

Paper - Small Radial Line Slot Array (RLSA) Antennas for Wi-Fi 5.8 GHz Devices

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Small Radial Line Slot Array (RLSA) Antennas for Wi-Fi 5.8 GHz Devices

Teddy Purnamirza¹, Imran M. Ibrahim², Puji Prowadi¹, Fitri Amillia¹

Abstract – This paper presents a brief review of the development of small radial line slot array (RLSA) antennas for Wi-Fi devices. Based on the review, we concluded that some of the RLSA antennas designed and implemented on Wi-Fi devices are not optimal. Hence, this study aimed to design a small RLSA antenna for point-to-point 5.8 GHz Wi-Fi devices with an optimum design using a previously developed technique known as the extreme beamsquint technique. We used this technique to design and simulate 50 small RLSA antenna models, and then we fabricated the best model. We measured the performance of the fabricated prototype to verify the simulation results. The following measurement results were obtained: a gain of 17.28 dBi, a bandwidth of 1 GHz, a beamwidth of 30°, and a mainlobe-to-sidelobe ratio of 10 dB. These results meet the required antenna specifications for Wi-Fi devices. Moreover, the prototype was successfully tested as an antenna for a Wi-Fi device. Copyright © 2017 Praise Worthy Prize S.r.l. - All rights reserved.

Keywords: RLSA, Extreme Beamsquint Technique, Wi-Fi Devices, Small Antennas

I. Introduction

Radial line slot array (RLSA) antennas were first developed for satellite communications, but they have a diameter of about 650 mm [1]-[3]. Because RLSA antennas have a flat array and high efficiency [2]-[4], researchers have tried to use them in Wi-Fi devices [5]-[14]. It is well known that antennas for Wi-Fi devices are much smaller than antennas for satellites [31]-[33]. A problem was identified when researchers realized that small RLSA antennas have a high reflection coefficient due to an insufficient number of slots [14]-[16].

Small RLSA antennas were initially developed by Hirokawa [15]. Hirokawa used the matching slot pair technique to reduce the remaining power at the perimeter of small RLSA antennas in order to minimize the reflection coefficient. Akiyama also used the same technique [17], [18]. However, based on our observation, the matching slot pair technique is only used to radiate the remaining power at the antenna perimeter; it does not contribute to antenna gain.

Zagriatski used long slots to increase the ability of the slots to radiate power in order to reduce the remaining power at the perimeter of small RLSA antennas and, thus, reduce the reflection coefficient [11]. However, based on our observation, while this method can reduce the reflection coefficient, it can also decrease the antenna gain because long slots cannot radiate the focused power.

Imran introduced a 5.8 GHz RLSA antenna with a gain of 26 dBi and successfully used it as an antenna for point-to-point links [19]-[21]. This design utilized the beamsquint technique, which is the same technique used to design RLSA antennas for satellite applications.

Hence, the 650 mm diameter of this antenna is still too

large to be applicable for small Wi-Fi devices.

Several other researchers have reported on the design of small RLSA antennas using FR4 materials [22], [23].

However, the antennas in those studies were not designed correctly; they had overlap slots and a cavity of antennas that consisted of several FR4 layers stuck together using glue, and they used high loss materials such as FR4. These mistakes resulted in low gain and high reflection coefficients.

Purnamirza reported on a small three-layer RLSA antenna, which consists of a polypropylene layer and two FR4 layers [13]. Although this antenna used affordable FR4 material, the fabrication was more complex because the three layers need to be aligned accurately.

Based on our knowledge, since 2012 no studies have reported on using small RLSA antennas for Wi-Fi point-to-point applications. Several papers that were published after 2012 only discussed the theory of RLSA antennas [24]-[30].

In 2012, we presented a simple technique (extreme beamsquint) that effectively reduces the reflection coefficient of small RLSA antennas [14]. As a continuation of that study, the present paper reports on using the simple technique we developed, which is an RLSA antenna that has the potential to be suitable for use in Wi-Fi devices. The development of this antenna began by studying the antenna specifications used by point-to-point Wi-Fi devices, including gain, beamwidth, and bandwidth, as detailed in Section II. Based on these specifications, we designed and fabricated an RLSA antenna using the extreme beamsquint technique. We then measured the fabricated antenna and tested its use in Wi-Fi devices.

II. Specifications of the Designed RLSA Antennas

Since our aim was to design RLSA antennas for Wi-Fi devices, to obtain the correct specifications for our proposed antenna, we identified specifications for a variety of Wi-Fi antennas that are currently available in the marketplace, including microstrip antennas, dish antennas, and grid antennas. We then averaged all the specification values and categorized them into three groups, as shown in Table I.

We chose the specifications for Group 3 (the highlighted row in Table I) as the specifications for our proposed RLSA antenna because this group had the best overall specifications.

TABLE I
AVERAGE VALUES OF THE SPECIFICATIONS

Group	Gain (dBi)	Beamwidth (Degree)	Bandwidth (MHz)	Dimensions (mm ²)
1	7-9	30-40	700	12,125
2	12-15	10-30	750	41,040
3	16-18	7-15	700	63,700

Table II and Table III show the design parameters of the RLSA antenna and the feeder developed in the present study. Some of the parameters are fixed values; and the optimum values were obtained from our previous studies [13], [14]. Some of the other parameters, such as the beamsquint angle (ϕ) and the number of slots (n), were varied in order to obtain the best antenna model.

TABLE II
DESIGN PARAMETERS OF THE RLSA ANTENNA [13], [14]

Specification Parameters	Symbols	Values
Center frequency	f	5.8 GHz
Beamsquint angle	ϕ	Varies from 60° to 89°
Wavelength inside the cavity	λ_g	33.88 mm
Slot length	l	0.5 λ_g
Slot width	w	1 mm
Radius of the antenna	r	115 mm
Number of slot pairs in the first ring	n	Varies from 12 to 16
Cavity thickness	d_1	8 mm
Thickness of the radiating element and background	d	0.08 mm
The permittivity of the cavity	ϵ_{r1}	2.33
Cavity material		Polypropylene
Material of the radiating element and background		Copper

TABLE III
DESIGN PARAMETERS OF THE FEEDER [13], [14]

Specs Parameters	Symbols	Values
Height of the disc	H	3 mm
Radius of the disc	r_a	1.4 mm
Lower air gap	b_1	4 mm
Upper air gap	b_2	1 mm
Material of the disc		Copper
Type of feeder		SMA Feeder

Since it is difficult to draw the RLSA antenna slots manually using simulation software, we developed a program using Visual Basic for Applications (VBA) that enabled us to draw the slots automatically. Thus, the drawing process and the simulation could be faster and more accurate.

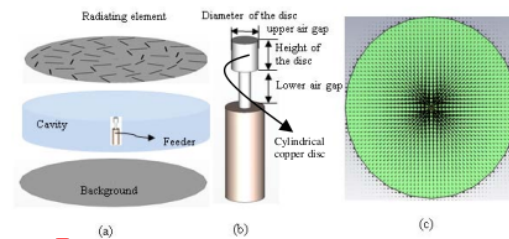
In order to identify the best antenna model, we designed 50 models with different beamsquint angles (ϕ) and a different number of slot pairs in the first ring (n).

The beamsquint angles varied from 60° to 89°; the number of slot pairs in the first ring varied from 12 to 16 (Table II).

III. Structure of the Designed RLSA Antennas

Figs. 1 show the structure of the 50 antenna models. It consists of a radiating element made of copper, a cavity made of polypropylene, a background element made of copper, and a feeder.

Copper was chosen as the radiating element and the background because it has good conductivity and it is affordable. Polypropylene was chosen as the dielectric material (cavity material) because it is very affordable and it has been successfully used in many previous studies [1], [10], [11], [13], [14].



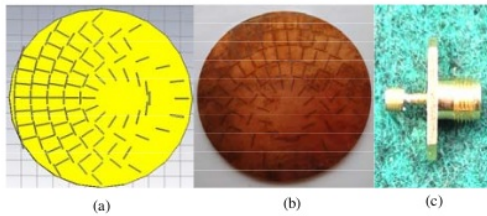
Figs. 1. (a) Structure of the RLSA antenna, (b) structure of the antenna feeder, (c) radially propagating power within the cavity

The feeder is an SMA feeder that was modified by adding a cylindrical copper disc with a height of 3 mm, as shown in Fig. 1(b). This head functions to convert the TEM coaxial mode into the TEM cavity mode, so the electromagnetic waves will propagate in radial directions within the cavity, as shown in Fig. 1(c). The design parameters of the feeder are presented in Table III. These specifications are the best ones obtained from previous studies [13], [14].

IV. Results and Discussion

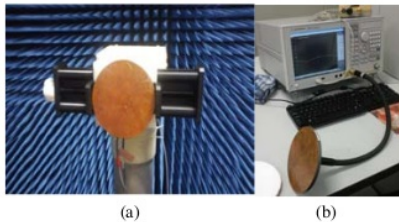
The 50 antenna models (see Section II) were simulated, and the best model was selected and fabricated.

The best antenna model has a beamsquint angle (ϕ) of 70° and 14 slot pairs in the first ring (n). Images of the best antenna model, the fabricated antenna model, and the fabricated feeder are shown in Figs. 2.



Figs. 2. (a) Best model, (b) fabricated model, (c) fabricated feeder

The radiation pattern, S_{11} , and the gain of the fabricated model were measured using an anechoic chamber and a network analyzer. The results are shown in Figs. 3.



Figs. 3. (a) Measurements in an anechoic chamber, (b) measurements using a network analyzer

Fig. 4 shows the response of S_{11} for both the measurements and the simulations. As seen, the antenna has a good S_{11} response and a wide bandwidth around 1 GHz, which is more than enough for Wi-Fi communications. Moreover, the extreme beamsquint technique implemented in this design successfully reduced the reflection coefficient in comparison to other techniques presented in previous studies [17]-[23].

Fig. 5 shows the measured and simulated radiation pattern of the prototype antenna. As seen, the antenna has a beamwidth of 30° . The mainlobe direction is 65° squinted from the boresight direction in the elevation direction.

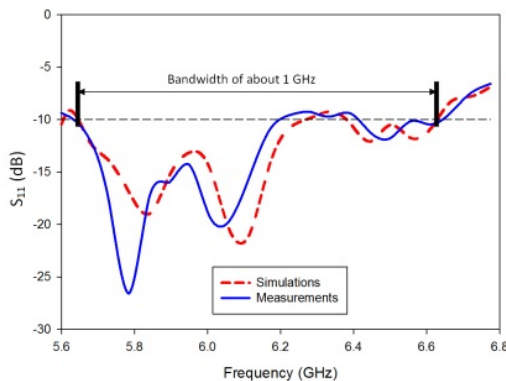


Fig. 4. Measured and simulated S_{11}

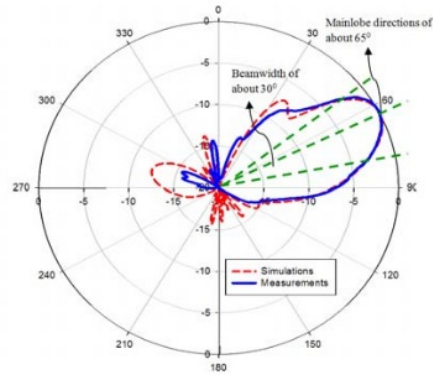


Fig. 5. Measured and simulated radiation pattern

The antenna gain (G) was obtained by measuring and comparing the received signal of the antenna ($P_{r,RLSA}$) to the received signal of a reference patch antenna ($P_{r,reference\ antenna}$), which has a gain ($G_{r,reference\ antenna}$) of 16 dBi. The measurement results are presented in Fig. 6.

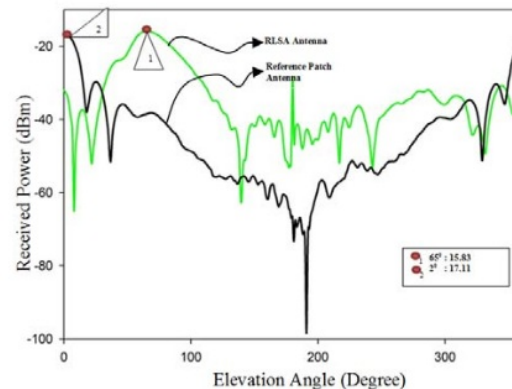


Fig. 6. Received power measurements

From the measured received power results (Fig. 6), the antenna gain was calculated as:

$$G = P_{r,RLSA} - P_{r,reference\ antenna} + G_{r,reference\ antenna} \quad (1)$$

$$= -15.83 - (-17.11) + 16$$

$$G = 17.28\text{ dBi} \quad (2)$$

The polarization of the antenna was measured by rotating the antenna 360° ; the result is shown in Fig. 7.

As seen, the polarization of the antenna is linear.

The other measured performance parameters of the antenna are listed in Table IV.

Based on the values of the gain, the bandwidth, and the beamwidth, which are 17.28 dBi, 1 GHz, and 30° , respectively, the performance of the RLSA antenna meets the market specification needs, as listed in Table I (Group 3).

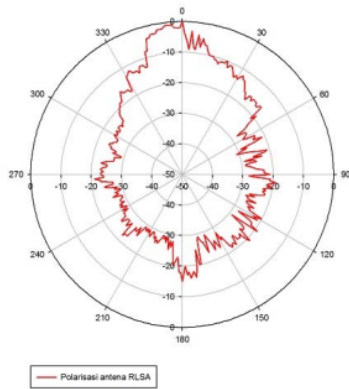


Fig. 7. Polarization measurement results for the proposed RLSA antenna

TABLE IV
PERFORMANCE PARAMETERS

Performance Parameters	Values
Gain	17.28 dBi
3 dB Bandwidth	± 1 GHz
3 dB Beamwidth	30°
Mainlobe-to-sidelobe Ratio	about 10 dB
Mainlobe directions	65° from the boresight direction
Efficiency	-0.1635 dB

As seen in Fig. 4 and Fig. 5, the simulation results are comparable to the measurement results. Any difference between the results is due to imperfections that occurred while fabricating the antenna model. The radiating element, the cavity, and the background were separated, so when they were combined during the fabrication process there was a slight shift from the correct position.

Moreover, the permittivity of the cavity was slightly increased because glue was used to attach the radiating element and the background to the cavity. Finally, soldering imperfections were observed at the head disc of the SMA feeder at the correct position.

In order to test the antenna's performance under real conditions, we built a test bed system (Fig. 8).

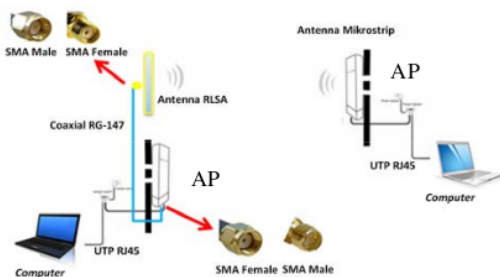


Fig. 8. Test bed system

The test bed consists of two 5.8 GHz radio access points (APs) as transceivers; the RLSA antenna was connected to one of the transceivers, a microstrip AP antenna was connected to the other transceiver, and two computers were connected to the two APs. We conducted

the test by setting up data communications between the two computers for several time points and distances. The test results show that the communications occurred without any problems, thus verifying the good performance of the antenna in a real environment.

The dimensions of the proposed RLSA antenna are $\pi \times (115 \text{ mm})^2 = 41,526 \text{ mm}^2$. The antennas currently available in the marketplace have an average dimension of $63,700 \text{ mm}^2$ (see Table I), which is quite a bit larger.

In terms of performance, our RLSA antenna has a gain of 18.4 dBi, a bandwidth of about 1 GHz, and a beamwidth of 29° . The antennas available in the marketplace have an average gain of 16–18 dB, an average bandwidth of 700 MHz, and an average beamwidth ranging from 7° to 15° . Therefore, our proposed RLSA antenna is significantly smaller than the currently available antennas, and it has a better performance. Furthermore, based on our observation, our fabricated RLSA antenna is flat, as are microstrip antennas, so it has the potential to be another antenna option for Wi-Fi devices.

V. Conclusion

We designed and fabricated an RLSA antenna. Based on simulations and measurements, we found that the proposed antenna is smaller and has better performance than antennas that are currently available in the marketplace. We also tested the RLSA antenna as an antenna for Wi-Fi devices and determined that its performance was good.

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