Experimental Verification of the Mathematically Modelled Equal-Size Tri-Operation Multilayer L and S-Band Antenna

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Abstract - This paper focuses on the design of a rectangular microstrip antenna which can operate at three frequencies over the L and S-band region. The chosen frequencies are the Global Positioning System (GPS) satellite frequencies in the L-band and 2.45 GHz of the Wireless Local Area Network (WLAN) system. The main objective of this work is to experimentally verify the mathematically modelled multilayer rectangular patch antenna having three equal-size radiating elements, each operates at a different frequency within the specified bands. The feed line is located at the non-radiating edge. The MathCAD software has been used for computing and correlating the relevant design formulations. A simple expression consisting of two variable parameters, the relative permittivity and its thickness, have been successfully developed. The three layers of the antenna have identical radiating sizes of 48 mm by 37 mm. The measured antennas exhibit well-matched frequency of operations that correspond to the simulated antennas and theory.

1. Introduction

The attractive features of microstrip antennas include low profile lightweight, low cost, ease of construction and ease of integration with printed circuits [1] to [3].

In this paper, the antenna is designed with equal-size radiating elements having three different operating frequencies. The frequencies chosen are 2.45 GHz (designated f_1) for Wireless Local Area Network application and 1.227 GHz (designated f_2) and 1.575 GHz (designated f_3) for Global Positioning System applications. The modelling is developed using MathCAD software [4].

Micropatch [5] and Sonnetlite [6] were used for the simulation work performed on the designed antennas. The antennas were then implemented on microwave laminate and tested for their single port performances, particularly the frequency of operations.

2. Mathematically Modelled Antennas

Theoretically, the size of the rectangular microstrip radiating element is inversely proportional to the frequency of operation. Hence, the parameters that can be changed while maintaining the antenna size are the relative permittivity of the substrate, ε_r, and the substrate thickness, *h*.

The physical size of the radiating element is determined by first solving the width, *W*, followed by its length, *L*. Then, one can use the Solving of Formulations Method or Graphical Approximation Method. Detailed discussion of this is given in references [7] to [9]. Both methods agree well with each other.

The command *linfit* in Mathcad was used to compute the corresponding mathematical formulation that relates *h* and ε_r based on two sets of data. The relationship is shown in Fig. 1. ε_r was chosen to be of the range $2 \le \varepsilon_r \le 11$. The relationship was found to be

$$h = 0.02\varepsilon_r^{\ 2} - 0.197\varepsilon_r + \frac{11.681}{\varepsilon_r + 1} \qquad (1)$$

When the parameter *h* in equation (1) is solved for the chosen $2 \le \varepsilon_r \le 11$ range, it was found that the results are in good agreement to that obtained using the formulation available in references [1] to [3]. Hence, the most practical sets of *h* and ε_r for the corresponding specified frequency of operations can be determined. These are tabulated in Table 1.

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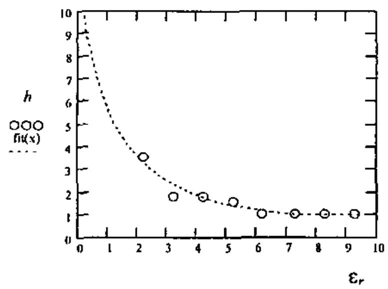

Figure 1: Relationship of h and ε_r

Table 1 : Sets of corresponding h and ε_r for the specified frequency of operations

Operating frequency / Substrate parameter	f_1	f_2	f_3
ε_r	2.2	6.15	10.2
h, mm	3.58	1.08	1.0

3. Numerical Simulations Investigations

3.1 Micropatch

Micropatch v.2 software is a simple PC based software yet is very useful in determining the optimum basic patch dimensions for operation. It allows the user to design and analyse one and two-port network of rectangular, circular and square microstrip patch antennas This is based on multiport network modelling approach. In the optimisation process, the command RPDesign was used.

There are several input parameters required which include dielectric constant, loss tangent, height of substrate, conductivity of conductor layer, thickness of conductor and surface roughness. The chosen microwave laminate has the specification obtained from Table 1.

The simulation results obtained are reflection coefficient (S_{11}), input impedance (Z_{in}), voltage standing wave ratio (VSWR), efficiency (η), directivity (D) and radiation pattern. The feeding method employed is the 50 ohm microstrip side feed at the non-radiating edge. This matches the 50 ohm impedance at the input of the antenna.

3.2 Sonnetlite Plus

Sonnetlite Plus software provides solution on electromagnetic analysis at high frequencies. The input parameters to this software are dielectric constant, loss tangent and the substrate thickness. Due to the limited analysis capability, Sonnetlite Plus can analyse circuits up to 32 Mb memory. During the simulation work carried out, the full version software was unavailable. Therefore, the nearest approximation of the antenna dimensions, but not compromising on the accuracy, has to be employed.

4. Simulation Results and Discussion

The dimensions of the antenna has been rounded off to the nearest millimetre as 48 mm by 38 mm. A slight disagreement is expected between both simulation results. The antennas are designated by Rsn. From Micropatch and Sonnetlite Plus simulations, the Rsn antennas exhibit low return loss ($|S_{11}|$) at their corresponding frequency of operations. These indicate very well-matched impedance at the inputs. Micropatch simulations showed better match antennas at the input. This is due to the limited memory capability of the Sonnetlite Plus and an ideal environment is assumed. The –10 dB reflection bandwidths obtained are narrow. It is observed that the percentage bandwidth decreases with the corresponding frequency of operation. The simulated return losses are plotted in Fig. 2. The corresponding performance indices are given in Tables 2 and 3, respectively.

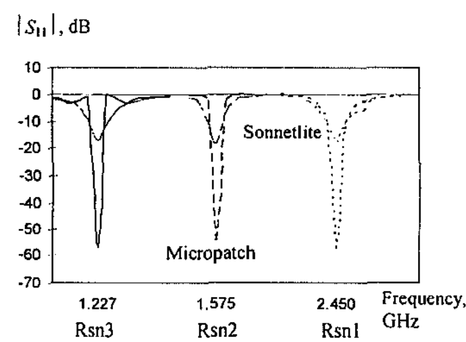

Figure 2 : Simulated return losses of Rsn antennas using Micropatch and Sonnetlite softwares.

Table 2 : Micropatch performance indices for the Rsn antennas.

Parameter	*Rsn1*	*Rsn2*	*Rsn3*
f_o, GHz	2.45	1.575	1.227
$\|S_{11}\|$, dB	-57.62	-54.47	-57.31
VSWR	1.0	1.0	1.0
Directivity, dB	6.85	5.63	5.30
Gain, dB	6.12	2.77	1.44
Efficiency, %	89	49	27
Bandwidth, %	4.08	0.64	0.58

Table 3 : Sonnetlite performance indices for the Rsn antennas.

Parameter	*Rsn1*	*Rsn2*	*Rsn3*
f_o, GHz	2.45	1.575	1.23
$\|S_{11}\|$, dB	-17.39	-18.42	-17.14
VSWR	1.12	1.12	1.13
Bandwidth, %	3.67	0.48	0.41

The simulated current distributions using Sonnetlite Plus software are shown in Fig. 3. The corresponding extraction across the antennas are plotted in Fig. 4.

All the antennas are observed to exhibit half-wavelength sinusoidal current distributions along the centre axial length. This is in good agreement with theory. Both the corresponding antennas have almost equal peaks, indicating equal radiation properties.

5. Experimental Investigations

The fabricated Rsn antennas are shown in Fig. 5, along with other corresponding patch antennas (feed at the radiating edge and coaxial feed from underneath the substrate). The adjacent antennas are not within the scope of this paper. Each Rsn antenna was measured separately for their one-port characteristics using a vector network analyser (VNA). The measured return losses are depicted in Fig. 6. The results are tabulated in Table 5. It can be inferred that the Rsn antennas are very well matched at their corresponding frequency of operations. A slight frequency shift is observed with the Rsn2 and Rsn3 antennas, probably due to fabrication tolerances. The reflection bandwidths decreases with frequency of operation. This is attributed to the difference in the substrate characteristics in terms of relative permittivity and thickness. The differences are within acceptable range.

6. Further Discussions

Equal-size radiating elements having rectangular shape operating at three different frequencies have been obtained using Mathcad software. A mathematical modelling formulation has been thus developed. The dimensions obtained are 48 mm by 37 mm. The radiating patches have different set of h and ε_r, in order to maintain the antenna dimensions for different operating frequencies. The highest operating antenna has the lowest ε_r but thickest substrate. The three radiating structures will be further tested by arranging them in a multilayer configuration.

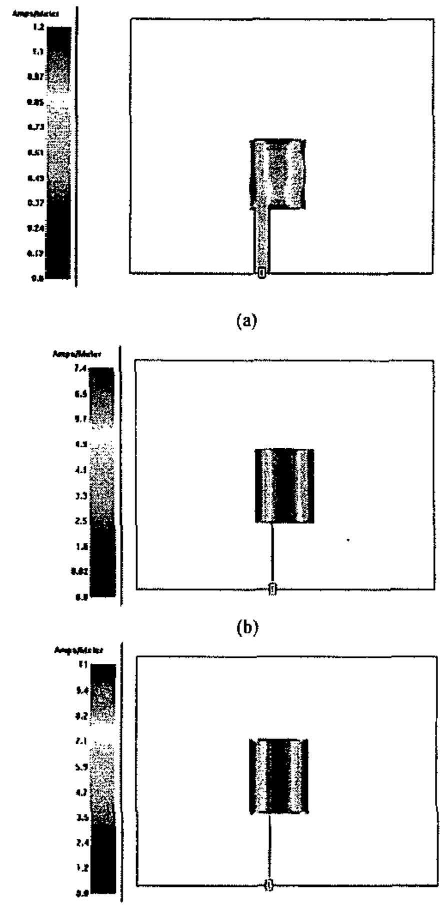

Figure 3 : Simulated current distribution using Sonnetlite software of (a) Rsn1 (b) Rsn2 (c) Rsn3 antennas.

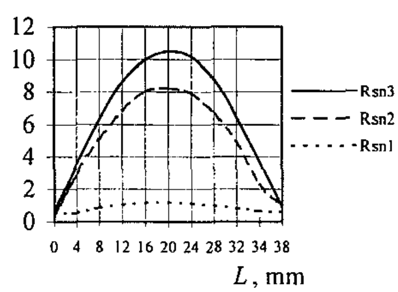

Figure 4 : Extraction of the simulated current distribution of the Rsn antennas using Sonnetlite software.

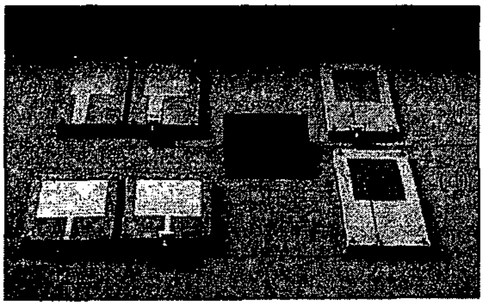

Figure 5 : (a) Identical Rsn antennas, (b) Coaxial feed rectangular antenna, (c) Rsn antenna operating at f_2, (d) Rsn antenna operating at f_3, (e) Corresponding antennas having side feed at the radiating edge.

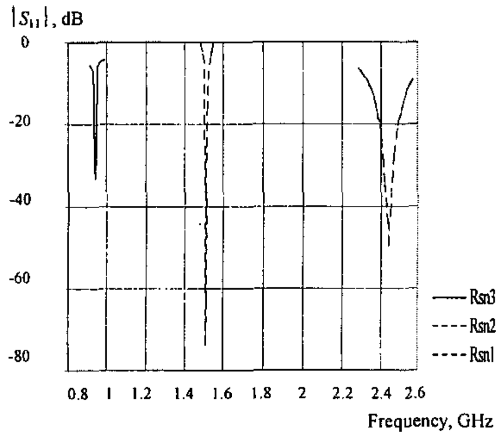

Figure 6 : Measured return loss responses of the Rsn antennas using VNA.

Table 4 : Simulated and measured return losses of Rsn antennas with corresponding resonance.

Parameter / Antenna	Return Loss, dB (Resonance, GHz)		
	M/Patch	*S/LiteP*	*VNA*
Rsn1	-57.61 (2.45)	-17.39 (2.45)	-25.02 (2.46)
Rsn2	-54.47 (1.575)	-18.42 (1.575)	-36.87 (1.525)
Rsn3	-57.31 (1.227)	-17.14 (1.227)	-16.56 (0.959)

Table 5 : Measured VSWR and corresponding percentage reflection bandwidth of the Rsn antennas at resonance.

Parameter / Antenna	Measured VSWR and percentage bandwidth	
	VSWR	*Bandwidth, %*
Rsn1	1.119	4.07
Rsn2	1.029	0.615
Rsn3	1.349	0.39

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