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Low Side Lobe Level Multilayer Antenna for Wireless Applications

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Abstract—A low cost and easy fabrication multilayer antenna for wireless applications was presented to cover the industrial, scientific, and medical ISM band of (5.725–5.875) GHz with a gain of 11.7 dB. The antenna was composed of a feeding patch fabricated on a Rogers RT/Duroid 5880 substrate, and three superstrate layers of Rogers RO3006 were located above the feeding patch at a specific height for each layer. The superstrate layers were added to enhance the bandwidth and gain of the antenna and reduce its side-lobe level and return loss. The simulated and measured results of the operating frequency, return loss, bandwidth, and gain for the antenna were presented. CST Microwave Studio was used in this design's simulation.

1. INTRODUCTION

Authors and researchers are focusing on the microstrip patch antennas (MPAs) used in wireless communications due to many advantages, such as low weight, low cost, easy fabrication, and operating with multiple resonant frequencies [1]. Nonetheless, MPA has certain disadvantages, including low gain, narrow bandwidth, low efficiency, and high side-lobe level (SLL) [2, 3]. Many researches have been conducted to enhance the operating bandwidth of MPA [4–11], while others have been conducted for enhancing the gain of MPA [12–15]. Multilayer antenna designs were used to improve the bandwidth [16] and enhance the gain of MPA [17, 18]. Researchers have used multilayer antennas to enhance the gain of MPA over ISM band (5.725–5.875) GHz and reduce the SLL. In [19], the gain was improved by 5.6 dB compared to the gain of the feeding patch (FP), through the use of an FR4 superstrate with partially reflecting surfaces (PRS) at a height of a half free-space wavelength (λ_o) from the ground plane. The FP was fabricated using an FR4 substrate which was separated from the ground plane with an air gap, to enhance the radiation efficiency and gain of the antenna. In [20], a metallic patch above an air substrate acted as the FP with PRS fixed on the bottom of two FR4 superstrate layers at 0.5 and $1.5\lambda_o$, respectively, achieved gain enhancement of 13 dB and a low SLL, compared to the FP. In [21], the effect of superstrate material, dimensions of the ground plane, and size of the PRS array were investigated. The gain of the antenna was increased from 9.4 dB up to 18 and 17 dB when FR4 and ceramic superstrates were added with PRS, respectively. In [22], a gain of 14.4 dB was achieved when an FR4 superstrate was added with 2×2 PRS on the bottom of the FR4 superstrate at $0.5\lambda_o$ above the ground plane. In addition, a feeding patch was fixed at 2 mm from the ground plane to enhance the efficiency and gain of the antenna. In [23] a numerical study had been proposed to investigate the effects of adding a superstrate layer on the gain of a rectangular patch and resonance condition to achieve high gain through optimizing the height of the superstrate layer. The reported designs of each antenna presented in [19–22] show a complex fabrication.

In this work, a MPA covered with dielectric superstrate slabs for wireless applications, which require high gain and unidirectional antenna that operates over the industrial, scientific, and medical (ISM)

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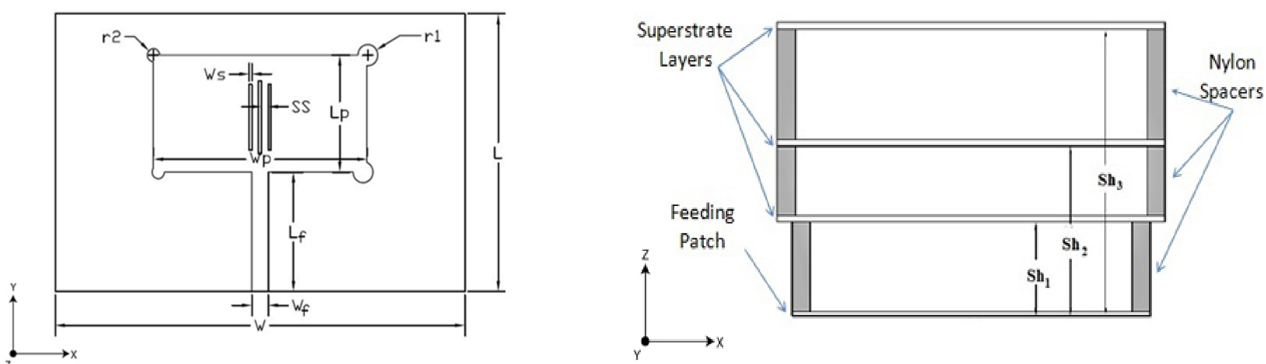
band (5.725 GHz to 5.875 GHz), was presented. Dielectric superstrates were added to achieve higher gain, directivity, operating bandwidth, and lower SLL than the FP. The proposed multilayer antenna in this work outperformed the antenna presented in [19] in terms of return loss (S_{11}), voltage standing wave ratio (VSWR), and radiation efficiency over the ISM band (5.725 GHz to 5.875 GHz). The SLL of the antenna's gain pattern was reduced owing to the optimized height of the superstrate layers without the using PRS.

2. ANTENNA DESIGN

The proposed multilayer antenna design was composed of four layers. These layers were the FP and three superstrate slabs fixed at specific heights as shown in Fig. 1.



(a) (b)

Figure 1. Proposed multilayer antenna structure. (a) Top view of the FP. (b) Side view of the proposed structure.

2.1. Feeding Patch

The FP was composed of an optimized rectangular patch to achieve a high gain at 5.8 GHz. The patch was fed using a microstrip line feeder with a length of L_f and width of W_f. This width was optimized to satisfy 50-ohm line impedance. The patch has a length of L_p and width of W_p which were optimized to operate over the ISM band ranging from 5.725 GHz to 5.875 GHz.

Four circles were added at the corners of the rectangular FP with radii of r_1 and r_2 for the right- and left-hand circles, respectively. Three slots were etched from the patch, the central slot and two other slots etched on both sides of the central slot. The central slot had length and width of L_{cs} and W_s, respectively. The two other slots were placed at the same distance (SS) from the central slot and have length of L_{ss} and width of W_s. The FP was printed on an RT Duroid 5880 substrate, which has a dielectric constant (ϵ_r) of 2.2, loss tangent ($\tan\delta$) of 0.0009, length and width of L and W, respectively, and a thickness of h. The ground was located under the substrate and had a thickness of t. Table 1 lists the dimensions of the FP.

2.2. Superstrate Layers

To enhance the performance of the patch antenna, multiple superstrate layers were placed above the FP. Three superstrate layers of Rogers RO3006 were used to obtain a high gain, cover the ISM band (5.725 GHz to 5.875 GHz), and reduce the SLL. The superstrate layers were located at Sh_1, Sh_2, and Sh_3 for the first, second, and third superstrate layers, respectively, from the ground plane and were fixed using nylon spacers. Table 2 illustrates the specifications and dimensions of the superstrate layers, and Fig. 1(b) shows the side view of the multiple superstrate layers above the FP.

Table 1. List of feeding patch parameters' values.

No.	Parameter		Dimension (mm)
	Name	Symbol	
1	Feeder width	W_f	2.41
2	Feeder Length	L_f	16.35
3	patch width	W_p	31.31
4	Patch length	L_p	16
5	Right hand circle's radius	r_1	1.45
6	Left hand circle's radius	r_2	0.9
7	Length of the central slot	L_{cs}	10
8	Length of two sides slots	L_{ss}	9
9	Slots' width	W_s	0.5
10	Distance between slots	SS	1
11	Substrate's width	W	60
12	Substrate's length	L	38
13	Substrate's thickness	h	0.787
14	Copper's thickness	t	0.017

Table 2. List of multiple superstrate layers specifications and dimensions.

No.	Parameter		Value
	Name	Symbol	
1	Dielectric constant	ϵ_r	6.15
2	Loss tangent	$\tan\delta$	0.002
3	Superstrate's thickness	h_2	1.28 mm
4	Superstrate's length	L_s	43 mm
5	Superstrate's width	W_s	65 mm
6	First Superstrate's Height	Sh_1	17.787 mm
7	Second Superstrate's Height	Sh_2	32.317 mm
8	Third Superstrate's Height	Sh_3	54.597 mm

3. SIMULATION RESULTS

The FP was resonated at 5.806 GHz with a gain of 8.23 dB, and an operating bandwidth of 130.15 MHz was achieved with a high SLL. To enhance the performance of the antenna (improving both the gain and operating bandwidth of the antenna and eliminating SLL), multiple superstrate layers were added above the FP at a specific height for each superstrate layer.

The multiple-superstrate structure was composed of three Rogers RO3006 layers. The height of each layer was set according to the study of the performance of the antenna and the tradeoff among its parameters such as resonant frequency, return loss, operating bandwidth, gain, and SLL. Three steps for enhancing the performance of the antenna are discussed as follows:

Step 1: The gain of the antenna was enhanced to 8.67 dB compared with the gain of the FP by adding the first superstrate layer. The antenna resonated at 5.824 GHz, while the operating bandwidth was decreased to 99.66 MHz. Sh_1 was optimized at 17.787 mm due to the tradeoff among the parameters of the antenna.

Step 2: The gain and operating bandwidth of the antenna were enhanced compared to Step 1 through adding the second superstrate layer. The antenna resonated at 5.821 GHz. In particular, the gain of the antenna was enhanced to 9.96 dB, and its operating bandwidth was improved to 153.42 MHz.

Sh_2 was optimized at 32.317 mm due to the tradeoff among the parameters of the antenna.

Step 3: The gain and operating bandwidth of the antenna were improved to 11.70 dB and 189.39 MHz, respectively, with a low SLL through adding the third superstrate layer. The antenna resonated at 5.806 GHz. Sh_3 was optimized at 54.597 mm due to the tradeoff among the parameters of the antenna. Table 3 presents a comparison between the performances of the FP and the three steps of adding superstrate layers.

Table 3. Performance of antenna's FP, Step 1, Step 2, and Step 3.

	Resonant Frequency (GHz)	Return Loss (dB)	Bandwidth (MHz)	Gain (dB)	VSWR	Radiation Efficiency
Feeding Patch	5.806	−32.07	130.15	8.23	1.051	88.98%
Step 1	5.824	−13.18	99.66	8.67	1.561	87.11%
Step 2	5.821	−19.92	153.42	9.96	1.224	88.81%
Step 3	5.806	−46.49	189.38	11.7	1.009	90.53%

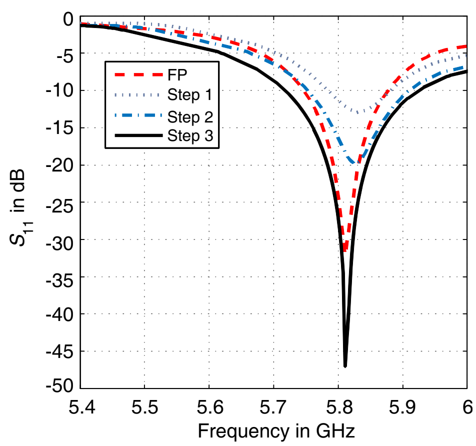


Figure 2. S_{11} plot vs. frequency for FP and steps of adding superstrate layers.

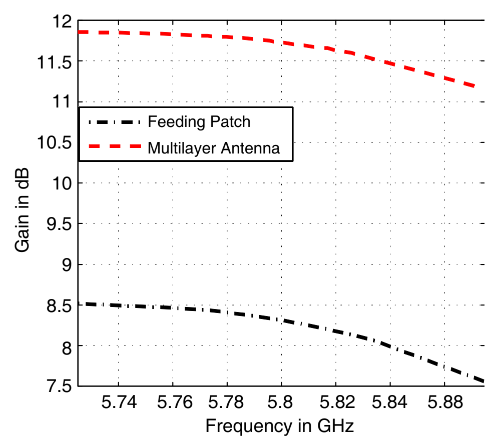
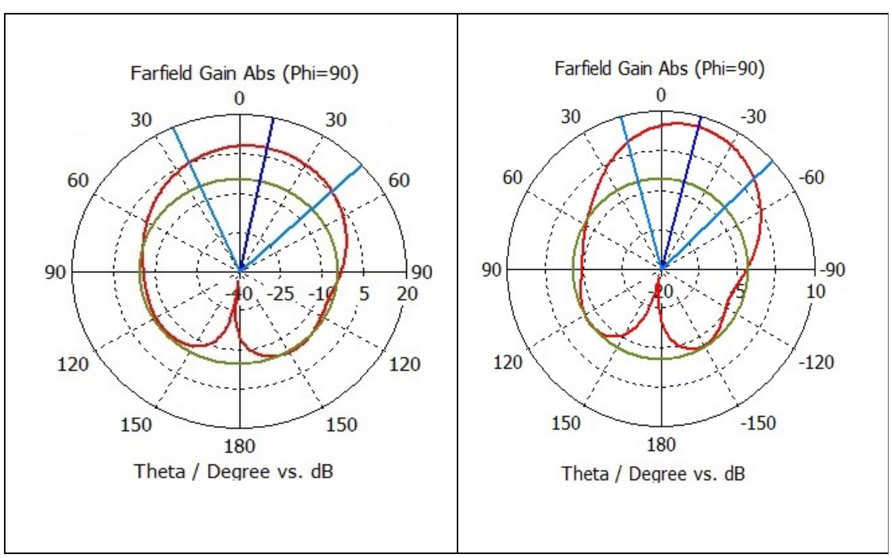
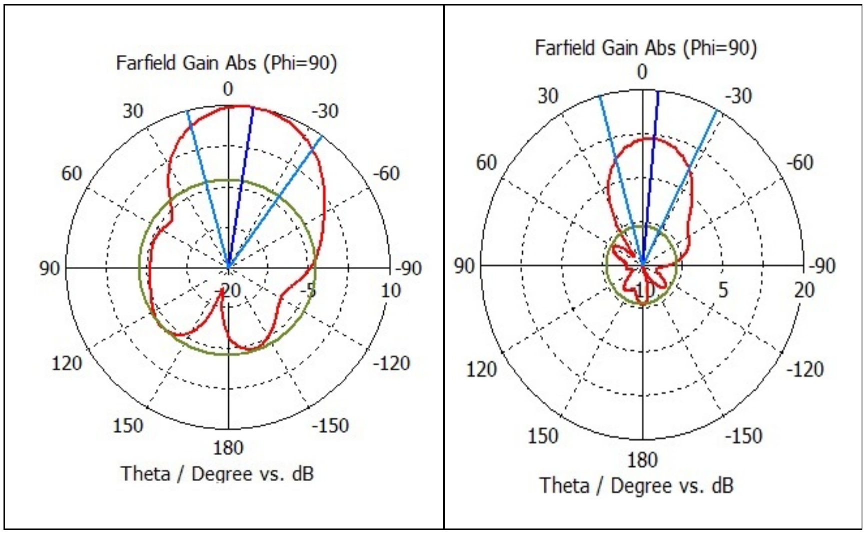


Figure 3. Gains over ISM band for FP and the proposed multilayer antenna.



(a) (b)



(c) (d)

Figure 4. Radiation pattern for: (a) feeding patch, (b) Step 1, (c) Step 2, (d) Step 3 (the proposed multilayer antenna).

The gain and operating bandwidth of the antenna were enhanced due to adding the multiple superstrate layers, while SLL was eliminated due to optimizing the height of each superstrate layer. Compared to the antenna presented in [19], the proposed multilayer antenna in this work achieved lower return loss, comparable gain, reduced size, and easier fabrication process. Fig. 2 shows the S_{11} for the FP and three steps of adding the superstrate layers. The gains over the ISM band (5.725–5.875) GHz for the FP and the multilayer antenna are presented in Fig. 3, while Fig. 4 presents radiation pattern for the FP and steps of adding superstrate layers. The red curve represents the far-field region; blue line depicts the direction and angle of the main lobe; the green color indicates the highest magnitude among the back and side lobes.

4. MEASUREMENTS RESULTS

The proposed multilayer antenna was fabricated with dimensions of $43 \times 65 \times 55.9\,\text{mm}^3$. Table 4 presents the simulated and measured results. The return loss of the proposed antenna was measured using a vector network analyzer (VNA Anritsu 37347 D), while the gain was measured using a signal generator (ROHDE and SCHWAZ), a spectrum analyzer (ADVANTEST R3267), and two dual-polarization horn antennas (A-INFOMW). Fig. 5 illustrates the fabricated multilayer antenna, and Fig. 6 shows the

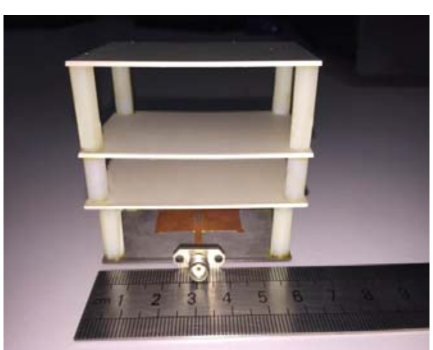


Figure 5. Fabricated multilayer antenna.

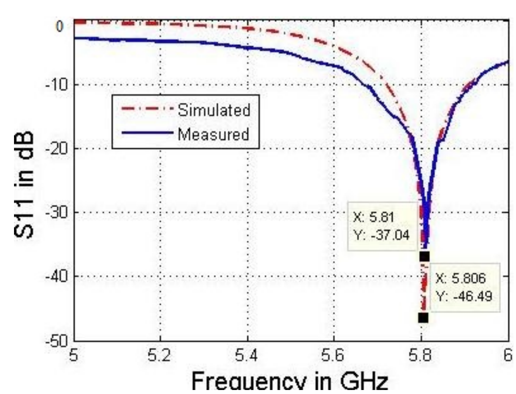


Figure 6. Simulated and measured S_{11} vs. frequency.

Table 4. Simulated and measured results for proposed antenna.

	Resonant Frequency (GHz)	Return Loss (dB)	Bandwidth (MHz)	Gain (dB)	VSWR	Radiation Efficiency
Simulated	5.806	−46.49	189.38	11.70	1.009	90.53%
Measured	5.81	−37.04	224.30	11.54	1.050	88.4%

simulated and measured of S_{11} for the proposed multilayer antenna. The measured gain of the antenna was 11.54 dB.

5. DISCUSSION

Adding Rogers RO3006 superstrate layers above the FP enhanced the gain and bandwidth of the antenna by 3.47 dB and 59.24 MHz, respectively, and reduced SLL. The half power beam width of the multilayer antenna was reduced to 43.1° compared to 70.5° for the FP, and therefore increased the antenna's directivity from 8.68 dB to 12.10 dB. The multilayer antenna provided a gain variation of 0.7 dB over the ISM band (5.725–5.875) GHz and a front-to-back (F/B) ratio of 15.60 dB. The proposed antenna was designed for wireless applications, which require high-gain and unidirectional antenna.

Table 5 compares the size reduction of the proposed antenna structure with that of other multilayer antennas presented in [19–22]. It can be observed that there is a difference between the simulated and measured results due to neglecting the sources of deficiencies and analogue losses by the simulator. The proposed multilayer antenna has low return loss, reduced size, high radiation efficiency, and comparable gain compared to the antenna presented in [19].

Table 5. Size reduction comparison between the proposed antenna and other multilayer antennas.

Ref. No.	Size Reduction Compared to The Proposed Antenna
[19]	76.34%
[20]	97.86%
[21]	83.48% in case of using FR4 superstrate. 71.24% in case of using Ceramic superstrate.
[22]	48.18%

6. CONCLUSION

The proposed multilayer antenna can provide a gain of 11.70 dB at an operating frequency of 5.806 GHz with an operating bandwidth of 189.38 MHz, a high radiation efficiency of 90.53%, and a low SLL. In this work, the gain and operating bandwidth of the antenna were enhanced due to adding superstrate layers above the patch antenna while SLL was eliminated. The size of the proposed multilayer antenna was reduced compared to the antennas presented in [19–22]. The SLL of the antenna's radiation pattern was eliminated due to optimizing height of the superstrate layers. The proposed antenna was designed for wireless point-to-point communications that need unidirectional antenna with high gain over the ISM band (5.725–5.875) GHz.

REFERENCES

1. Jothi Chitra, R. and V. Nagarajan, "Double L-slot microstrip patch antenna array for WiMAX and WLAN applications," *Comput. Electr. Eng.*, Vol. 39, No. 3, 1026–1041, 2013.
2. Mak, C., H. Wong, and K. Luk, "High-gain and wide-band single-layer patch," *IEEE Trans. Veh. Technol.*, Vol. 54, No. 1, 33–40, 2005.

3. Kim, J. W., T. H. Jung, H. K. Ryu, J. M. Woo, C. S. Eun, and D. K. Lee, "Compact multiband microstrip antenna using inverted-L- and T-shaped parasitic elements," *IEEE Antennas Wirel. Propag. Lett.*, Vol. 12, 1299–1302, 2013.
4. Munir, A., G. Petrus, and H. Nusantara, "Multiple slots technique for bandwidth enhancement of microstrip rectangular patch antenna," *2013 Int. Conf. Qual. Res. QiR 2013 — Conjunction with ICCS 2013 2nd Int. Conf. Civ. Sp.*, 150–154, 2013.
5. Sun, X. B., M. Y. Cao, J. J. Hao, and Y. J. Guo, "A rectangular slot antenna with improved bandwidth," *AEU — Int. J. Electron. Commun.*, Vol. 66, No. 6, 465–466, 2012.
6. Kamakshi, K., A. Singh, M. Aneesh, and J. Ansari, "Novel design of microstrip antenna with improved bandwidth," *Int. J. Microw. Sci. Technol.*, Vol. 2014, 7 Pages, 2014.
7. Wu, C. M., Y. L. Chen, and W. C. Liu, "A compact ultrawideband slotted patch antenna for wireless USB dongle application," *IEEE Antennas Wirel. Propag. Lett.*, Vol. 11, 596–599, 2012.
8. Chen, W., G. Wang, and C. Zhang, "Bandwidth enhancement of a microstrip-line-fed printed wide-slot antenna with a fractal-shaped slot," *IEEE Trans. Antennas Propag.*, Vol. 57, No. 7, 2176–2179, 2009.
9. Awida, M. H., S. H. Suleiman, and A. E. Fathy, "Substrate-integrated cavity-backed patch arrays: A low-cost approach for bandwidth enhancement," *IEEE Trans. Antennas Propag.*, Vol. 59, No. 4, 1155–1163, 2011.
10. Ang, B.-K. and B.-K. Chung, "A wideband E-shaped microstrip patch antenna for 5–6 GHz wireless communications," *Progress In Electromagnetics Research*, Vol. 75, 397–407, 2007.
11. Lotfi-Neyestanak, A. A., "Ultra wideband rose leaf microstrip patch antenna," *Progress In Electromagnetics Research*, Vol. 86, 155–168, 2008.
12. Mekki, A. S., M. N. Hamidon, A. Ismail, and A. R. H. Alhawari, "Gain enhancement of a microstrip patch antenna using a reflecting layer," *Int. J. Antennas Propag.*, Vol. 2015, 7, 2015.
13. Guha, D., S. Chattopadhya, and J. Y. Siddiqui, "Estimation of gain enhancement replacing PTFE by air substrate in a microstrip patch antenna," *IEEE Antennas Propag. Mag.*, Vol. 52, No. 3, 92–95, 2010.
14. Liu, Y., X. Chen, X. Ren, and C. Liu, "High-gain planar array designed by using fragmented slots," *Int. J. RF Microw.*, 382–388, 2013.
15. Nayan, M., M. F. Jamlos, and M. A. Jamlos, "Circularly polarized MIMO antenna array for point-to-point communication," *Microw. Opt. Technol. Lett.*, Vol. 54, No. 1, 2781–2784, 2015.
16. Lee, R. and K.-F. Lee, "Experimental study of the two-layer electromagnetically coupled rectangular patch antenna," *IEEE Trans. Antennas Propag.*, Vol. 38, No. 8, 5, 1990.
17. Li, D., Z. Szabo, X. Qing, E.-P. Li, and Z. N. Chen, "A high gain antenna with an optimized metamaterial inspired superstrate," *IEEE Trans. Antennas Propag.*, Vol. 60, No. 12, 6018–6023, 2012.
18. Dutta, K., D. Guha, C. Kumar, and Y. Antar, "New approach in designing resonance cavity high-gain antenna using nontransparent conducting sheet as the superstrate," *IEEE Trans. on Antennas and Propag.*, Vol. 63, No. 6, 2807–2813, 2015.
19. Vaidya, A. R., R. K. Gupta, and S. K. Mishra, "Right-hand/left-hand circularly polarized high-gain antennas using partially reflective surfaces," *IEEE Antennas Wirel. Propag. Lett.*, Vol. 13, 431–434, 2014.
20. Vaidya, A. R., R. K. Gupta, S. K. Mishra, and J. Mukherjee, "Efficient, high gain with low side lobe level antenna structures using parasitic patches on multilayer superstrate," *Microw. Opt. Technol. Lett.*, Vol. 54, No. 6, 2781–2784, 2012.
21. Mukherjee, R. K. G. J., "Effect of superstrate material on a high-gain antenna using array of parasitic patches," *Microw. Opt. Technol. Lett.*, Vol. 52, No. 1, 82–88, 2010.
22. Gupta, R. K. and G. Kumar, "High-gain multilayer 2×2 antenna array for wireless applications," *Microw. Opt. Technol. Lett.*, Vol. 50, No. 11, 2781–2784, 2008.
23. Vandenbosch, G. A. E. and A. van de Capelle, "Study of gain enhancement method for microstrip antennas using moment method," *IEEE Trans. Antennas Propag.*, Vol. 43, No. 3, 227–231, 1995.