

Figure-3. Return loss Vs frequency.

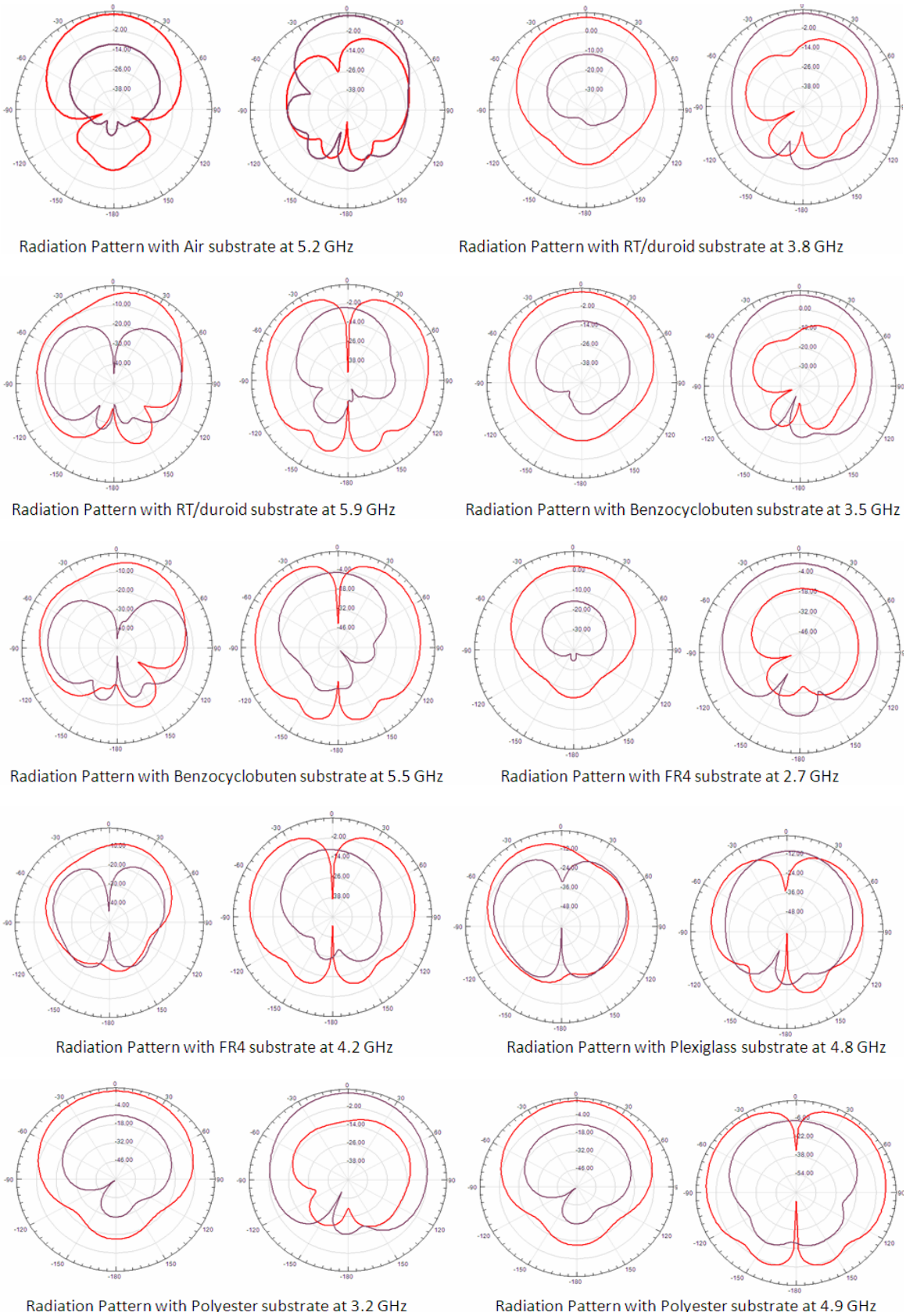

Figure-4. Antenna radiation pattern curves for different materials at different frequencies.

Antenna radiation pattern is the display of the radiation properties of the antenna as a function of spherical coordinates (θ, φ). In most cases the radiation pattern is determined in the far field region for constant radial distance and frequency. For a linearly polarized antenna, the E and H planes are defined as the planes containing the direction of maximum radiation and the electric and magnetic field vectors respectively. Figure-4 shows the radiation pattern of antenna in E and H planes at all the resonating frequencies for different substrate materials.

Figure-5 represents the current distribution of the antenna at different frequencies with change in dielectric constant.

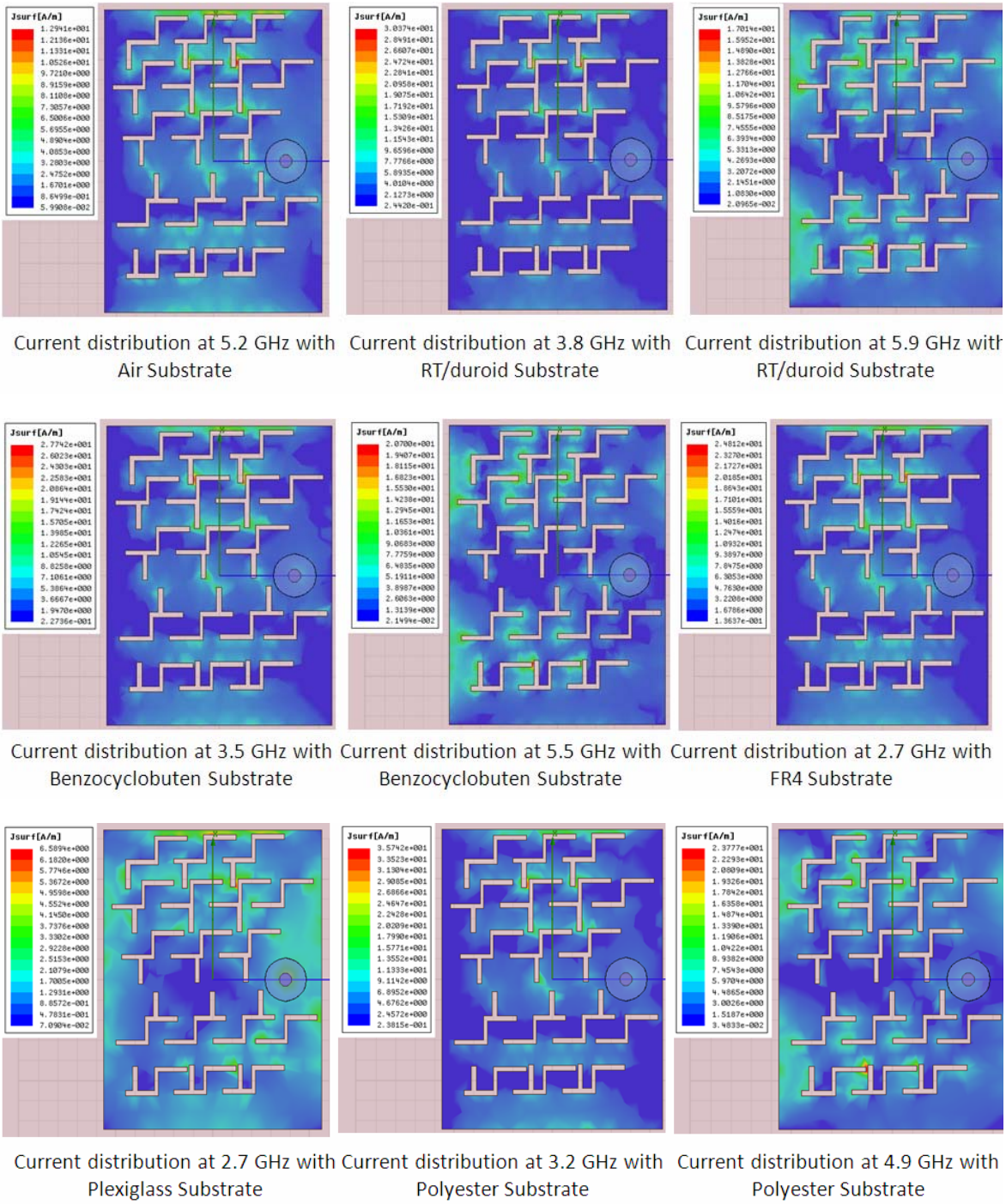

Figure-5. Current distribution plots at different frequencies.

CONCLUSIONS

A novel hybrid slot aperture microstrip patch antenna was designed and its performance evaluation is observed by varying different dielectric materials. Except for air and Plexiglas substrate material, the proposed hybrid slot antenna is resonating at dual band. Highest gain and bandwidth enhancement is obtained for RT-duroid material compared to other materials. Excellent return loss is obtained for the benzocyclobuten with -38.38 dB at 5.5 GHz. In this way the range of validity of the models can begin to be ascertained, and a database is made available for testing of the future models.

ACKNOWLEDGEMENTS

Authors like to express their gratitude towards Department of ECE and management of Sri Sivani College of Engineering and K L University for their support and encouragement during this work. Further authors like to thank Er. K. Satyanarayana garu, President, K L University for providing excellent R and D facilities at ECE Department of K L University to carry out this work.

REFERENCES

Sreenivas Kasturi and Daniel H. Schaubert. 2006. Effect of Dielectric Permittivity on Infinite Arrays of Single-Polarized Vivaldi Antennas. IEEE Transactions on Antennas and Propagation. 54(2): 351-358.

G. P. Gauthier, A. Courtay and G. H. Rebeiz. 1997. Microstrip antennas on synthesized low dielectric-constant substrate. IEEE Trans. Microwave Theory Techn. 45: 1310-1314.

B T P Madhav, Madhuri Kandepi, Satish Kanapala, B Anjaneyulu, N Anada Rao, K Vijaya Vardhan, “Serrated Spike Antenna Performance Evaluation Based on Arlon Substrate Materials”, International Journal of Applied Engineering Research, ISSN 0973-4562, Volume 9, Number 1, Jan-2014, pp. 117-124.

Wayne S. T. Rowe and Rod B. Waterhouse. 2003. Theoretical Investigation on the Use of High Permittivity Materials in Microstrip Aperture Stacked Patch Antennas. IEEE Transactions on Antennas and Propagation. 51(9): 2484-2486.

Q. Wu, R.-H. Jin and J.-P. Geng. 2008. Pulse Preserving Capabilities of Printed Circular Disk Monopole Antennas with Different Substrates. Progress In Electromagnetics Research, PIER. 78: 349-360.

J.-Y. Sze, T.-H. Hu and T.-J. Chen. 2009. Compact Dual-Band Annular-Ring Slot Antenna with Meandered Grounded Strip. Progress In Electromagnetics Research, PIER. 95: 299-308.

Y.-C. Lee and J.-S. Sun. 2008. Compact Printed Slot Antennas for Wireless Dual- and Multi-Band Operations. Progress In Electromagnetics Research, PIER. 88: 289-305.

B T P Madhav, K V V Kumar, A V Manjusha, P Ram Bhupal Chowdary, L Sneha, P Renu Kantham, “Analysis of CPW Fed Step Serrated Ultra Wide Band Antenna on Rogers RT/Duroid Substrates”, International Journal of Applied Engineering Research, ISSN 0973-4562, Volume 9, Number 1, Jan-2014, pp. 53-58.

J. S. Colburn and Y. Rahmat-Sammii. 1999. Patch antennas on externally perforated high dielectric constant substrate. IEEE Trans. Microwave Theory Techn. 47: 1785-1794.

B.T.P. Madhav, D. Ujwala, Habibulla Khan, Atluri Lakshmi Tejaswani, Sriram Guntupalli and Atluri Bala. 2013. Substrate Permittivity Effects on the Performance of Slotted Aperture Stacked Patch Antenna. International Journal of Applied Engineering Research, ISSN 0973-4562. 8(8): 909-916.