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Tri-band microstrip antenna design for wireless communication applications

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Abstract This paper introduces a novel rectangular tri-band patch antenna that is fabricated and measured for wireless communication systems. The introduced antenna is designed for WLAN and WiMAX applications.

The desired tri-band operation was obtained by proper loading for a rectangular patch antenna using slots and shorting pins. The optimal location and dimension for the loaded elements were obtained with the aid of interfacing a Genetic Algorithm (GA) model with an Ansoft High Frequency Structural Simulator (HFSS). The results obtained from our simulated antenna show 5.8% impedance matching band width at 2.4 GHz, 3.7% at 3.5 GHz and 1.57% at 5.7 GHz.

In addition, an equivalent circuit of the proposed antenna is introduced using the least square curve fitting optimization technique.

1. Introduction

There is a growing demand for a multiband terminal antenna that is capable of receiving multiple services introduced by different wireless technology networks. These networks include Bluetooth, which operates at the ISM band 2.4 GHz, WiMAX, which operates at 3.5 GHz, and WLAN which allocates 2.4 and 5.7 GHz for its applications.

The multiband antenna was dedicated by many publications, most designs for multi band planar antenna is for dual-band operation (Wong, 2002; Chen et al., 2003; Yang et al., 2003; Kundukulam et al., 2001; Lin et al., 2004; Pan et al., 2006; Ting-Ming, 2008; Ansari et al., 2008; Mishra et al., 2009) some of them dedicate dual band for mobile applications (Wong, 2002; Chen et al., 2003; Yang et al., 2003), others dedicate dual band for wireless network applications (Lin et al., 2004; Pan et al., 2006; Ting-Ming, 2008; Ansari et al., 2008; Mishra et al., 2009), antennas discussed in Cap et al. (2005) were designed for mobile application and Bluetooth band 2.4 GHz. Fewer efforts aim at a tri-band planar antenna

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for wireless communication network applications (Paitoon et al., 2009; AbuTarboush et al., 2009; Tawk et al., 2008).

Some of dual band antennas that were introduced in technical literature (Wong, 2002) use shorting-pin to control tunable frequency ratio.

A proper selection of the patch parameters (length, thickness, shape, feed point position and method) and shorting-pin position will excite desired bands. Shorting pins change the field distribution and provides inductive loading to the patch and hence changes its resonance frequency. Other publications such as (Kundukulam et al., 2001; Mishra et al., 2009) discuss adding a reactive load introduced by cutting slots or notch parallel to radiating edges in order to alter the equivalent circuit of the loaded patch, and hence adjust the dual frequency operation. In (Cap et al., 2005), four different multiband patch antennas were obtained by etching different slot shapes that affect resonant frequencies.

Analyzing microstrip antennas can be done using three models: transmission-line model, cavity model, and full-wave model (the most accurate model). Our initial design procedure used both transmission-line model and cavity model. Next, this design was fine-tuned by the full-wave model using Ansoft High Frequency Structural Simulator (HFSS) version 10 http://www.ansys.com/Products/Simulation+Technology/Electromagnetics/High-Performance+Electronic+Design/ANSYS+HFSS. Initially, we adjust patch dimension and feed position for fundamental resonance frequency then adding reactive loads to affect other resonance modes is done with the aid of HFSS simulator.

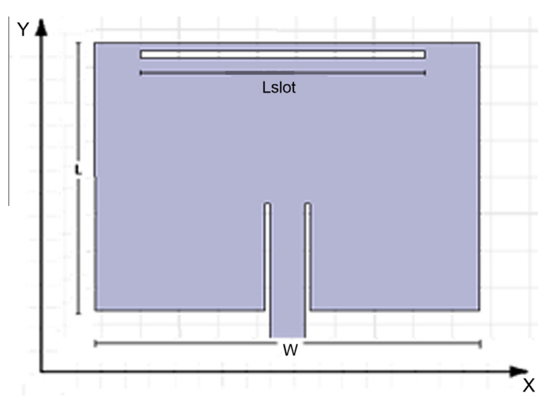

Fig. 1 Rectangular microstrip slotted antenna.

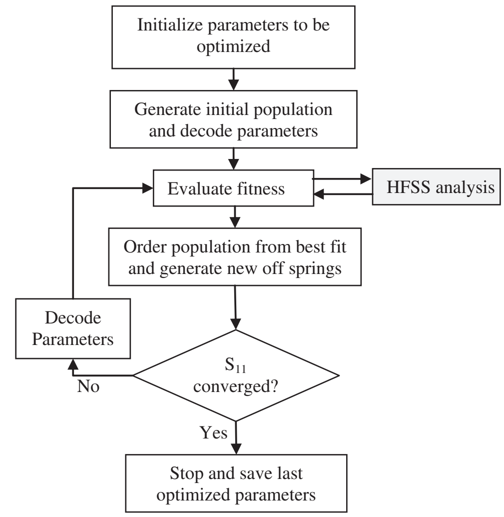

Fig. 3 Framework of genetic search with HFSS.

2. The structure of reactive loaded patch

Initially, we used transmission line model equations listed in Constantine and Balanis, 2005 to design the fundamental resonant frequency, 2.4 GHz, with: (1) patch dimension $L \times W \times H$, (2) Rogers RT/duroid 5880™ dielectric material with $\varepsilon_r = 2.2$ for substrate, and (3) 50 Ω microstrip line feed. We also added a slot near radiating edge to enhance impedance matching at the fundamental resonance frequency. The added slot resulted in a reduced patch length with $L = 3.635$ cm, $W = 4.941$ cm, $H = 0.1588$ cm and slot length $L_{slot} = 3.63$ cm with 0.1 cm width (Fig. 1).

The return loss (S_{11}) of the previous design is shown in Fig. 2. The resulted excited modes appeared at $TM_{01} = 2.4$ GHz, $TM_{20} = 3.9$ GHz, $TM_{02} = 4.7$ GHz and $TM_{12} = 5.2$ GHz. These results were obtained using HFSS simulator.

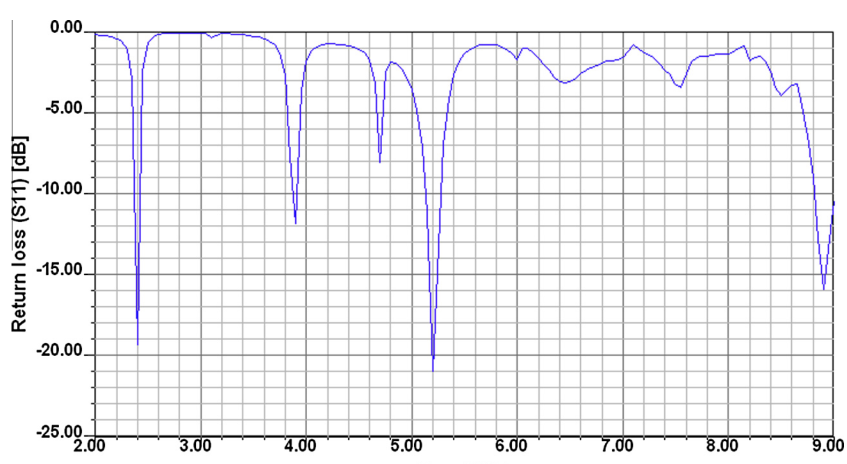

Fig. 2 Simulated return loss for the slotted antenna.

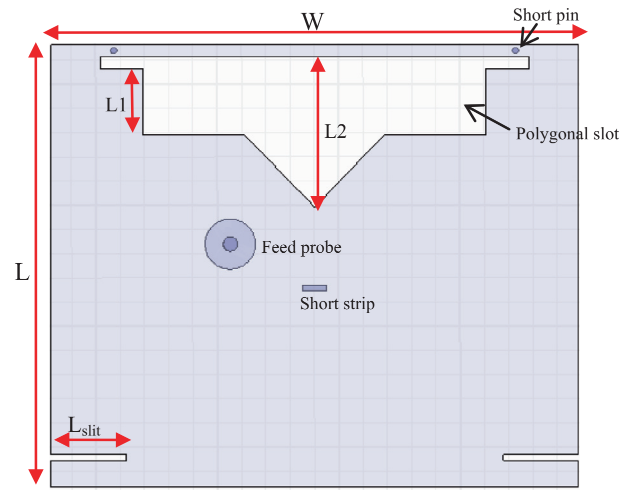

Fig. 4 Rectangular patch antenna with reactive loads.

Table 1 Antenna dimension in (mm).

Patch dimension $L \times W \times H$	36.56 × 43.42 × 1.588	
Slit dimension Lslit × thick	6.2 × 0.5	
Polygon slot dimension	L1	5.5
	L2	12.43
Short strip dimension	1.98 × .5 × 1.588	
Feed position from left corner	(15,20)	

The above excited modes are different from the ones that are commonly used for WiMAX and WLAN applications. In the next section, we show how impedance matching for the above excited resonance modes can be adjusted by adding reactive loads to the antenna structure.

3. Genetic algorithm and HFSS simulation

Adding reactive loads to patch antenna will change surface current distribution which ultimately changes the excited resonance modes.

The proper shapes and locations of the reactive loads that we added to the antenna structure were obtained in two phases.

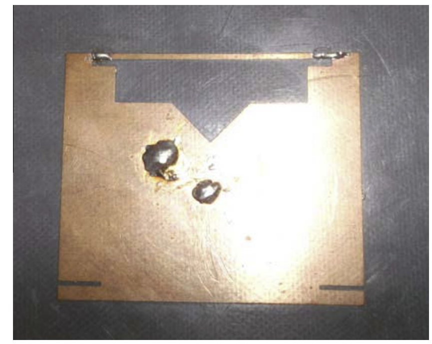

Fig. 6 Designed antenna.

Table 2 Equivalent circuit parameters.

L (nH)	1.275	$Q_{0,4}$	35.068
$Q_{0,1}$	32.353	$R_{0,4}$ (Ω)	81.674
$R_{0,1}$ (Ω)	53.388	$Q_{0,5}$	36.889
$Q_{0,2}$	20.331	$R_{0,5}$ (Ω)	202.109
$R_{0,2}$ (Ω)	58.169	$Q_{0,6}$	24.301
$Q_{0,3}$	64.582	$R_{0,6}$ (Ω)	138.131
$R_{0,3}$ (Ω)	41.957		

In the first phase, we started by manually changing the shapes and positions of the slot, short strip, shorting pins, and slits (Fig. 4). We did a manual extensive search in order to approach near desired frequencies. Several geometry combinations of reactive loads were analyzed using a full wave electromagnetic solver HFSS.

However, it was difficult to manually find the exact desired frequencies. Therefore, in the second phase of our approach we used an optimization tool, namely Genetic Algorithm (GA) Randy et al., 2004, in order to find the desired frequencies.

Genetic algorithm is an optimization technique that keeps most fit solutions to an optimization problem. This is done by converting optimized parameters to genes; these genes form the candidate solutions (chromosomes) to the optimization problem. GA evaluates the fitness of the solutions and keeps ones that most fit, these solutions form new genes using certain criteria, chromosomes made by new genes are to be evaluated

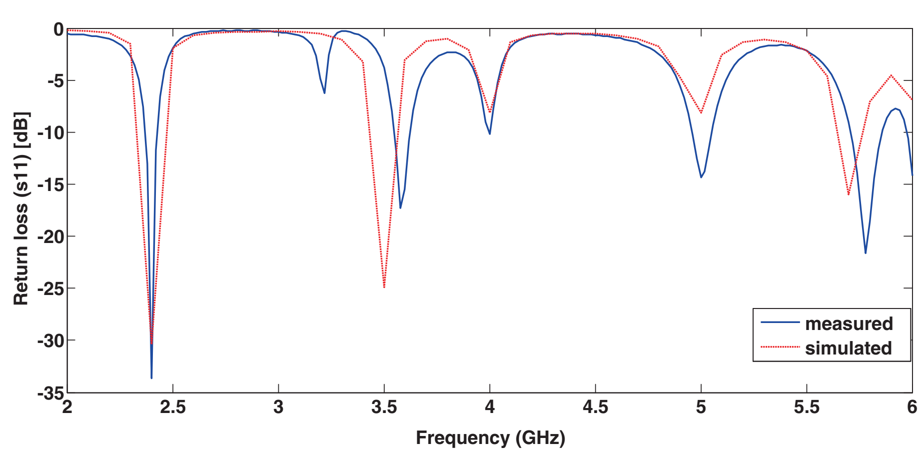

Fig. 5 Measured and simulated return loss.

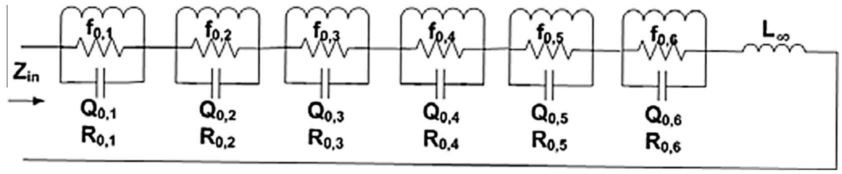

Fig. 7 Topology of equivalent circuit.

to keep most fitted genes, the search process continues forming new generations until the terminating goal is met. Evaluating each chromosome requires HFSS to analyze the antenna with the parameters suggested by the genes; the results are then used by GA to compute the cost. Fig. 3 shows a framework of GA and HFSS interaction. Pairing, mating and mutation are all included in the new offsprings generation.

GA main program is done by MATLAB and a visual basic (VB) script is written to operate HFSS from MATLAB.

In our approach, we used the GA to optimize the following parameters in our antenna design: position of the feed probe, length and position of the slits, length and position of the short strip, shape of the polygonal slot, position of shorting pins, and length and width of the patch antenna with minimum changes from its original dimensions listed in Section 1.

During the application of the GA algorithm, twenty chromosomes in each generation are evaluated, cost is computed for each individual as the sum of return losses at desired frequencies (Eq. (1)), and the fitness is to minimize the cost:

$$\text{Cost} = \sum\nolimits_{i=1}^{3} S_{11}(f_i) \quad (1)$$

where S_{11} is the return loss, f_i is the ith desired resonance frequency.

Mutation rate is selected to be 5%, pairing chromosomes is done using cost weighting.

The resultant antenna with optimized parameter is depicted at Fig. 4 and its parameters are listed at Table 1.

4. Fabrication and results

The antenna was fabricated and measured at the Microstrip Department of Electronics Research Institute. In the fabrication process, we first applied photolithographic process then we added the short strip and short pin to the antenna. There was difficulty in having precise shorts without air within it. This caused the final measured results to deviate by 0.08 GHz from the simulated results (Fig. 5).

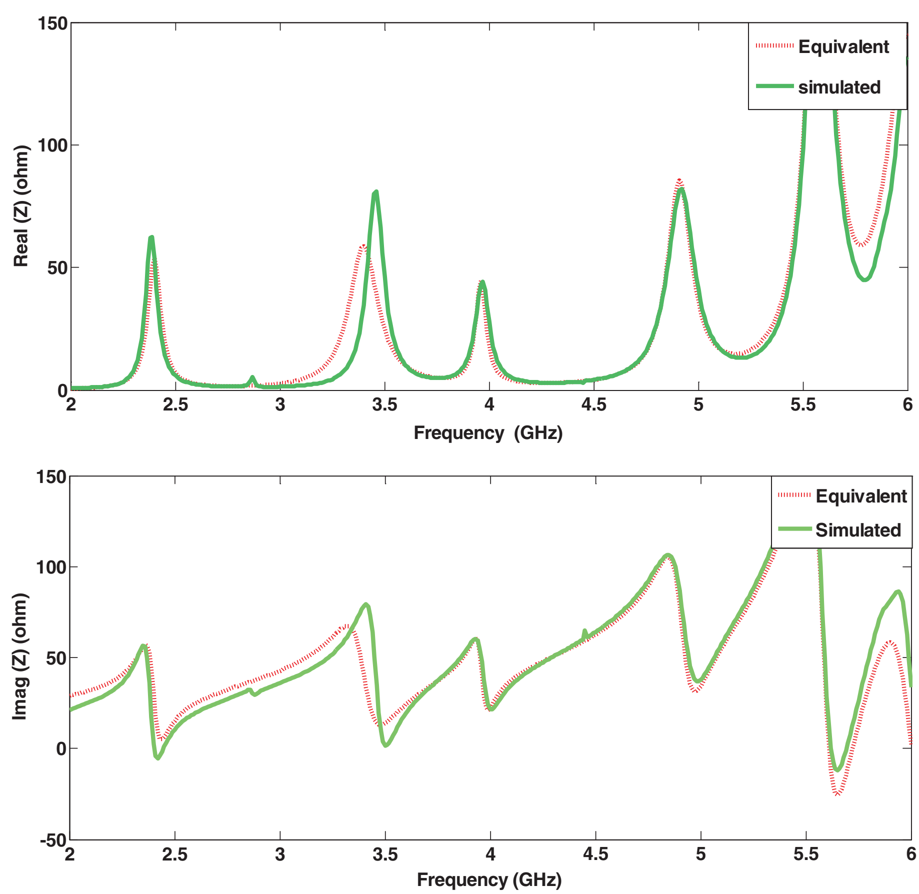

Fig. 8 Equivalent and simulated input impedance real and imaginary parts.

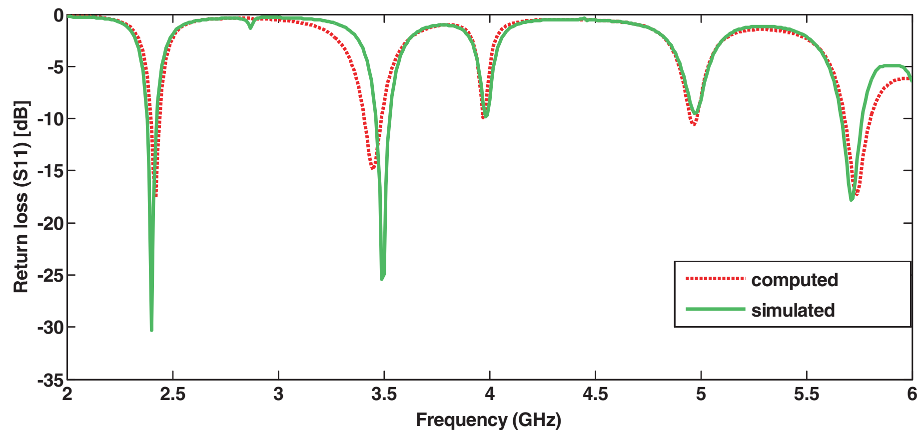

Fig. 9 Simulated and equivalent circuit S_{11}.

A photo of our antenna prototype is shown in Fig. 6 and dimensions of antenna are listed in Table 1.

5. Lumped elements equivalent circuit

This section presents a sample electric circuit that is equivalent to our fabricated antenna. The presented wideband lumped equivalent circuit is necessary when analyzing any electronic circuit that includes our antenna.

According to the cavity model (Garg et al., 2001), the input impedance of a microstrip antenna can be computed by considering the electromagnetic fields between the patch antenna and the ground plane. This can be expanded in term of a series of cavity resonant modes; each radiating mode can be represented by a general parallel resonant RLC circuit as shown in Fig. 7 with an equivalent input impedance of:

$$Z_{\text{eq}}(f) = j\,2\pi f L_{\infty} + \sum_{i=1}^{M} \frac{R_{o,i}}{1+jQ_{o,i}\left(\frac{f}{f_{o-i}} - \frac{f_{o-i}}{f}\right)} \tag{2}$$

where Z_{eq} is the input impedance of the equivalent circuit at feed point of the antenna, L_{∞} is feed point impedance at higher frequency bands, M is the number of radiating resonance at the operating band, and $f_{o,i}$, $Q_{o,i}$ and $R_{o,i}$ are the resonance frequency, Q-factor and radiation resistance of the ith radiating mode, respectively

Computing the equivalent circuit parameters over a wideband is done using the optimization technique discussed in Ansarizadeh and Ghorbani, 2008, which uses least square curve fitting to match the equivalent input impedance with the one obtained from the HFSS simulator. The parameter values are listed in Table 2, and the results from the fitting process are shown in Figs. 8 and 9.

6. Conclusion

A novel planar antenna structure was proposed with slots and shorting elements to control surface current distribution on the patch antenna to achieve multi-band operation. We first studied the effect of the reactive loads on the excited modes, and then we applied a genetic search to precisely adjust the antenna parameters. Experimental measurement to our optimized antenna shows a good matching between the experimental results and the simulated results. A broadband equivalent circuit model was introduced and a good agreement of input impedance between electromagnetic simulator and modeled equivalent circuit was realized.

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