Analytical Study on Effects of Substrate Properties on the Performance of Microstrip Patch Antenna

Bilal Ahmed, Ilyas Saleem, H. Zahra, Hunaina Khurshid and S. Muzahir Abbas

Department of Electrical Engineering, COMSATS Institute of Information Technology, Islamabad, Pakistan
bilalahmed_33@yahoo.com, ilyas-saleem@hotmail.com, hijab.zahra@ymail.com,
hunaina.eng@live.com, muzahir_abbas@comsats.edu.pk

Abstract

In this work, effect of substrate properties on the performance of microstrip patch antenna is presented. Proposed geometry has been optimized to achieve a useful impedance bandwidth from 2.30 to 2.46 GHz at VSWR $\leq$ 2. Comparison has been done on the basis of physical dimensions, gain response and radiation properties.

Keywords: *Patch Antenna, Substrate, Slit, Relative Permittivity*

1. Introduction

Optimization of patch antenna has always been an area of interest for design engineers [1]; though size/SAR reduction, gain enhancement and efficiency improvement are the key constraints which must be addressed primarily [2]. As patch antenna establishes its physical attributes on a dielectric substrate having effective electrical and magnetic properties, so selecting a correct substrate is important as well.

Duroid substrate with relative permittivity 10.5 is used in [3]; whereas stacking of Roger 4003 substrate is done in [4]. In [5], relative permittivity of substrate is 4.5, while [6] utilizes Isola Gigaver 210.

In our work, effects of relative permittivity's on the resonant characteristics of patch antenna have been thoroughly analyzed. The antenna geometry has been optimized to cover requisite bandwidth for LTE (2300-2400 MHz) and Bluetooth (2400-2484 MHz). Moreover, discussions on the impedance bandwidth, realized gain and directivity have also been given in the literature.

2. Antenna Design

The antenna prototype is shown in Figure 1 and Table 1 states the optimized dimensions for the design. It was designed on a FR4 epoxy substrate having relative permittivity of 4.4, relative permeability of 1, dielectric loss tangent of 0.02 and physical height of 1.6 mm. Width (W_4) and Length (L_4) of the patch have been calculated using (14-6) and (14-7) of [7]. Feed width (W_3) is calculated using (14-19b) of [7]. Feed line is connected deep into the patch, creating an inset for the nullification of the capacitive/inductive-effect setting the

impedance of the radiator at 50 Ω. Mathematically the inset length is calculated using (14-20a) of [7]. Two rectangular slits have been added to acquire the required bandwidth.
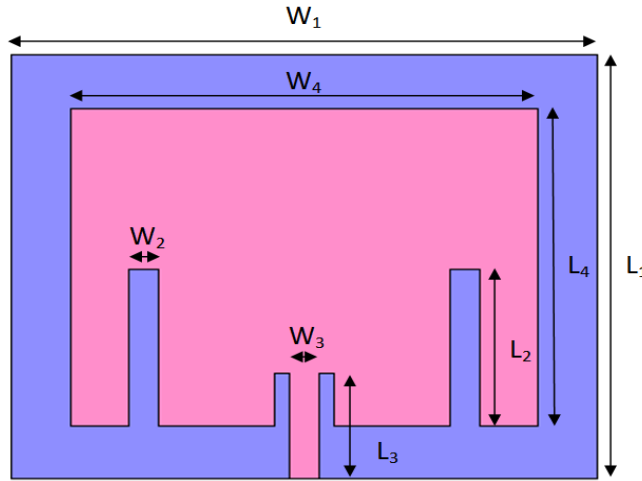

Figure 1. Antenna Geometry

Table 1. Antenna Dimensions

Length	Value (mm)	Width	Value (mm)
L_1	38	W_1	47.6
L_2	14	W_2	2.4
L_3	9.5	W_3	2.4
L_4	28.5	W_4	38

3. Analysis and Results

Analysis has been performed on the basis of results generated by Ansoft HFSS (High Frequency Structural Simulator) and plotted using MATLAB R2009A. Discussion is focused on exploring the antenna performance by varying the material properties of substrate. A comparative analysis is presented by using both the physically existing and the theoretical substrates. In the upcoming sections, detailed insights on both geometric and materialistic effects on antenna performance are discussed.

3.1. Variation in the Inset Feed

Inset feed is employed to get suitable impedance matching between the patch and input port. As shown in Figure 2, antenna provides wider bandwidth and higher return loss as we extend the inset length to the calculated distance but the response declines on further extension.
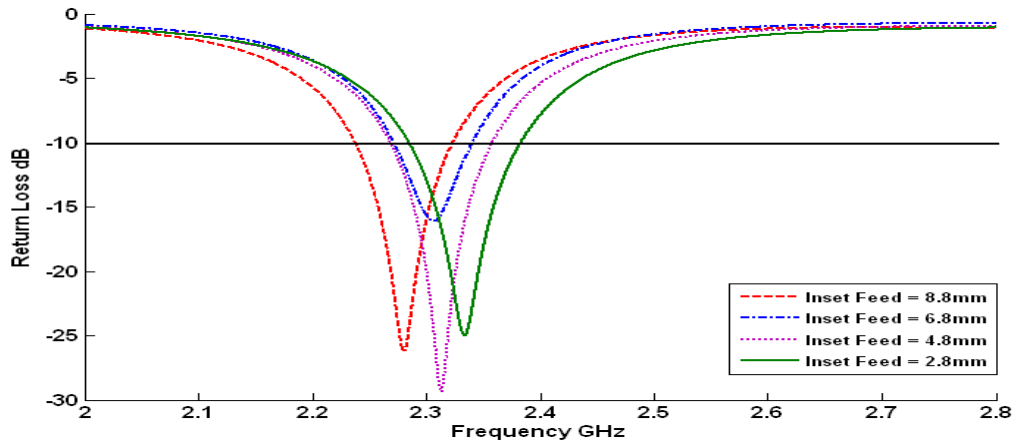
Figure 2. Effects on Return Loss at Different Feed Lengths

3.2. Variation in the Slits

Two rectangular slits were placed on each side of the patch. Parametric analysis of slit's length at three different values of W_2 has been performed and the results are shown in Figure 3. Both slits were varied simultaneously to maintain uniformity of pattern from the radiating structure. Figure 3(a) shows the effect of L_2 at $W_2 = 4.8$ mm, where Figure 3(b) shows the effect of L_2 at $W_2 = 2.4$ mm and finally effect of L_2 at $W_2 = 1.2$ mm is shown in Figure 3(c). At $W_2 = 4.8$ and 2.4 mm, the decrease in L_2 from 28 mm to 6 mm shifts the operational bandwidth forward towards the higher frequencies, whereas at $W_2 = 1.2$ mm and $L_2 = 14$ mm not only the original resonant frequency of 2.35 GHz is maintained but wide impedance bandwidth is also achieved with a high degree of efficiency.
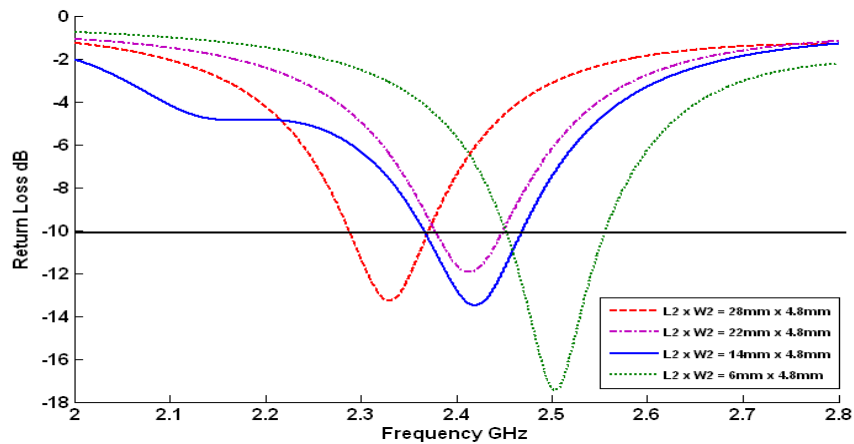
(a) Effect of L_2 on return loss at $W_2 = 4.8$mm.
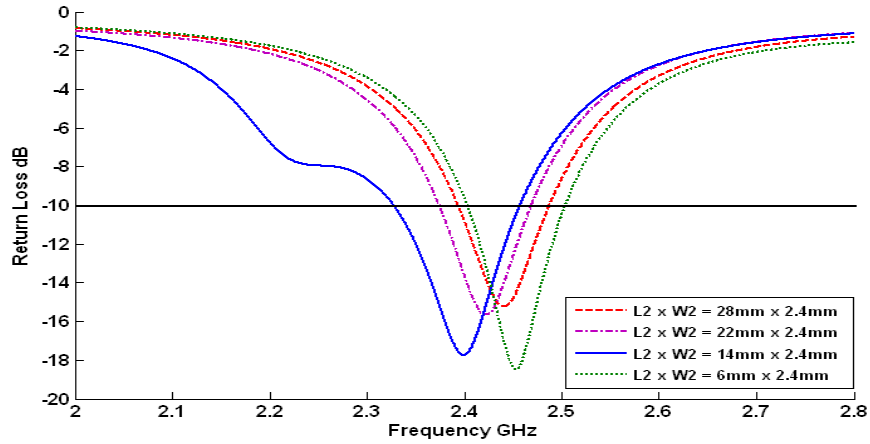
(b) Effect of L_2 on return loss at $W_2 = 2.4$mm.
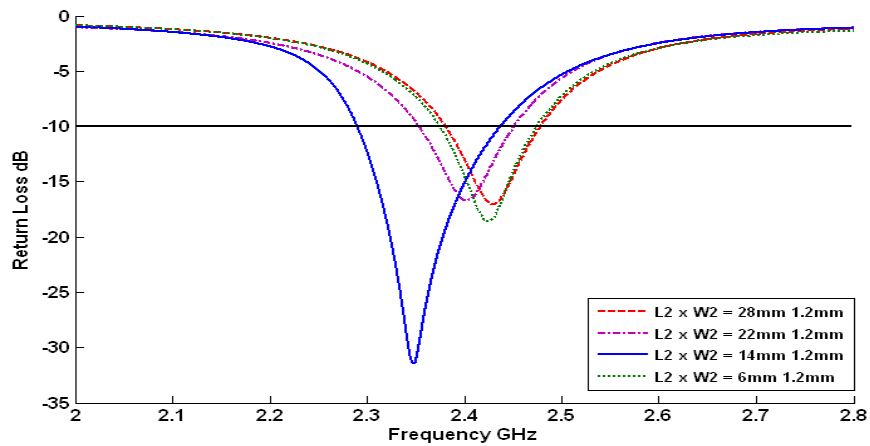
(c) Effect of L_2 on return loss at $W_2 = 1.2$mm.

Figure 3. Effects of Side Slits on Return Loss

3.3. Effect of Relative Permittivity

Primarily FR4 epoxy substrate was used in antenna design. Then, fundamental characteristics including the relative permeability and the dielectric loss tangent were kept as standard; but relative permittivity was varied been varied on a scale of 2.2 to 8.2 with a step size of 1. Dimensions of patch were calculated using the standard dielectric constants of FR4 epoxy. Figure 4 shows that the operational band is shifted towards the lower frequencies with increasing relative permittivity. Table 2 shows good similarity between the calculated and simulated resonant frequencies.
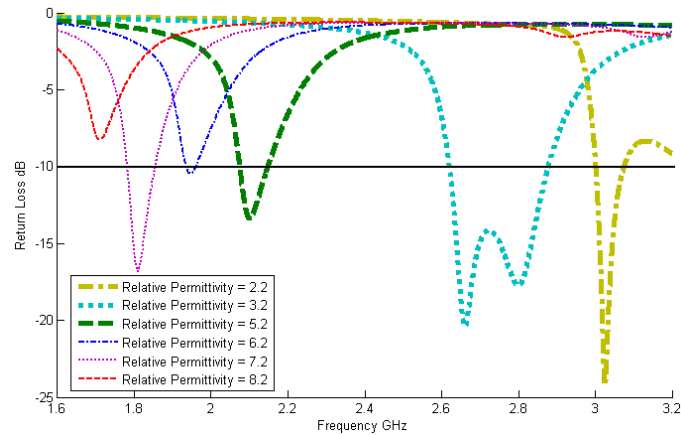
Figure 4. Effects on Impedance Bandwidth with the Change in Relative Permittivity

Table 2. Variation in Resonant Frequency

Relative Permittivity	Calculated Resonant Frequency (GHz)	Simulated Resonant Frequency (GHz)
2.2	3.29	3.02
3.2	2.75	2.75
5.2	2.17	2.15
6.2	1.99	1.98
7.2	1.849	1.82
8.2	1.73	1.69

3.4. Effect of variation in substrate

After observing the shifting pattern of bandwidth, nine substrates were chosen and analyzed. Return loss shown in Figure 5 reinstates the band shifting concept discussed previously. Attributes of materials and resonant frequencies are given in Table 3.
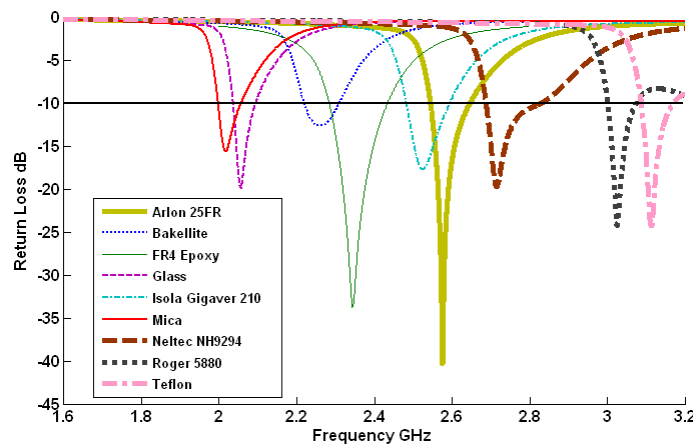

Figure 5. Return Loss Response using Different Substrates

Table 3. Comparison of Calculated and Simulated Results

Material Name	Relative Permittivity	Dielectric Loss Tangent	Calculated Resonant Frequency (GHz)	Simulated Resonant Frequency (GHz)
Arlon 25FR	3.43	0.0035	2.65	2.58
Bakellite	4.8	0.002	2.25	2.23
FR4 Epoxy	4.4	0.02	2.35	2.35
Glass	5.5	0.0	2.11	2.15
Isola Gigaver 210 (tm)	3.75	0.003	2.55	2.58
Mica	5.7	0.0	2.075	2.08
Neltec NH9294 (tm)	2.94	0.0025	2.866	2.76
Rogers RT/Duroid 5880 (tm)	2.2	0.0009	3.29	3.08
Teflon	2.1	0.001	3.3686	3.15

3.5. Effect of Substrate on Antenna Gain

In order to study the effect of substrate variation on the gain, antennas were designed using all the above mentioned substrates at the same central frequency. Same geometric shape and substrate thickness was used in all designed prototypes in order to have a valid comparison for gain. It can be concluded that Teflon and Glass substrate offer much higher gain then the FR4 epoxy but at the same time occupy more volume. Values of gain for the comparative impedance bandwidths for all the substrates are shown in Figure 6 while Table 4 contains the patch dimensions for the respective substrates.
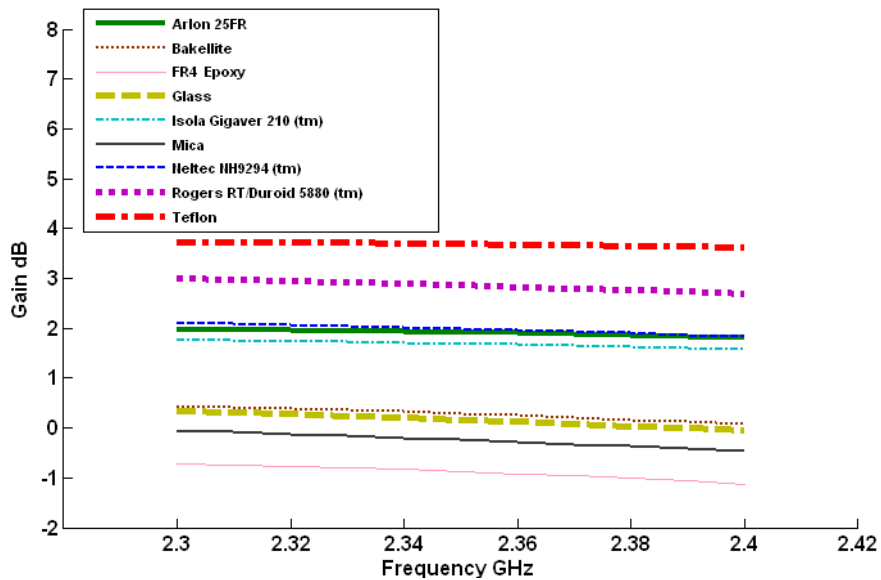

Figure 6. Gain Response of the Antenna with Different Substrates

Table 4. General Patch Dimensions

Material Name	Resonant Frequency (GHz)	Length (mm)	Width (mm)
Arlon 25FR	2.4	33.286	41.99
Bakellite	2.4	28.2	36.7
FR4 Epoxy	2.4	28.44	38.03
Glass	2.4	26.36	34.67
Isola Gigaver 210 (tm)	2.4	31.86	40.55
Mica	2.4	25.9	34.15
Neltec NH9294 (tm)	2.4	35.899	44.52
Rogers RT/Duroid 5880 (tm)	2.4	41.35	49.41
Teflon	2.4	42.29	50.2

3.6. Effect of Substrate on Antenna Directivity

Directivity comparison has been performed on the same prototypes as from the previous section. Rogers RT/Duroid 5880 substrate offers highest directivity and largest volume after Teflon. Values for directivity are given in Figure 7.
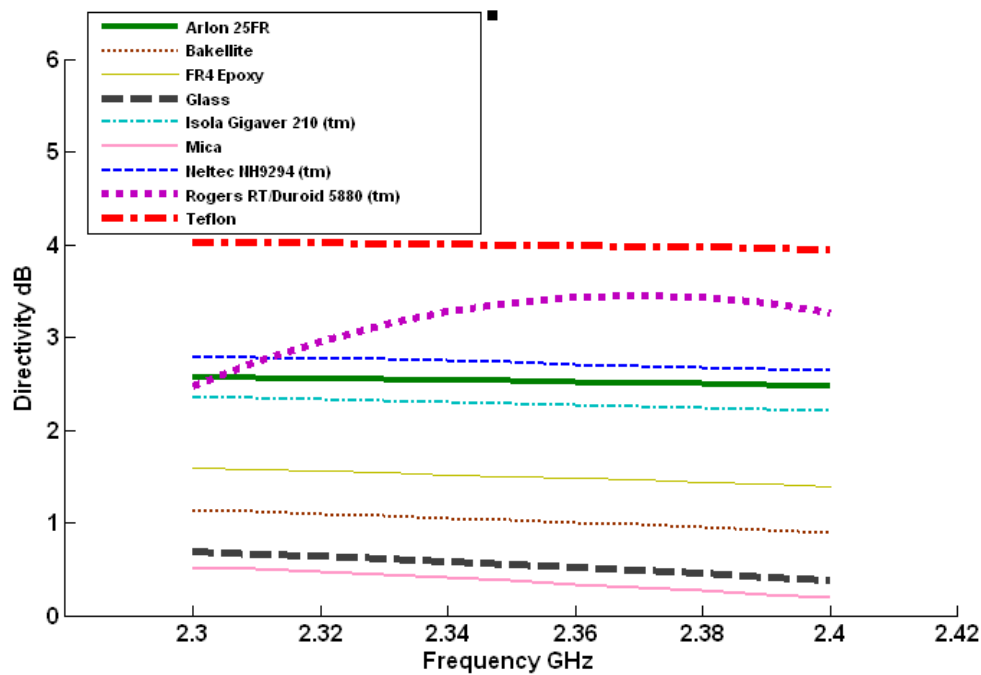

Figure 7. Directivity of the Antenna with Different Substrates

3.7. Radiation Patterns

The proposed prototype has been designed to provide uniform radiation patterns on the broadside of the radiating surface. Figures 8-10 show the 2D plots of the radiation pattern in all the three principle planes for both the corner and the center frequencies.
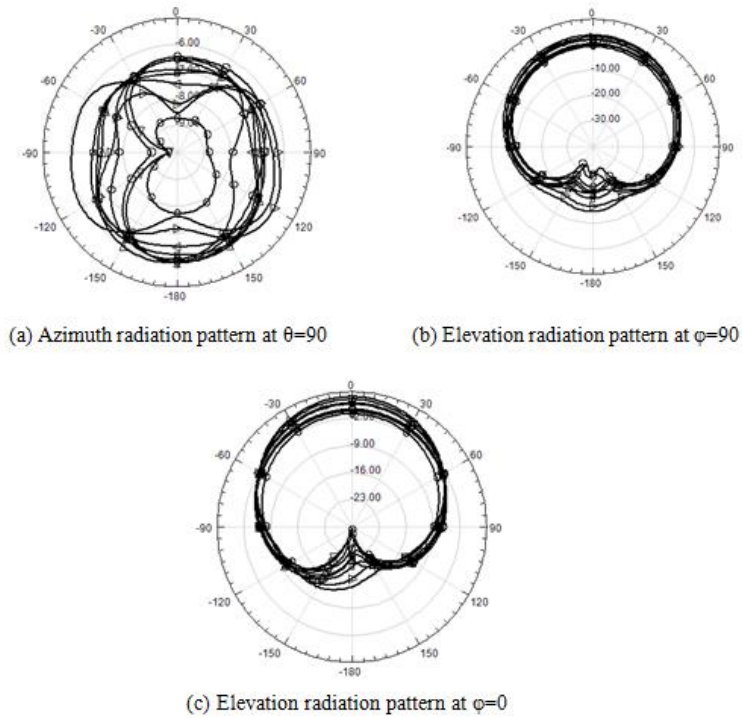
(a) Azimuth radiation pattern at θ=90

(b) Elevation radiation pattern at φ=90

(c) Elevation radiation pattern at φ=0

Figure 8. Radiation Pattern at 2.30 GHz

(a) Azimuth radiation pattern at θ=90

(b) Elevation radiation pattern at φ=90

(c) Elevation radiation pattern at φ=0

Figure 9. Radiation Pattern at 2.35 GHz

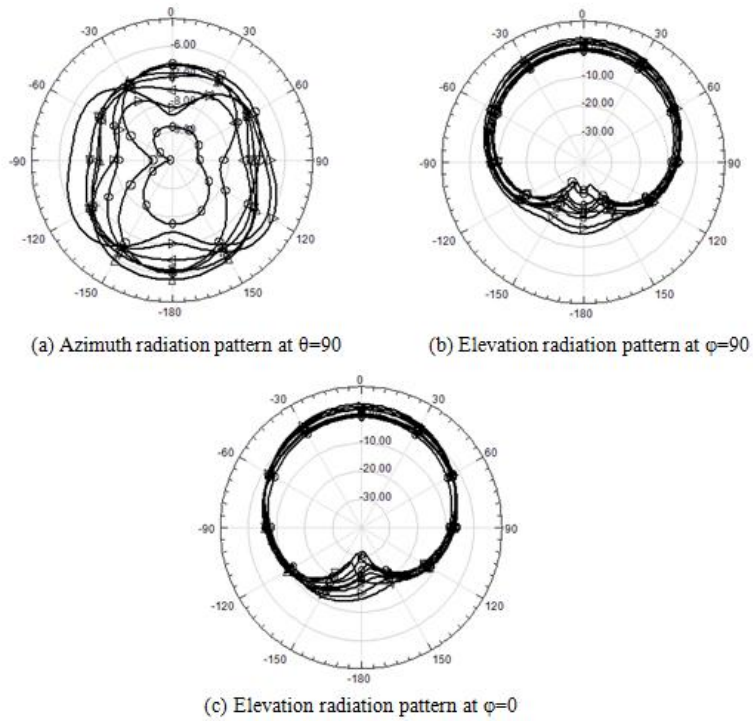(a) Azimuth radiation pattern at θ=90   (b) Elevation radiation pattern at φ=90
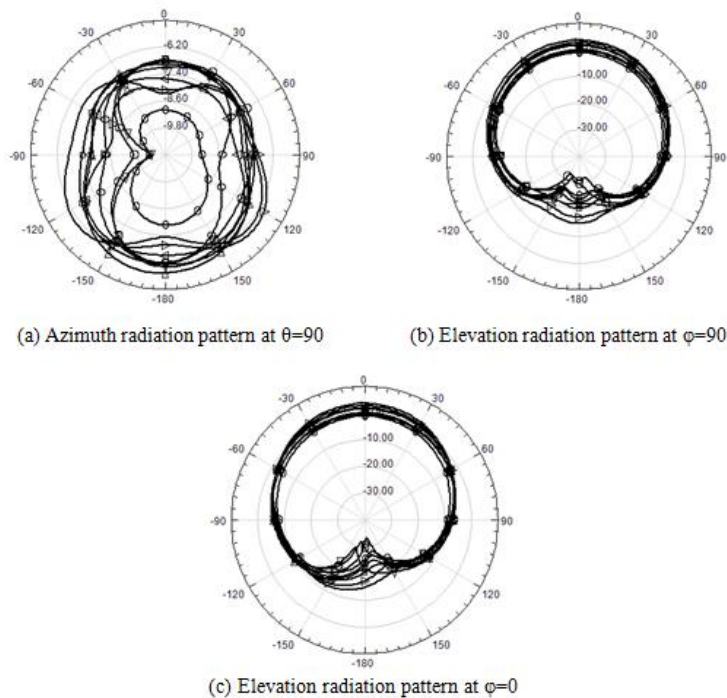

(c) Elevation radiation pattern at φ=0

Figure 10. Radiation Pattern at 2.40 GHz

4. Conclusion

In this paper, various comparative analysis were carried out to provide a basis for substrate material selection for application specific designing of patch antenna. The prototype is applicable for LTE and Bluetooth technologies. It has been concluded that selection of the substrate is a key feature in achieving desired efficiency, gain, directivity and the antenna size.

References

[1] I. Saleem, H. Nawaz, I. Ahmed and S. M. Abbas, "Analytical Evaluation of Tri-band Printed Antenna", Information Sciences Letters, vol. 1, no. 2, (2012), pp. 85-89.

[2] S. M. Abbas, I. Saleem, A. Parveen, H. Zahra and S. A. Khan, "Chebyshev Multiband Patch Antenna", Emerging Trends and Applications in Information Communication Technologies, CCIS vol. 281, B. S. Chowdhry, F. K. Shaikh, D. M. A. Hussain, and M. A. Uqaili, Eds., ed: Springer Berlin Heidelberg,, Springer-Verlag, ISBN 978-3-642-28961-3, (2012) Pakistan, pp. 10-19.

[3] N. Ghouddane and M. Essaaidi, "A novel compact multiband planar antenna for wireless and mobile handsets", Microwave Symposium, (2009), Mediterranean.

[4] R. Caso, A. A. Serra, M. Rodriguez-Pino, P. Nepa and G. Manara, "A wideband slot-coupled stacked-patch array for wireless communications", IEEE Antennas and Wireless Propagation Letters, vol. 9, (2010).

[5] B. Li, Y. -Z. Yin, Y. Zhao and Y. Ding, "A CPW-fed triple-band antenna with a Π-shaped slot for WLAN and WiMAX applications", Proceeding of the Cross Strait Quad-Regional Radio Science and Wireless Technology Conference, (2011).

[6] M. Al-Husseini, Y. Tawk, A. El-Hajj and K. Y. Kabalan, "A low cost microstrip antenna for 3G/WLAN/WiMAX and UWB applications", Proceedings of Advances in Computational Tools for Engineering Applications, (2009) July 15-17, Lebanon.

[7] C. A. Balanis, "Antenna Theory: Analysis and Design", John Wiley & Sons, Second Edition, New York (1997).

Authors

Bilal Ahmed did his BS-Electrical (Telecommunication) Engineering from COMSATS Institute of Information Technology (CIIT), Islamabad in 2012.

Ilyas Saleem was born in 1990 and received his bachelor's degree in Electrical Engineering from CIIT, Islamabad, Pakistan. In 2011, he worked with RF Communication Research Group at CIIT on active and multi band printed antennas for wireless communications. Currently, his research interest is meatmaeterials and their applications for beamforming and microwave systmes.

Hijab Zahra received her Bachelors of Science in Electrical (Telecommunication) Engineering from COMSATS Institute of Information Technology, Islamabad in 2007. Currently, she is student of MS in Electrical Engineering at Center for Advanced Studies in Engineering (CASE), Islamabad. She has published several research papers in the fields of Antenna Design and Wireless Communications.

Hunaina Khurshid is a student of BS-Electrical (Telecommunication) Engineering from CIIT, Islamabad.

Syed Muzahir Abbas received his Bachelors of Science in Electrical (Telecommunication) Engineering from COMSATS Institute of Information Technology, Islamabad and completed his Masters of Science in Computer Engineering from Center for Advanced Studies in Engineering (CASE), Islamabad in 2006 and 2009 respectively. He is Lecturer at Department of Electrical Engineering, COMSATS Institute of Information Technology, Islamabad. He has published several research papers in the fields of Wireless Communications, Image Processing & Antenna Design.