Design of a Novel Patch Antenna with Enhanced Gain and Side Lobe Reduction

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ABSTRACT

The design of an efficient and directive small size antenna, for modern wireless applications, is a major challenge. This paper introduces the design and simulation of new method to enhance the gain and side lobe reduction that improve the performance of a conventional microstrip patch antenna. In this work three models were discussed and analyzed. The first model consists of a reference patch antenna plus superstrate-1 of different thickness. Modification of this model by adding square copper ring represents the second model. In the third model a second superstrate on the top of the square copper ring was added. Simulation results illustrate that the first model gives a small enhancement for the gain and side lobe reduction, only gain enhancement was obtained in the second model and greater enhancement was achieved for the performance of the patch antenna in the third model.

Keywords: Microstrip Antenna, Gain enhancement, Side lobe reduction, Dielectric cover patch antenna.

تصميم حديث لهوائي الشريحة مع تحسين الربح وتقليل الفصوص الجانبية

الخلاصة

ان تصميم هوائي صغير كفوء وموجه، لاغراض التطبيقات اللاسلكية الحديثة، يعد تحديا كبيرا. يقدم هذا البحث تصميم ومحاكاة لطريقة جديدة لتحسين ربح الهوائي وتقليل الفصوص الجانبية والتي تؤدي الى تحسين مواصفات هوائي الشريحة الاعتيادي. في هذا العمل تم اقتراح ثلاثة نماذج وقد خضعت جميعها للمناقشة والتحليل. النموذج الاول يتضمن اضافة شريحة متكونة من طبقة عازلة وبأسماك مختلفة توضع على السطح العلوي لهوائي الشريحة المرجعي. تطوير هذا النموذج من خلال اضافة حلقة نحاسية مربعة الشكل ليمثل النموذج الثاني. في النموذج الثالث تم اضافة شريحة عازلة ثانية فوق الحلقة النحاسية. اثبتت نتائج المحاكاة بأن النموذج الاول ي}من تحسين بسيط في ربح الهوائي والفصوص الجانبية و هنالك تحسين في ربح الهوائي فقط يمكن الحصول علية باستخدام النموذج الثاني، اما النموذج الثالث فقد يؤمن تحسين في كلا المواصفتين مما يؤدي الى تحسين ملحوظ في مواصفات الهوائي.

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INTRODUCTION

Microstrip patch antennas (MPAs) have attracted widespread interest due to their small size, light weight, low profile and low cost as well as to the fact that they are simple to manufacture, suited to planar and non planar surfaces, mechanically robust, easily integrated with circuits, allow multi frequency operation to be achieved [1]. However, two major disadvantages associated with microstrip antennas are low gain and narrow bandwidth. Most works have been done in improving the bandwidth, but little in enhancing the antenna gain [2], and very little in enhancing side lobe level. Side lobes usually represent radiation in undesired directions, and they should be minimized.

Gain enhancement of patch antenna can be achieved by more than one approach, the following some of these approaches:

- The use of patches of multiple laminated conductors to reduces the ohmic loss of this antenna [3, 4].
- The use of partial substrate removal to reduces the losses due to surface waves and dielectric substrate [5, 6].
- The use of the photonic band-gap (PBG) concept [7].
- The use of Electromagnetic Bandgap (EBG) structure as a superstrate. EBG superstrate can be used as spatial angular filters for filtering undesired radiation by sharpening the radiation pattern (grating lobes suppression) of microstrip array antennas and for increasing the antenna gain. While increasing the gain of the antenna is important, what is typically neglected is t he consequential effect on the other antenna performances [8].
- Loading of the rectangular parallelepiped or circular cylindrical dielectric in front of a source with the ground plane. The dielectric loaded antennas with the diameter d= (1-3) λ_0 have the mixed properties of dielectric covered antennas, rod antennas and lens antennas [9].
- The gain enhancement can also be achieved by employing a frequency selective surface (FSS) type structure, which has conducting patch arrays etched on a substrate layer and spaced at a height from the radiating element [10].
- Another method for increasing the gain of microstrip patch antenna was characterized by employing a dielectric cover that is spaced at some height above the antenna [10]. For this method the impedance matching bandwidth increases with increase in the spacing height (λ_0, $2\lambda_0$), in this case the antenna dimensions become impractical for many applications.

This paper introduces a novel approach to enhance the gain and side lobe level of the micro-strip patch antennas. The simulation tool used in this work is CST MWS 2010.

DESIGN PARAMETERS OF THE REFERENCE ANTENNA

The three essential parameters for the design of Microstrip Patch Antenna are:

- Frequency of operation (f_0): The resonant frequency of the antenna must be selected appropriately according to the given task(ISM band, 2.4 GHz, in this work).

- Dielectric constant of the substrate (ε_r): The dielectric material selected for this work is FR-4 of relative permittivity of 4.3.
- Height of dielectric substrate (*h*): The height of the dielectric substrate is selected to be 1.6 mm.

To get better matching at the desired operating frequency some adjustment for the dimensions of the patch and feeding point was made to the calculated values using the transmission line model analysis, the result of this process is:

$$L \times W = 28 \text{ mm} \times 28 \text{ mm}$$

The transmission line model is applicable to infinite ground planes only. However, for practical considerations, it is essential to have a finite ground plane. Similar results for finite and infinite ground plane can be obtained if the size of the ground plane is greater than the patch dimensions by approximately six times the substrate thickness all around the periphery. Hence, for this design, the ground plane dimensions would be given as:

$$L_g = L + 6h = 37.6 \text{ mm.}$$

$$W_g = W + 6h = 37.6 \text{ mm.}$$

The antenna is fed by a coaxial probe feed of characteristic impedance 50 Ω.
The geometry of the reference antenna is shown in Figure- (1).

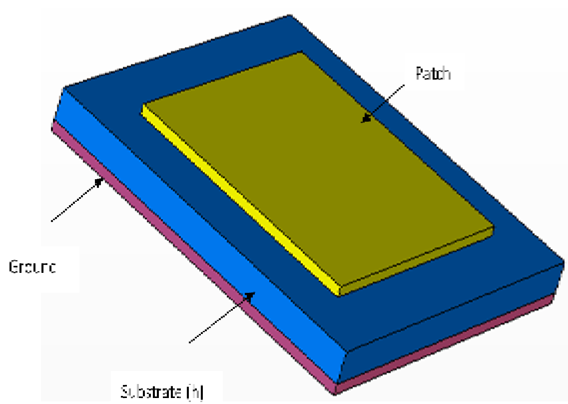

Figure (1): The geometry of the reference antenna.

PROPOSED DESIGN MODIFICATIONS

Many proposed modifications have been introduces to enhance the performances of the reference micro-strip antennas at 2.4 GHz operating frequency.

Model -1: Reference antenna + Superstrate (h1)

In this proposed structure, the patch was covered by FR-4 superstrate of thickness (h1) of dielectric constant 4.3 (the same as that of the substrate h). Different superstrate thicknesses (h1= 5, 10, 15, 20, 25, 28) mm were studied and analyses.

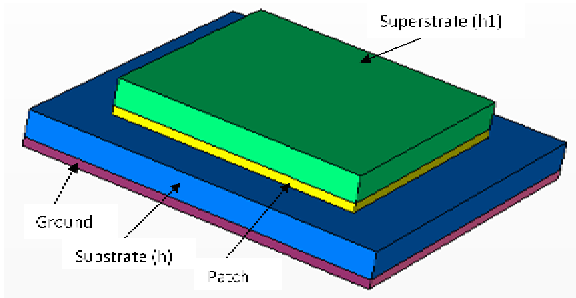

Figure (2): The geometry of Model-1 antenna

Model -2: Reference antenna + Superstrate (h1) + Square Copper Ring
Model -1 was modified by adding square copper ring on the top of the superstrate (h1) with thickness 0.05mm and width of (0.1L x 0.1W). Different superstrate thicknesses (h1= 0.5, 1, 2, 3, 5, 7, 10, 15, 20) mm were studied and analyses.

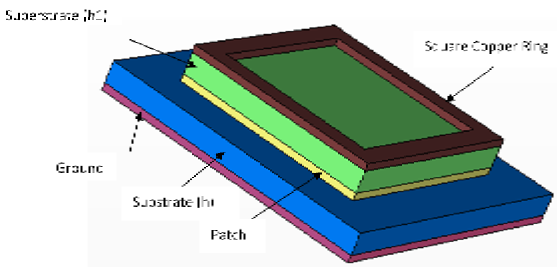

Figure (3): The geometry of Model-2 antenna

Model -3: Reference antenna + Superstrate (h1) + Square Copper Ring + Superstrate (h2)
Model -2 was modified, for h1=3mm, by adding another superstrate on the top of the copper square ring with thickness (h2). Different superstrate thicknesses (h2=1, 3, 5, 10, 15, 20, 25, 28, 40, 50) mm were studied and analyses.

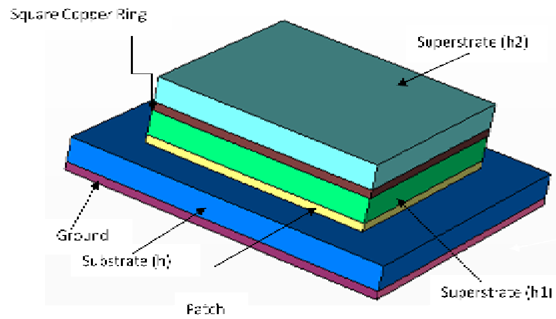

Figure (4): The geometry of Model-3 antenna

RESULTS AND DISCUSSION

The proposed models are designed to operate at center frequency 2.4 GHz. The simulation results for the reference antenna are illustrated in the figures (5, 6, and 7).

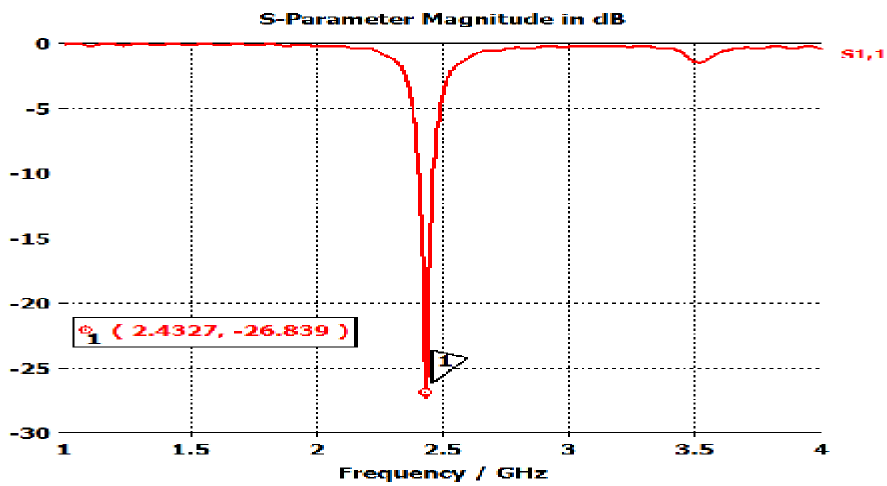

Figure (5): Return loss characteristic of the reference antenna.

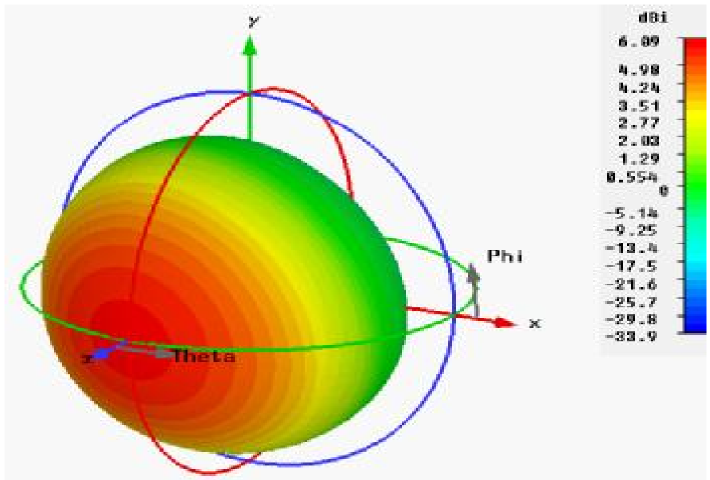

Figure (6): 3D radiation pattern of the reference antenna.

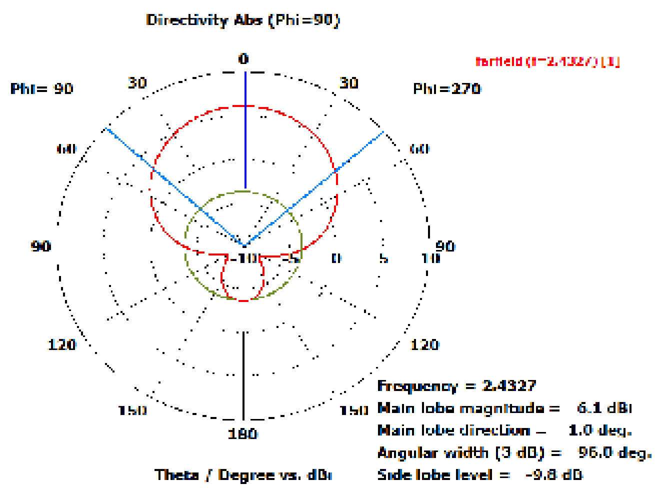

Figure (7): 2D radiation pattern of the reference antenna.

From these results it was found that the antenna parameters have the following values:

Gain = 4.023

Side lobe level = -9.8 dB.

These values not satisfy with the requirements for certain applications.

Model -1: (h1=62mm)

The simulation results for this type of antenna are illustrated in the figures (8, 9 and 10) for h1=62mm.

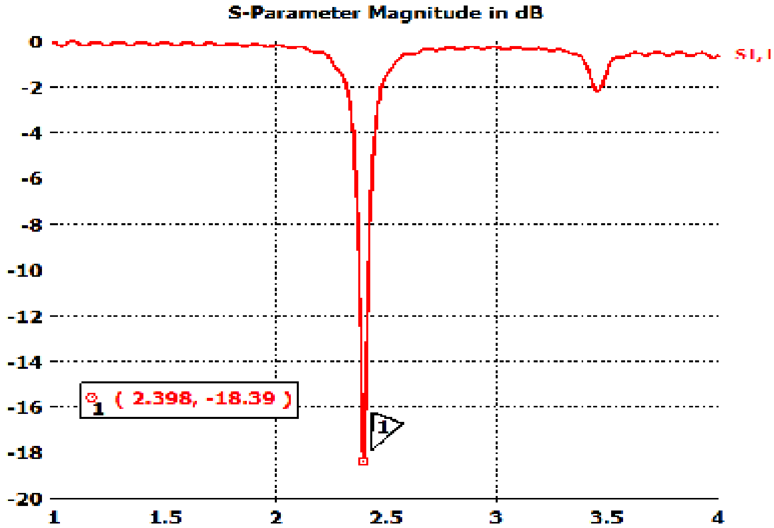

Figure (8): Return loss characteristic of Model-1 antenna.

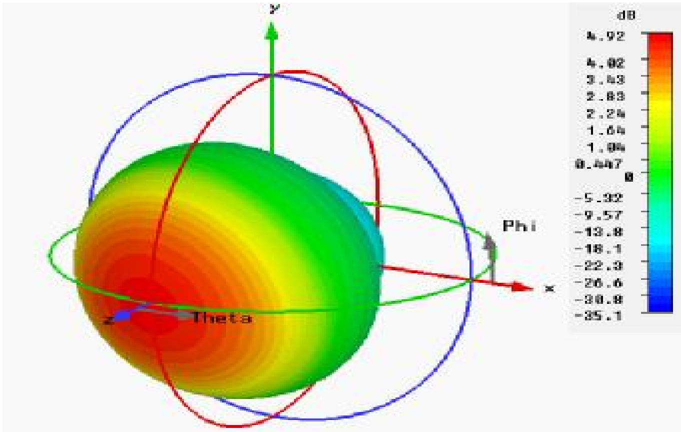

Figure (9): 3D radiation pattern of Model-1 antenna.

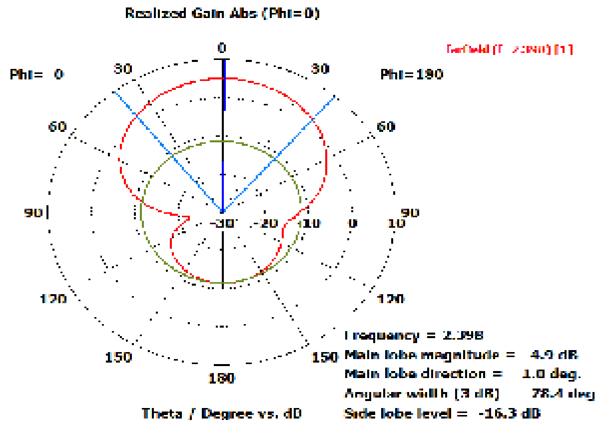

Figure (10): 2D radiation pattern of Model-1 antenna.

Different values of h1 was simulated, the results of this simulation was demonstrated in Table(5).

Table (5): Simulation results of Model-1 antenna.

h1 (mm)	F_0 (GHz)	S11	Gain dB	Gain Enhancement %	Side Lobe Level (dB)
0	2.4327	-26.839	4.023	-	-9.8
5	2.404	-27.982	3.857	-	-11
10	2.3988	-22.426	3.795	-	-11.9
15	2.3949	-21.14	3.784	-	-12.2
20	2.3946	-22.016	4.034	2.625 %	-12
25	2.3946	-23.758	4.249	5.35 %	-11.6
28	2.3946	-24.61	4.373	8.402 %	-11.4
40	2.3979	-25.136	4.684	16.45 %	-11.5
50	2.3979	-20.65	4.752	18.28 %	-13
62	2.3979	-18.357	4.918	22.896 %	-16.5

From these results it was found that there is small enhancement in the gain and side lobe level for the higher thickness only.
These values still not satisfy with the requirements for certain applications.

Model -2: (h1=3mm)

The simulation results for this type of antenna are illustrated in the figures (11, 12and 13) for h1=3mm.

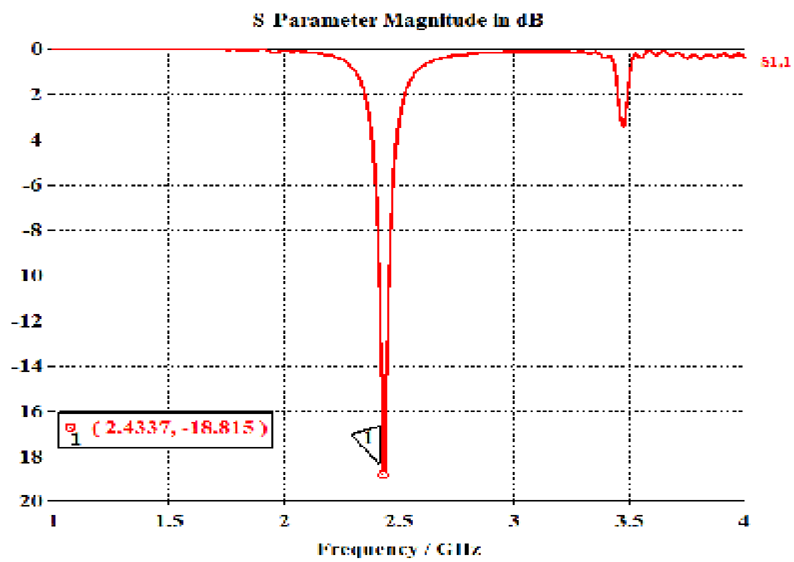

Figure (11): Return loss characteristic of Model-2 antenna.

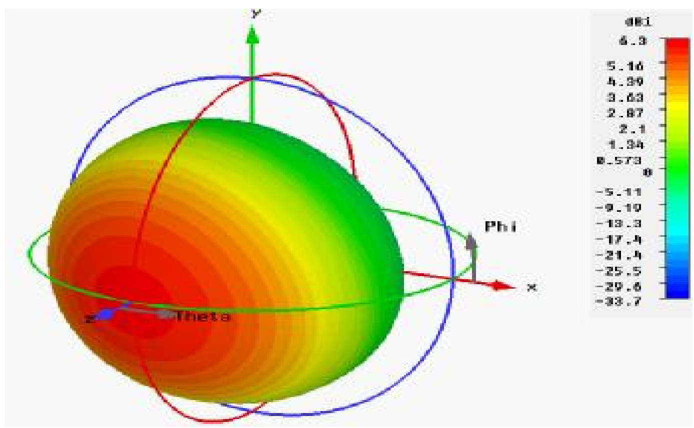

Figure (12): 3D radiation pattern of Model-2 antenna.

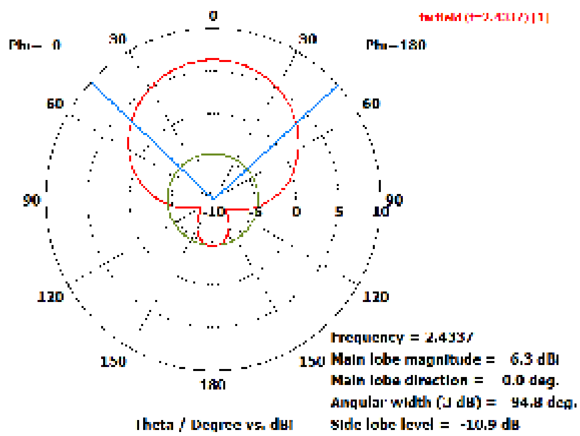

Figure (13): 2D radiation pattern of Model-2 antenna.

Different values of h1 was simulated, the results of this simulation was demonstrated in Table(6).

Table (6): Simulation results of Model-2 antenna

h1 (mm)	F_0 (GHz)	S11	Gain dB	Gain Enhancement %	Side Lobe Level (dB)
0	2.4327	-26.839	4.023	-	-9.8
0.5	2.4493	-19.966	5.275	33.425 %	-10.1
1	2.4466	-19.736	5.317	34.72 %	-10.3
2	2.4405	-19.244	5.36	36.062 %	-10.6
3	2.4337	-18.815	5.384	36.879 %	-10.9
5	2.424	-16.83	5.356	35.93 %	-11.4
7	2.419	-14.982	5.255	32.812 %	-11.9
10	2.4174	-12.123	4.966	24.26 %	-12.4
15	2.4155	-8.98	-	-	-
20	2.4128	-7.414	-	-	-

From these results it was found that there is an enhancement in the gain and side lobe level for values of h1 less than 10mm. The square copper ring has an important effect on the gain and the side lobe level as well as the scattering parameters.

Model -3: (h1=3mm, h2=5mm)

The simulation results for this type of antenna are illustrated in the figures (14, 15 and 16) for h1=3mm and h2= $\lambda/2$ =62mm.

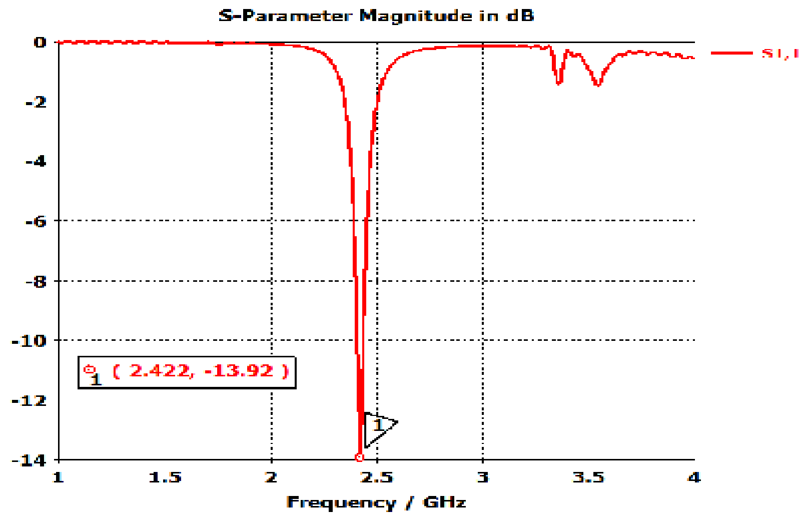

Figure (14): Return loss characteristic of Model-3 antenna.

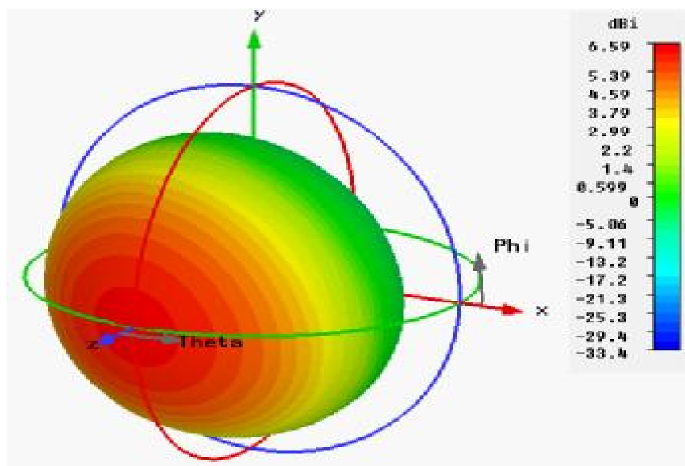

Figure (15): 3D radiation pattern of Model-3 antenna.

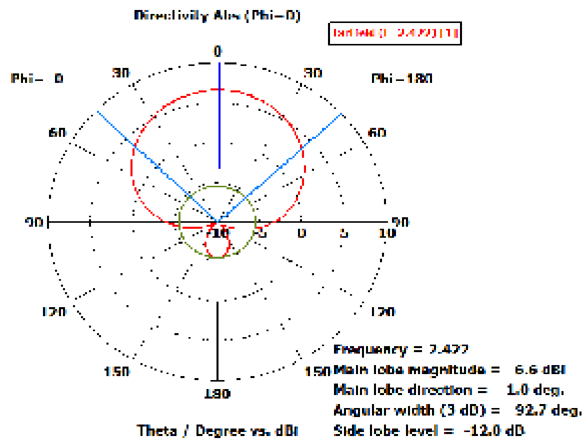

Figure (16): 3D radiation pattern of Model-3 antenna.

Different values of h2 were simulated for h1=3mm, the results of this simulation were demonstrated in Table(7).

Table (7): Simulation results of Model-3 antenna

h2 (mm)	F_0 (GHz)	S11	Gain (dB)	Gain Enhancement %	Side Lobe Level (dB)
0	2.4327	-26.839	4.023	-	-9.8
1	2.4317	-16.623	5.375	36.5 %	-11.2
3	2.425	-15.113	5.355	35.9 %	-11.6
5	2.4218	-13.895	5.335	35.28 %	-12
10	2.4188	-12.985	5.401	37.35 %	-12.6
15	2.4186	-13.127	5.553	42.24 %	-12.6
20	2.4162	-13.816	5.742	48.57 %	-12.2
25	2.4172	-14.731	5.943	55.61 %	-11.8
28	2.422	-16.378	6.05	59.5 %	-11.7
40	2.422	-14.331	6.335	70.3 %	-12.2
50	2.422	-12.187	6.463	75.4 %	-14.3
$\lambda/2$	2.4216	-11.03	6.739	86.912%	-18
λ	2.4212	-11.483	8.53	182.3%	-15.8
1.5λ	2.4184	-11.683	9.731	272.25%	-13.1
2λ	2.4184	-11.853	10.714	423.86%	-11.9

From these results it was found that there is additional enhancement in the gain and side lobe level.
Comparison between the performance of reference antenna and new designed models is demonstrated in Table(8).

Table (8): Comparison among the performances of the designed antennas

Model	Gain Enhancement %	Side Lobe Level dB
Reference Model	**-**	**-9.8**
Model-1 h1=62mm	**22.896 %**	**-16.5**
Model-2 h1=3mm	**36.879 %**	**-10.9**
Model-3 h1=3mm, h2=62mm	**86.912 %**	**-18**

CONCLUSIONS

A novel microstrip antenna structure with enhanced gain and side lobe reduction is presented in this paper. Three modified models were designed, simulated, and analyzed. The performance of these models was compared with the performance of the reference antenna (before modification). Simulation results show that Model-3 can gives a gain enhancement of 86.912 % and side lobe reduction enhancement of 8.2dB with acceptable dimensions.

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