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Parametric Variation Based Analysis AND Effective Design of Rectangular Patch Antenna for Bluetooth Application

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Abstract : *This paperdevelops an understanding of creating and improving the design of microstripantenna by the performance analysis of resultsfromitsvarious configurationsrelating to rectangular patch microstripantenna. Furthermore, itaccommodates a simulated patch antennawith effective results for bluetooth applicationsatafrequency of 2.4GHz. The proposed antenna is not only designed on the formulated calculations but also analyzed on different sizes, positions and orientations of substrate, feeding point and slots respectively.*

Propagation parameters are greatly improved by amendments suggested by the analysis of the variation based studies provided by this paper. The initial resultsobtained using formulae based designs are compared with the ameliorated results to illustrate the effects of such variations on antenna parameters. The final antenna show significantly improved return losses of -46.7dB, VSWR of 1.0093, Bandwidth of 180MHz and a far field radiation pattern with a gain of 2.2782dB. The Antenna designed is optimized and interpreted with Ansoft HFSS 13.0 simulator.

Keywords: *Bluetooth, rectangular patch antenna, feedpoint, trial and error method, slot orientation, wide bandwidth.*

I. Introduction

The evolution of patch antenna in the past few years, has greatly optimized the performance of communication systems. In particular, size and efficiency of antennae have been greatly improved due to research in patch antennae.[1]shows a detailed study of patch antennae comprising of characteristics that improve bandwidth.Microstrip patch antennaspecialty over other antennaeare low profile, compactness, light weight and ease of fabrication. Applications, in particular, Wireless LAN, Bluetooth, Zigbee, Missile guiding systems and Microwave engineering require systems with small sizes, which is comparatively easier toachieve through the use of patch antennae. The ISM band inhibitsone of the largestconcentration of applications, most of which lie at the frequency of 2.4GHz.

In wireless communications, Bluetooth Technology is a non-line-of-sight communication system that supports short distances and low data rate with an operating frequency of 2.4 GHz.

Notableresearch has been carried out and published in patch antenna designingusing T-shaped slots in ground plane [7] that provide wide bandwidth, circular patches [2] that provide dual band applications, U-notch [3] and rectangular patch[4] with improved bandwidth. In [7] a novel idea of incorporating ground plane into plane of patch was published, yielding return losses of -35dB at 2.4GHz, whereas, in [4], a simple rectangular patch is introduced with return losses of -30dB at 2.4GHz.

More recently, developments in patch antenna provide us with the evidence that slots in patches improve gain, bandwidth and losses exhibited by antennae, [5] show an example of high gain slot coupled patch antenna and [6] relates the creation of slot with high bandwidth application. Interestingly, different antennae configurations having change in position and orientation of slot in the patch have shown to be very different from each other.

This paper presents a study of configurations of antenna relating to feeding point, height, size of substrate and position of slot into the patch. With variations in these parameters we observe different patterns whichprovide a study of behavior of radiation parameters of an antenna. With a frequency sweep of 1GHz to 10GHz, we observe changes with respect to height, length, width of substrate and position of rectangular slot and hence, we design an efficient patch antenna with a simple rectangular patch.

II. Antenna Design Relations

Initially, parametric equations were used to design an antenna with center frequency of 2.4 GHz. Fr4 epoxy was used as a substrate material due to its ease in application in PCB designing. It has a permittivity constant of 4.4 and a loss tangent of 0.01.

A very effective approximation of width of patch[9] was found by:

$$W = \frac{c}{2f_o\sqrt{\frac{\varepsilon_r+1}{2}}} \qquad (1)$$

A finite ground plane with the same size of width W and length L as of substrate is situated below the substrate. Patch, ground length and width are calculated by using transmission line model. The relative dielectric constant (ε_r)[9] of the substrate is given as

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1+12\frac{h}{W}\right]^{-\frac{1}{2}} \quad (2)$$

An effective approximation for normalized extension of length[9],[10] is given as:

$$\Delta L = 0.142h\frac{(\varepsilon_r+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_r-0.258)\left(\frac{W}{h}+0.8\right)} \qquad (3)$$

The effective length[9] of this patch is given by:

$$L = L_{eff} - 2\Delta L \quad (4)$$

Effective and practical consideration feed locations[9], were found by

$$y_f = \frac{W}{2} \text{ and } x_f = \frac{L}{2\sqrt{\varepsilon_{reff,L}}} \qquad (5)$$

Hence, the formula based calculations of this antenna were as, length of substrate and ground plane were 44mm, width of substrate and ground were 53.2763, length of patch was approximately 28mm, width of patch was found to be 38mm, feed locations found by (5) were(19.0181,7.2943)height of substrate chosen for the simulation was chosen to be 2.54mm due to its practical form available in PCB.

2.1 Formulae Based Model Simulation

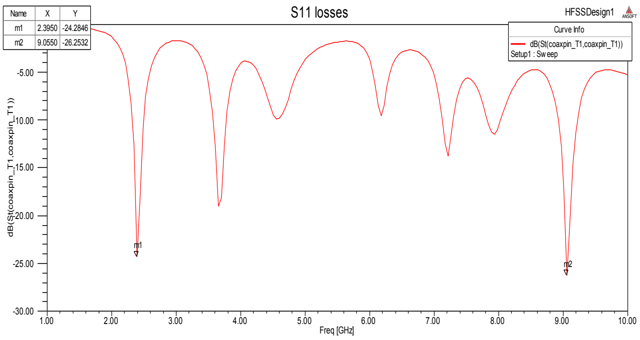

Figure 1. *S11 losses of the formulated antenna*

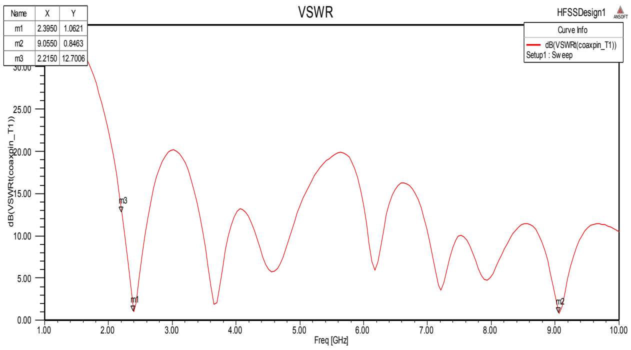

Figure 2. *VSWR of the formulated antenna*

The formulae based model yeilded results with S11 return losses of -24.28dB and VSWR of 1.0621 was observed at a frequency of 2.3950 GHz.

III. Performance Analysis

3.1 Proposed feed location

Feeding method we used was through coax cable with impedance of 50ohm due to ease of fabrication, matching and a quality of low spurious radiation. In Coax feeding method the inner conductor of the coaxial is attached to the radiating patch of the antenna while the outer conductor is connected to the ground plane where, the best impedance match would yield the best results.

However, direct calculation didnot provide efficient matching.Using co-ordinates of (5) for feed location, the observed return losses were-11.8284dB, which conclude that design require changes for better impedance matching. By applying trial and error method used to adjust the feed point to 50Ω, variations in return losses were obtained as accumulated Table 01:

Table 1.*Feed Location Based Results*

Feed locations (X_f, Y_f) (mm)	Return losses (dB)
(9.3 , 19)	-5.3688
(8.3 , 19)	-7.7937
(7.3 , 19)	-10.7472
(6.3 , 19)	-14.5601
(5.3 , 19)	-19.0056
(4.3 , 19)	-24.2846
(3.3 , 19)	-21.3562
(2.3 , 19)	-18.0722

The best match was achieved over the co-ordinates of (4.3, 19), resulting in return losses of -28.4259dB.

3.2 Substrate and Ground Size Impact on Design

The proposed structure was further tested with different substrate sizes on feed points of (4.3, 19) and was observed to be improving after a certain point. It was observed that equalsize of ground plane and the substrate provided the best results. Hence, the size of substrate and ground was kept same at all times.

Dimensions in Table 02were taken into account to analyze the antenna parameters.

Table 2.*Substrate Location Based Results*

Length*width (mm)	S11 Losses (dB)	VSWR (dB)
44,53	-24.2846	1.1301
45,55	-23.0772	1.1509
50,60	-29.5581	1.0688
55,65	-22.7030	1.1581
60,75	-26.7099	1.0968
65,80	-27.0437	1.0930
70,90	-29.7871	1.0670
75,95	-28.4281	1.0788
80,105	-29.6398	1.0682
95,115	-32.0942	1.0510
105,125	-35.8228	1.0329

Hence, size of substrate was chosen to be (105,125)mmfor further analysis, as it had the widest bandwidth and improved responses.

3.3 Height adjustment

Selected substrate size (i.e. 105mm*125mm) was then examined under height variations. 10 equidistant points were analyzed based on the permitted range of .003lambda<h<.05lambda. The observed results are displayed in Table 3.

Table 3.*Height Adjustments in Substrate*

Height	Resonant Frequency	S11	VSWR
0.375	4.5	-13.17	1.5745
1.0278	3.745	-16.38	1.2849
1.6806	2.44	-28.70	1.0407
2.3334	2.395	-25.46	1.0487
2.9862	2.395	-21.79	1.172
3.639	2.350	-33.35	1.0407

4.2918	2.3050	-27.47	1.1014
4.9446	2.3050	-25.77	1.1064
5.5974	4.66	-22.71	1.1268
6.25	4.555	-22.39	1.1336

Referring to Table 3, it could be seen that improvements in VSWR were observed as height was enlarged, whereas, losses were trim downat mediocre values of permitted height.
Observation suggested a height selection between 2.3334 and 4.2918; hence, we selected the size to be 2.54 and proceeded with its further amendments.

3.4 Slot Orientation
3.4.1 Horizontal
Horizontal slots wasproduced with a length*width of 21*1mm^2. The slot wastraversed from at least 1 point from one edge of the patch to at most 3 points from other edge as:

Table 4. *Horizontal Slot Orientation*

Points from edge (mm)	Resonant frequency (GHz)	Return losses (dB)	Gain (dB)	VSWR
1	2.215	-25.3841	1.1829	1.1137
4	1.99	-24.1012	-3.6133	1.1330
8	3.5650	-22.3378	-4.4762	1.1654
13	4.78	-25.1358	-2.3483	1.1172
18	8.425	-14.3974	0.0779	1.4710
21	8.65	-23.9915	1.2457	1.1348

Simulated results showed a gradual increase in resonant frequency from 2.15GHz to 8.65GHz as it moves towards the feed.

3.4.2 Vertical
Furthermore, the design was evaluated on the basis of vertical slot orientations. Samples of slot sizes were taken. Best results were inhibited in the slot width of 1mm and a height of 21mm. Various orientations were experimented on the slot. The slot was moved from beside the feed to the end of patch, yielding results as illustrated in Table 5.

Table 5.*Vertical Slot Orientation*

Points away from edge	Return Losses(dB)	Gain (dB)	VSWR
1	-33.1402	2.3975	1.045
4	-30.6349	2.3306	1.0606
8	-31.9108	2.3984	1.0521
13	-46.7054	2.2782	1.0093
19	-31.9629	2.4104	1.0518
25	-35.0115	2.3461	1.0362
30	-35.8225	2.3138	1.0329
34	-33.0617	2.3554	1.0455
37	-33.5953	2.3774	1.0427

Considerable decrement in Return Losses was observed as the slot was traversed towards the feeding point, whereas, minor changes were observed in VSWR and Gain.The slot creation at 13mm from the corner gave us further optimized results in terms of Gain, VSWR, Bandwidth and return losses at 2.395GHz.

IV. Final Design
Taking into account all the optimized results, we constructed an antenna with dimensions that provided best results after all amendments.Following were the simulated results

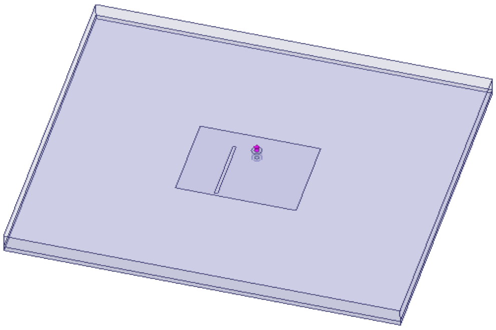

Figure 3. *HFSS model of final antenna*

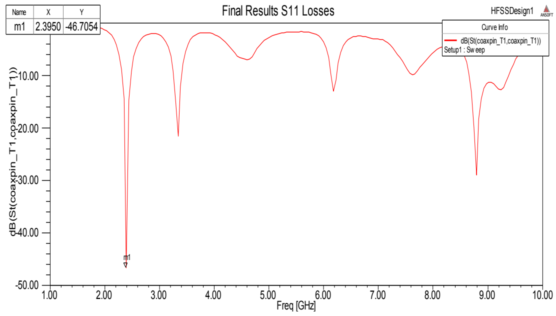

Figure 4. *Return losses of final antenna*

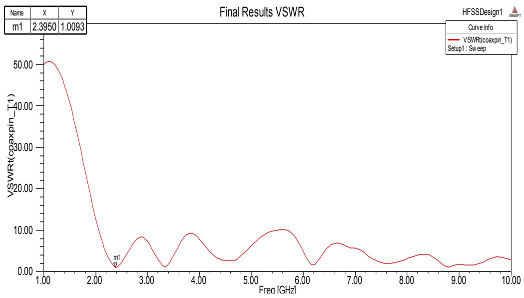

Figure 5. *VSWR of final antenna*

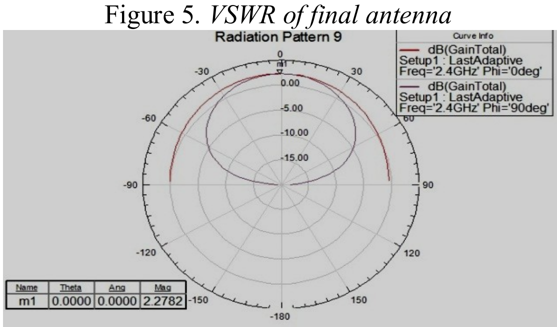

Figure 6. *Radiation pattern of final antenna*

Table 6. *Design Parameters*

Material	Fr4 Epoxy
Electric Permitivity	4.4
Loss Tangent	.02
Patch Length	28mm
Patch Width	38mm
Substrate Length	105mm
Substrate Width	125mm
Ground Length	105mm
Ground Width	125mm
Substrate Height	2.54mm

Table 7. *Results*

Frequency	2.3950GHz
Bandwidth	180MHz
VSWR	1.0093dB
Return losses	-46.7054dB
Gain	2.2782dB

V. Conclusion

Multiple design patterns of patch antennae were analyzed and one completely designed patch antenna was constructed in this research. The patterns showed that up to two times increases in substrate size from the formulated values will provide better return losses. Ground and substrate provide better results when of identical size.Height of substrate effects resonant frequency of antenna. Horizontal slot, when taken near the feeding point, impinge on frequencies from 1GHz to 5GHz and when taken away from feed point, affects 5GHz to 10GHz. Vertical slot, when taken midway, from feed to end, provided the best results.

Hence, an antenna with a gain of 2.2782dB, VSWR of 1.0093, bandwidth of 180MHz and return losses of -46.7dB at 2.3950GHz was designed.

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