PERFORMANCE IMPROVEMENT FOR PATCH ANTENNA FOR WLAN APPLICATIONS OVER ISM BAND (5.725 - 5.875) GHz USING MULTIPLE SUPERSTRATES

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***Abstract*- A multilayer antenna structure proposed to enhance the performance of patch antenna used for WLAN applications. The antenna composed of three layers of Rogers RO3010 located above a feeder patch the antenna. Adding superstrate (dielectric) layers above feeding patch improved the overall performance of antenna. An agreement between simulated and measured results was achieved in terms of reflection coefficient (S_{11}), gain, and operating bandwidth. The proposed antenna had achieved a gain of 11.30 dB, Front-to-Back (F/B) ratio of 18 dB, and gain variation around 0.6 dB over the Industrial, Scientific and Medical ISM band (5.725 - 5.875) GHz. The simulated and measured S_{11}, resonant frequency, gain and bandwidth for the proposed design are presented. Computer Simulation Technology (CST Microwave studio) was used as a simulation environment for this design.**

***Keywords*- Performance Improvement; Superstrate Layers; Multilayer Antenna; Side Lobe Layer; WLAN Applications.**

I. INTRODUCTION

Microstrip patch antenna shows many features such as being a low-cost antenna with low weight and operating within multiple resonant frequencies, while it is suffering disadvantages such as narrow operating bandwidth, low gain, high side lobe level (SLL), and low radiation efficiency[1]–[3]. Many works have been conducted to improve the performance of patch antenna[4]–[13] [14]–[16]. Multilayer antennas were used to improve the performance of patch antenna over the (5.725 - 5.875) GHz band. [17] had presented an antenna composed of a feeding patch (FP) covered by FR4 superstrate and an array of 2×2 partially reflecting surfaces (PRS). The effects of array size, dimensions of each PRS, and spacing between array elements' have been studied. The dimensions of ground plane superstrate layer were 100×100 mm^2. The antenna had achieved a maximum gain of 14.4 dB at 5.8 GHz.[18] had presented an antenna composed of an FP covered with FR4 superstrate layer and 4×4 PRS array. The antenna had used a square finite ground plane which has dimensions of 155×155 mm^2. The antenna achieved gain less than 17 dB over the ISM band [19] had enhanced the gain of a patch antenna from 9.4 dB to 18.3 dB due to using a circular array of PRS printed on the bottom of FR4 superstrate with dimensions of 181×181 mm^2 for the superstrate layer and the ground plane. The work in [20] had achieved a gain of 22.4 dB due to printing 3×3 and 9×9 arrays of PRS on FR4 layers which were located at half free space wavelength (λo) and 1.5λo, respectively, above FP. The design reported in [21] had used 139×139 mm^2 ceramic superstrate and a finite ground plane which has same dimensions of superstrate layer with 5×5 PRS array to achieve a gain of 17 dB while using 181×181 mm^2 FR4 superstrate and ground plane with 55× PRS array a gain of 18 dB was obtained. A multilayer antenna composed of an FP printed on FR4 substrate which was isolated from (155×155 mm^2) ground by 1 mm of free space air. The FP was covered by FR4 superstrate and 55× PRS array located at the height of 0.5 λo from the ground plane. The antenna had achieved 12.7 dB maximum gain [19].

In this work adding three superstrate layers had improved the antenna's performance (enhanced the gain and operating bandwidth, while SLL were reduced). A reduction of SLL was achieved by optimizing the height of Rogers RO3010 (superstrate layers) without using PRS. The designed antenna has a lower S_{11}, a wider operating bandwidth, comparable gain, and higher efficiency in comparison with antenna presented by [22].

II. Antenna Geometry

The designed multilayer antenna is composed of an FP covered by three superstrate layers. FP composed of rectangle shape patch and four circles located at its corners, which are used to increase the physical area of metallic patch as well as have an operating frequency close to 5.8 GHz. The radius of the circles located at the right-hand corners is (r_r), while the radius of the circles which located on the left-hand is (r_l). Three slots removed from the patch's surface to achieve a wider bandwidth; a slot located in the center of the patch which has length of (CS_L). The other two slots which have length of (SS_L) and the width of the three slots is (S_w) with (SS) distance separating between each two neighbor slots. Rogers RT/Duroid 5880 ($\epsilon_r = 2.2$ and tanδ = 0.0009) used as substrate for feeder antenna. The dimensions of the FP are 38×60×0.787 mm^3. The FP was fed by microstrip feeder which has length and width of (f_L) and (f_w), respectively. A full copper ground plane of the proposed multilayer antenna is located under the substrate of the FP. Table I shows a list of FP's dimensions. Fig. 1 shows the top view and side view of the designed multilayer antenna. The dimension for the FP were optimized based on microstrip design formulas [23].

The superstrate layers are composed of three Rogers RO3010 ($\epsilon_r = 10.2$ and tanδ = 0.0023) layers. Each layer has the dimensions of 38×60×0.64 mm^3. The first superstrate layer was located at the height of (Sh_1) from the ground plane, as well as for the second and third layers which were located at the heights of (Sh_2) and (Sh_3), respectively. The superstrate layers were fixed using nylon spacers. The height and dimensions of each Rogers RO3010 layer were estimated based on concept of filling fractions [24].

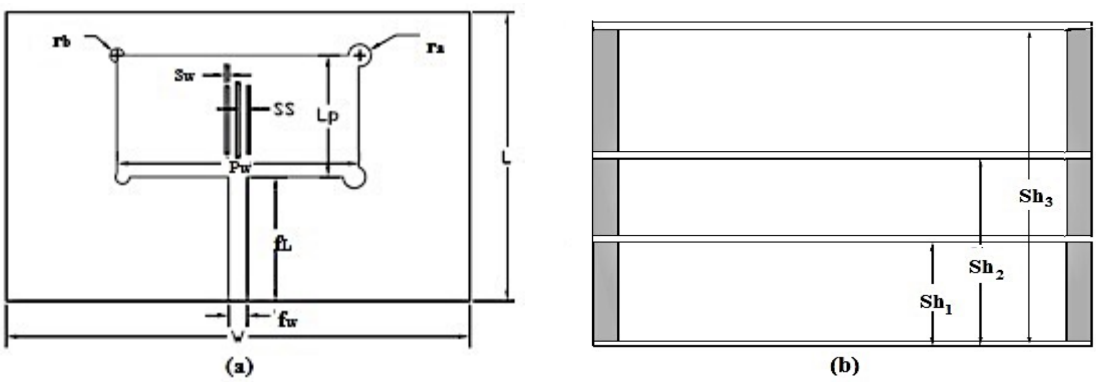


Figure 1. The proposed antenna: (a) top view (b) side view.

TABLE I
LIST OF FP'S DIMENSIONS

No.	Parameter		Dimension (mm)
	Name	Symbol	
1	Width of Feeder	f_w	2.40
2	Length of Feeder	f_L	16.30
3	Width of patch	P_W	31.30
4	Length of Patch	P_L	16
5	Right hand circle's radius	r_r	1.45
6	Radius of Left hand circle's	r_l	0.95
7	Length of the central slot	CS_L	10
8	Length of two sides slots	SS_L	9
9	Width of Slots'	S_w	0.5
10	Slot's Separation Distance	SS	1
11	Width of Substrate	W	60
12	Length of Substrate	L	38
13	Thickness of Substrate	h	0.787
14	Thickness of Copper	t	0.017

III. SIMULATION RESULTS

FP has a resonating frequency at 5806 MHz with an operating bandwidth of 130.15 MHz and a gain of 8.23 dB with high SLL. Multiple superstrate structure which was made of three slabs of Rogers RO3010 layers was located above the feeding patch to enhance the performance of the antenna. Three steps below describe the effects of adding the multiple superstrate layers on antenna's performance:

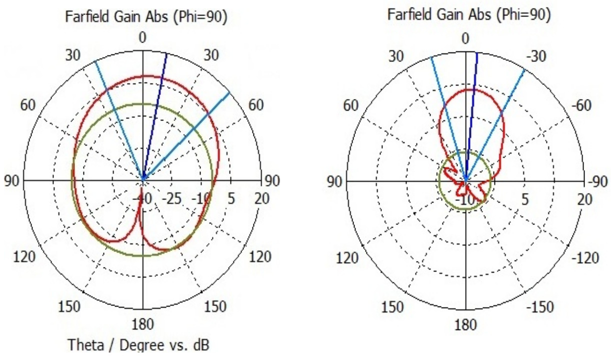
1) *Substrate layer (I):* the first superstrate layer was located at the height of Sh_1 from the ground plane. The resonant frequency was shifted up to 5.833 GHz, while the gain and bandwidth increased to 8.76 dB and 146.70 MHz, respectively, compared to the FP. Sh_1 was optimized to 15.8 mm.
2) *Substrate layer (II):* adding the second superstrate layer at the height of Sh_2 from the ground plane had shifted the resonant frequency to 5.824 GHz and enhanced the antenna's gain and operating bandwidth to 9.83 dB and 183.65 MHz, respectively, while S_{11} and SLL were reduced compared to (I). Sh_2 was optimized to 32.3mm.
3) *Substrate layer (III):* adding the third superstrate layer at the height of Sh_3 had improved the antenna's performance. Sh_3 was optimized to 53.6 mm which led to having a resonant frequency at 5.8 GHz. The gain, as well as the operating bandwidth, were enhanced to 11.30 dB and 190.54 MHz, respectively, while SLL were

eliminated. The values for Sh_1, Sh_2, and Sh_3 were optimized due to a tradeoff between parameters of the antenna. Table II shows the performance of FP, I, II, and III.

TABLE II
PERFORMANCE OF FP, I, II AND III.

Parameter	FP	I	II	III
Resonant Frequency (GHz)	5.806	5.833	5.824	5.800
S11 (dB)	-32.07	-17.42	-34.59	-35.67
Bandwidth(MHz)	130.15	146.70	183.65	190.54
Gain(dB)	8.23	8.76	9.83	11.30
Radiation Efficiency	88.98%	87.71%	89.41%	90.85%

Adding the three layers of Rogers RO3010 had improved antenna's performance through increasing its gain and bandwidth and reducing SLL and S_{11} with a simple increment in the radiation efficiency. The proposed multilayer antenna has a comparable gain and size reduction in comparison to antenna presented by [22] which used 5×5 PRS array to reduce the SLL. The proposed antenna had eliminated the SLL due to optimizing the height of superstrate layers. Fig.2 shows the radiation pattern for feeding patch and designed multilayer antenna structure, while Fig. 3 shows gain over (5.725 - 5.875) GHz for FP and steps of adding superstrate layers (I, II, and III). It is apparent that the performance was enhanced due to adding the superstrate layers.



(a) (b)

Figure 2. Radiation pattern for: (a) FP, (b) designed multilayer antenna

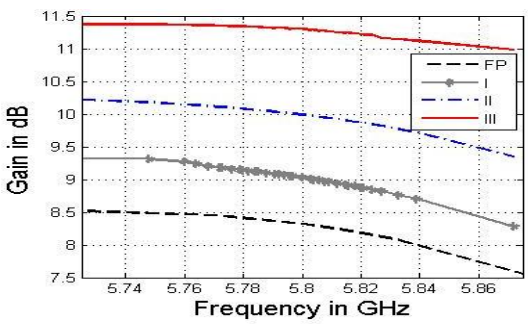


Figure 3. Gain over frequency for FP, I, II, and III.

IV. Measurements

The designed multilayer antenna has been fabricated as shown in Fig. 4. S_{11} for the fabricated antenna has been measured using a VNA (Vector Network Analyzer - Anritsu 37347D). Two dual polarized horn antennas (A-INFOMW), a signal generator (ROHDE and SCHWARZ SMR 60), and an ADVANTEST R3267 spectrum analyzer have been used for measuring the gain of the designed antenna which was (11.12) dB. The fabricated antenna has a bandwidth of (253) MHz. The simulated and measured S_{11} for the proposed antenna are shown in Fig. 5. The dimensions of the fabricated antenna were 38×60×54.2 mm^3. Table III shows comparison between the simulated and measured results for the proposed multilayer antenna.

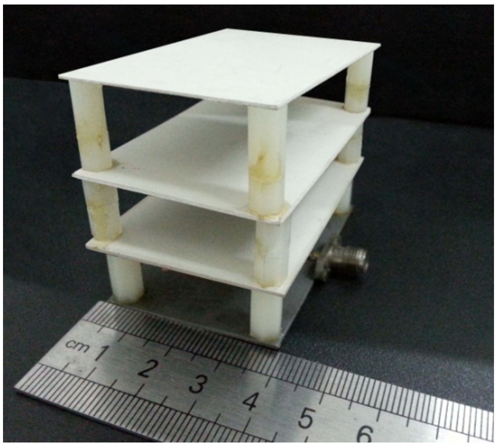


Figure 4. Fabricated multilayer antenna.

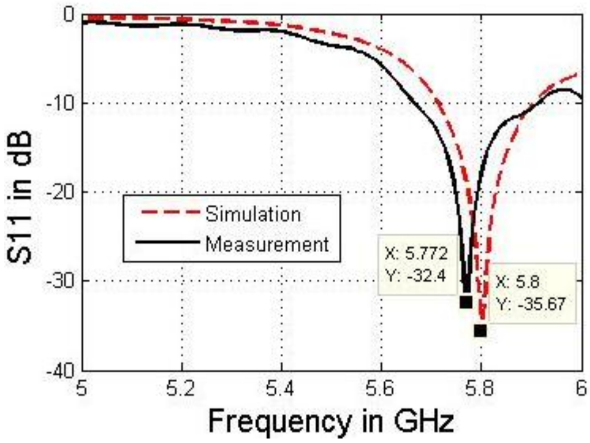


Figure 5. Simulated and measured S_{11} for the proposed multilayer antenna.

TABLE III

COMPARISON BETWEEN SIMULATED AND MEASURED RESULTS

Parameter	Simulated	Measured
Resonant Frequency (GHz)	5.800	5.77
S_{11} (dB)	-35.67	-32.40
Bandwidth(MHz)	190.54	253.31
Gain(dB)	11.30	11.12

V. Discussion

Adding the superstrate layer had improved the performance of patch antenna. The gain was enhanced more than 3 dB, and the operating bandwidth improved more than 60 MHZ, while the SLL was reduced. The half power beam width (HPBW) was narrowed around 24.1° due to adding the superstrate layers. Moreover, 18 dB (F/B) ratio was obtained. A difference between the simulated and measured results had occurred due to neglecting deficiencies and analogue losses by the simulation environment. The designed multilayer antenna structure has a reduced size compared to the multilayer antennas presented in [17]–[22] as shown in Table IV. The proposed multilayer antenna had overcome the antenna presented in [22]in terms of S_{11}, operating bandwidth, radiation efficiency, reducing SLL without using PRS, and reduced size with a comparable gain.

TABLE IV
SIZE REDUCTION COMPARISON.

Reference number	Size Reduction in Compared with Designed Antenna
[17]	58%
[18]	82.52%
[19]	87.18%
[20]	97.66%
[21]	86.25% using FR4 superstrate 76.68 % using ceramic superstrate
[22]	81.24%

VI. CONCLUSION

Efficient multilayer antenna operating over (5.725-5.875) GHz band with operating bandwidth and gain of 190.54 MHz and 11.30 dB, respectively, for WLAN applications was presented. The designed multilayer antenna has a reduced size as compared with multilayer antennas operating over (5.725-5.875) GHz, presented in the literature review. The antenna's performance was improved due to adding low loss superstrate layers above the feeding patch which led to enhance the gain and operating bandwidth, while the SLL was reduced due to optimizing height of these layers.

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