Paper - A Design of Compact Radial Line Slot Array (RLSA) Antennasfor Wi-Fi Market Needs

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A Design of Compact Radial Line Slot Array (RLSA) Antennas for Wi-Fi Market Needs

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Abstract—This paper proposes a compact Radial Line Slot Array (RLSA) antenna for 5.8 GHz Wi-Fi devices, which meets market needs. Various small RLSA antenna models with radius of 140 mm, were designed using extreme beamsquint technique. The models then were simulated to result in a best model. A prototype of the best model was then fabricated and measured to verify the simulation. The measured parameters are: a gain of 18 dBi, bandwidth of 1 GHz, beamwidth of 20°, and mainlobe to sidelobe ratio of 15 dB, which meet antenna specifications for market needs. The prototype was tested as an antenna for a Wireless Fidelity (Wi-Fi) device in order to show its performance. The test showed that the prototype worked properly. Lastly, we compared the size of the prototype with the average size of various antennas available in markets. We found that the prototype had the advantage of small size and flat, with similar performance.

1. INTRODUCTION

Initially, RLSA antennas were developed for satellite signal reception antennas with diameter of not less than 600 mm [1–3]. Due to the advantages of RLSA antennas, such as high gain, flat and high efficiency [2–4], RLSA antennas were also developed for other applications, such as for Wi-Fi [5–14]. In contrast to satellite applications, Wi-Fi needs much smaller antennas. However, the design of small RLSA antennas was not easy since small size RLSA antennas normally had high reflection coefficient [14–16].

Several papers introduced several designs of RLSA antennas for Wi-Fi applications. In 2004, Imran introduced a 5.8 GHz RLSA antenna with gain of 26 dBi and successfully used it as an antenna for point to point links [17–19]. However, this design utilized a beamsquint technique similar to a technique used to design RLSA antennas for satellite applications. Hence, the diameter of this antenna is still considered large with diameter of 650 mm, so that it is not applicable to small Wi-Fi devices.

In 2008, Islam developed RLSA antennas using materials of a Flame Retardant (FR4) board [20, 21]. The antennas were designed by still using the beamsquint technique same as the technique used to design RLSA antennas for a satellite. This antenna was quite small with a diameter of 150 mm since it was designed using small slots. However, there are some drawbacks in designing this antenna, such as a design of overlap slots, a loss cavity due to the use of several FR4 boards, and the use of loss material of FR4. These all lead to low gain (only 8 dB) and low bandwidth (75 MGHz).

Purnamirza and Rahman, in 2012, introduced a design of RLSA antennas using a 3-layer cavity, which are one polypropelene layer and two FR4 layers [13]. This design has successfully reduced the problem of high reflection coefficient in small RLSA antennas. However, this design has a weakness of complex fabrication process since it consists of three layers. As far as the authors' knowledge, since

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2012, there have been no other efforts to bring RLSA antennas as a potential antenna for Wi-Fi point to point applications. Some researches after year of 2012 only discuss the theory of RLSA antenna [22–24].

In year of 2013, we introduced a new simple technique called extreme beamsquint technique to design high performance small RLSA antennas [14]. This technique is quite interesting compared to other previous techniques developed for RLSA antennas since it can obtain small antennas with high gain, wide bandwidth and low reflection coefficient. As a continuation, in this paper, using this technique, we try to realize a small RLSA antenna as a potential antenna that meets market needs for Wi-Fi point to point applications. Our work was started by finding the specification of antennas used by point to point Wi-Fi devices usually available in markets, including gain, beamwidth, and bandwidth. Based on the specifications, we then designed and fabricated a small RLSA antenna using the extreme beamsquint technique. The fabricated antenna was measured and tested. Lastly, to show the advantage of the small RLSA antenna, we compared the size of the RLSA antenna with the average size of various antennas available in market. We found that the designed RLSA antenna has the advantage of small size and flat, with the performance comparable to other types of available antennas in markets.

2. SPECIFICATIONS OF DESIGNED RLSA ANTENNAS

In this research, information about the specifications of various antennas used in point to point Wi-Fi devices usually available in markets is collected and analyzed. The average values of the specifications are shown in Table 1 below. Based on these values, RLSA antenna models are designed as explained in Section 4.

Table 1. Average values of the specification of various antennas for 5.8 GHz point to point links that available in markets.

Gain (dBi)	Beamwidth (Degree)	Bandwidth (MHz)
14–18	±25	150–200

3. STRUCTURE AND PARAMETERS OF DESIGNED RLSA ANTENNAS

In this research, the structure of designed RLSA antennas consists of a copper radiating element, a copper background element, a polypropylene cavity, and a Sub-miniature version A (SMA) feeder, as shown in Figure 1. The SMA feeder is an ordinary SMA feeder available in market, modified by adding a copper head, as shown in Figure 1(b). The head serves to transform Transverse Electric Mode (TEM) coaxial mode signal within coaxial cable into TEM cavity mode signal within the cavity structure, so that the signal from the feeder will propagate in radial directions within the cavity of the antenna. Table 2 and Table 3 show design parameters of the designed RLSA antenna and the feeder.

4. STEPS OF ANTENNA DESIGN

In this research, using the parameters listed in Table 2 and Table 3, various RLSA antenna models are designed using following steps:

a. Develop a computer program: Every single RLSA antenna has about 130 slots, which is unique in positions and tilts. Therefore, in order to ease and fasten the calculation of slots position and the drawing time of slots, we develop a Visual Basic Application (VBA) macro program that functions to calculate the slots positions and draw them automatically in accurate positions.

b. Parameterization: In order to obtain an antenna which meets the specification listed in Table 1, we carry out a parameterization by varying two design parameters: beamsquint angle (Φ varies from $60°$ to $89°$) and the number of slot pairs in first ring (n varies from 12 to 16). Hence, we develop about 100 RLSA antenna models for each value of Φ and n.

c. Simulations: We simulate the 100 antenna models using CST STUDIO SUITE^{TM} Software and obtain a best antenna model.

d. Fabrication: The best antenna model is then fabricated to yield a prototype.

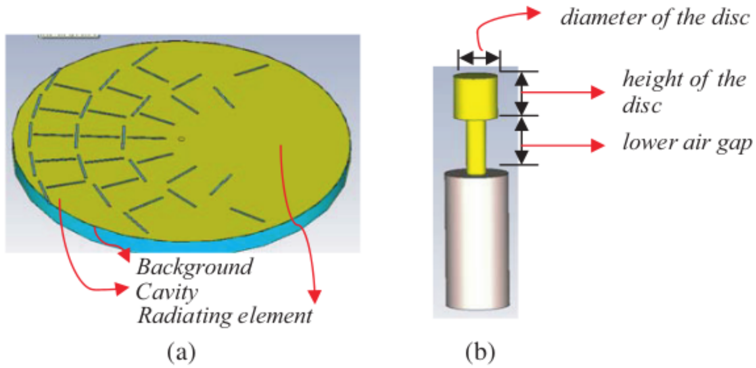


Figure 1. (a) Structure of RLSA antennas. (b) Structure of antenna feeders [13, 14].

Table 2. Design parameters of the RLSA antenna [13, 14].

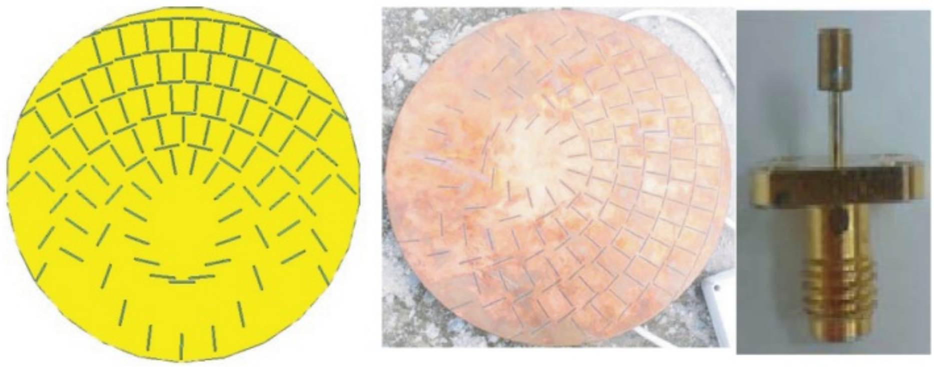
Specification Parameters	Symbols	Values
Centre frequency	f	*5.8 GHz*
Beamsquint angle	Φ	*Vary from 60° to 89°*
Wavelength inside the cavity	λ_g	*33.88 mm*
Slot length	l	$0.5\lambda_g$
Slot width	w	*1 mm*
Radius of antenna	r	*140 mm*
Number of slot pair in first ring	n	*Vary from 12 to 16*
Cavity thickness	d_1	*8 mm*
The thickness of radiating element and background	d	*0.05 mm*
The permittivity of cavity	ε_{r1}	2.33
Cavity material	*Polypropylene*	
The material of radiating element and the background	*copper*	

Table 3. Design parameters of feeder [13, 14].

Specification Parameters	Symbol	Values
The height of disc	h	*3 mm*
The radius of disc	r_a	*1.4 mm*
The lower air gap	b_1	*4 mm*
The upper air gap	b_2	*1 mm*
The material of the disc	*Copper*	
The type of the feeder	*SMA Feeder*	

5. RESULTS AND DISCUSSIONS

The simulation of 100 RLSA antenna models obtains the best antenna model that meets the specification shown in Table 1. Moreover, the best antenna model also has a best performance in term of gain, bandwidth, and S_{11}, compared to other 99 models. This best model has parameter of $\Phi = 78°$ and $n = 14$. The design of slots configuration is shown in Figure 2(a). The best model and its feeder are then fabricated, and their prototypes are shown in Figures 2(b) and 2(c).



(a) (b) (c)

Figure 2. (a) Design of RLSA antenna model. (b) Fabricated antenna model. (c) Fabricated Fedeer.

The prototype antenna was measured in an Anechoic Chamber to get its radiation pattern, beamwidth, ratio of mainlobe to sidelobe, and gain. The S_{11} was obtained by measuring the prototype antenna using a Network analyzer.

Figure 3 shows the measured and simulated S_{11} of the prototype antenna. From this figure, it can be observed that the prototype antenna has a bandwidth about 1 GHz at the centre frequency around 5.8 GHz. This bandwidth is more than enough for Wi-Fi signal which typically needs bandwidth only around 150 MHz.

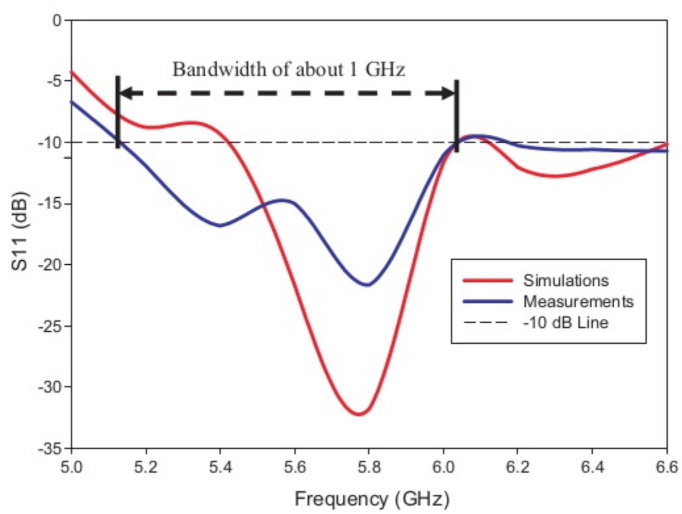


Figure 3. Measured and simulated S_{11} of the RLSA antenna.

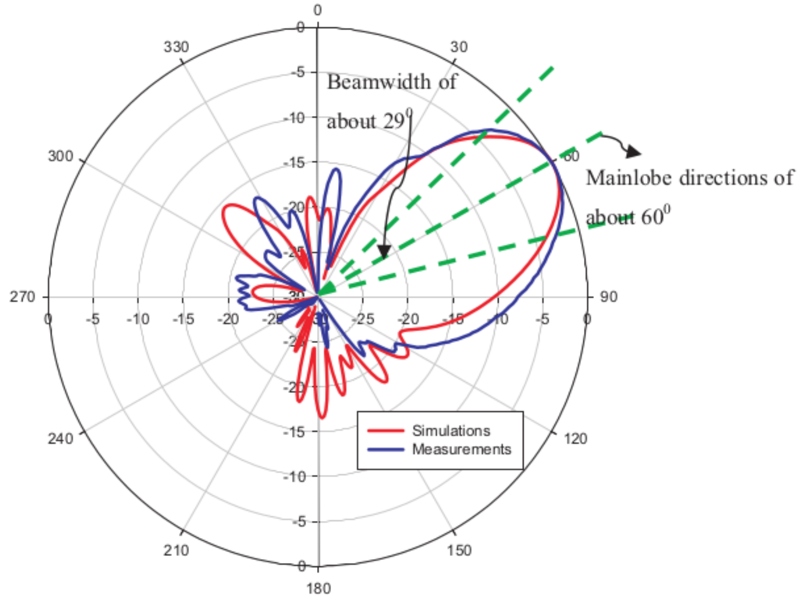


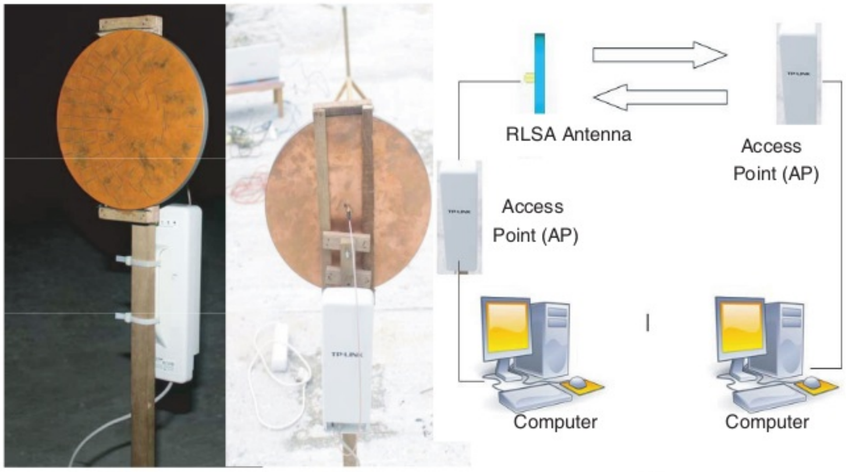
Figure 4. Measurement and simulation result of radiation pattern.

Figure 4 shows the measured and simulated radiation patterns of the prototype antenna. From this figure, it can be observed that the antenna has a beamwidth of 29° and mainlobe direction of about 60°. Other measured performance parameters of the antenna are listed in Table 4. Based on the values of gain, bandwidth and beamwidth, which are 18.4 dBi, 1 GHz, and 29°, respectively, it can be concluded that the performance of the RLSA antenna meets the need of market specification performance as listed in Table 1.

Table 4. Performance parameters.

Performance Parameters	**Values**
Gain	18.4 dBi
3 dB Bandwidth	±1 GHz
3 dB Beamwidth	29°
Mainlobe to Sidelobe Ratio	about 16 dB
Mainlobe directions	60° from boresight direction
Efficiency	−0.123 dB

From Figure 3 and Figure 4, it can be observed that the simulation result shows a comparable reading to the measurement result. The difference between them is due to the imperfections during the fabrication process of the antenna model. The causes of imperfections are as follows. Firstly, the radiating element, cavity and background are separated elements, so when they were combined during the fabrication process, there was a slight shift from the correct position. Secondly, the permittivity of the cavity is slightly increased due to the use of glue to stick the radiating element and the background to the cavity. Thirdly, there is an imperfection in soldering the head disc at the SMA feeder at the correct position.



(a) (b) (c)

Figure 5. (a) Transmitter (front view). (b) Transmitter (back view). (c) Testbed System.

In order to test the performance of the antenna in real conditions, we have built a testbed system as shown in Figure 5(c). The testbed consists of two 5.8 GHz radio Access Point (AP) as transceivers, the RLSA antenna connected to one of the transceivers, a microstrip AP antenna connected to the other transceiver, and two computers connected to the two APs.

There are two scenarios of the test. Firstly, one transceiver is connected to the RLSA antenna, and the other transceiver is connected to the microstrip antenna. Secondly, we use two microstrip AP antennas, and each is connected to one transceiver.

In the first and second scenarios, we send an amount of data from one transceiver to the other, thus measure the transfer data rate for about ten times. From this test, the averagely measured data rate for the first scenario is about two times higher than the data rate for the second scenario. This higher rate of the first scenario is due to the wider bandwidth and higher gain of the RLSA antenna than the bandwidth of the embedded microstrip AP antenna.

To show the advantage of RLSA antenna, we compare the size of prototype and the size of various antennas available in markets. We find that our RLSA prototype is attractive due to its flat shape, whereas the other antennas usually have the shape of convex (like parabolic or grid). So, in term of volume, the RLSA prototype is smaller than other antennas with averagely same performance. The only flat antenna available in market is microstrip antenna. However, microstrip antennas have weakness of low efficiency and low gain.

6. CONCLUSIONS

A new small 5.8 GHz RLSA antenna for Wi-Fi point to point devices is designed and fabricated. The simulation, measurement, and test results show that this antenna is able to perform at industrial specification. We also find that this antenna is attractive compared to other types of antennas due to its flat shape and small size.

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