Multiple element of miniaturized printed log-periodic second series koch dipole array antenna for wideband chipless RFID tag reader

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Article Info

Article history:

Received Jan 25, 2020
Revised Feb 29, 2020
Accepted May 14, 2020

Keywords:

Chipless RFID
Compact array antenna
Koch fractal
Log periodic antenna
Reader antenna

ABSTRACT

This paper aims to produce a low profile, wideband, and high gain antenna for chipless RFID tag readers. A miniaturized and wideband printed Log-Periodic Second Series Koch Dipole Array (LPSSKDA) with eleven elements operating over 0.8 GHz-3.2 GHz is designed using the FR4 board. The single LPSSKDA antenna, which acts as the chipless RFID reader antenna having gain between 5.2 and 6.1 dBi and frequency range from 1-3 GHz. A double element of the LPSSKDA antenna is proposed for improving the antenna gain to 6.9-7.9 dBi over the frequency range. The antenna is fabricated to validate the simulation and measurement results in terms of reflection coefficient, radiation pattern, and surface current distribution

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1. INTRODUCTION

Chipless Radio Identification (RFID) is wireless identification capturing data technology using transmission and reception of electromagnetic waves without a microchip [1, 2]. This microchip is called Application Specific Integrated (ASIC) Circuit for the application of product packaging, object tracking, inventory control and authentication activities [3]. The chipless RFID system can reduce complexity and minimize manufacturing and implementation cost the conventional chip RFID [4]. The chipless RFID can compete with commercial barcode technology with providing better performance in term capability of detection line of sight with obstacle and range distance and rate speed detection [5]. Many variations small size, high capacity, and printable chipless RFID based frequency domain and time domain have been designed to fulfill the requirement of the chipless RFID system [6, 7]. Most structure of chipless RFID structures has implemented microwave structure such as dipole arrays [8], trefoil resonator [9], microstrip resonator [10], radar cross-section (RCS) [11] and frequency-selective surface (FSS) [12] with various conductor layout, design and shape for coding identification. This innovative technology of chipless RFID with the integration of Internet of Thing (IoT) [13] including smart radio-frequency sensors [14], 5-G communication technologies [15] and cloud computing storage can offer an enormous potential to replace the conventional visual optical barcode and conventional RFID system [16]. Among them, the chipless RFID based frequency domain is more relevant due to the ability of high capacity data and minimum size structure. The chipless RFID system consists of a transponder, including an encoding element and tag antenna and reader system with a reader antenna, as shown in Figure 1. The reader antenna will transmit the signal to the transponder and receive back interrogation signal with information number.

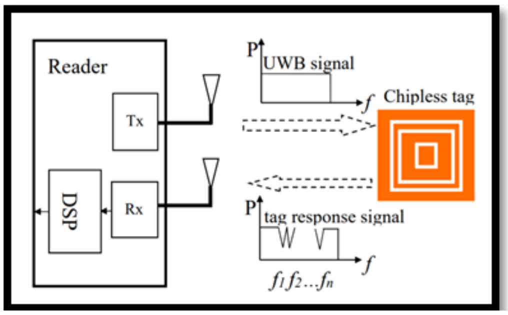

Figure 1. A proposed chipless RFID system with two reader antenna as transmitter and receiver [17]

One of the crucial elements of chipless RFID is a reader antenna [18] The reader antenna requires high bandwidth to maximize the data information capacity in the frequency range. Furthermore, small size, lightweight, rigid mobile reader antenna ensure the consistent behavior of $|S_{21}|$, the transmission coefficient of both reader antenna as data information results in facilitating the commercial user. Another requirement is a high gain antenna for increasing detection distance range and minimize power transmitted following maximum Effective Isotropic Radiated Power (EIRP) [19]. The Federal Communication Commission (FCC) will regulate the maximum EIRP for reducing the risk of RF interference with other systems. For example, M. A. Islam has designed 4 × 4 dual-polarized (DP) aperture-coupled millimeter (mm)-wave chipless RFID tag reader has for producing wide frequency range with high isolation performance with 16-dBi realized gain [20]. Besides, F Yang has produced a Vivaldi antenna operating between 3-6 GHz with boresight gain between 6 -10.8 dBi [21]. A new design of a 2x2 array of dipole reflector antenna is presented, producing a peak gain of 13.6 dBi in the range frequency between 4.8-5.4 GHz as shown in [22]. A. Islam introduces a single element linearly polarized (LP) aperture coupled microstrip patch antenna (ACMPA) in 6.5-10.6 GHz using Taconic TLX-8 with permittivity of 2.55[23]. M Zommoroddi proposes four-element of double-side printed dipole (DSPD) array antenna with a dimension of 22 mm × 14 mm at 57-64 GHz around 12% bandwidth on Taconic TLX-8 substrate with permittivity of 2.25 as shown in [24]. Ihamji proposed a compact miniature fractal planar antenna for RFID reader with a dimension of 21 mm ×52 mm operating between 2.27 – 2.68 GHz [25]

A log-periodic antenna consisting of a half-wave dipole element is suitable for the proposed chipless RFID reader antenna due to its high gain, low cross-polarization, and wideband characteristic [26-28]. This multi-element directional antenna often works for wideband frequency applications. In this paper, a high gain Printed Log-Periodic Second Series Koch Dipole Array (LPSSKDA) is introduced operating between 1-3 GHz using FR4 substrate with permittivity of 5.3 and loss tangent of 0.025 at 2 GHz. The first iteration Koch Fractal series structure is introduced to miniaturize 16% the actual length of dipole length. Then, this research paper shows a double-element of log-periodic Koch Fractal array antenna to enhance gain for improvement distance range measurement. Lastly, this paper will present a comparative analysis of simulated and measured reflection coefficient, gain, and radiation pattern.

2. ANTENNA DESIGN

The proposed printed Log-Periodic Second Series Koch Dipole Array (LPSSKDA) antenna with eleven elements has been designed operating between 1-3 GHz using the FR4 substrate covering at Ultra High-Frequency (UHF) band as shown in Figure 2. The Koch Fractal log periodic antenna is created by substituting all series of conventional straight dipoles with Koch Fractal dipole with two series of triangle curves. There have three crucial parameters for designing a periodic log antenna that are geometric ratio, angle factor, and spacing factor, as shown in (1) and (2). The geometric ratio symbolized with τ determines the length, the spacing, the width, and the resonant frequency between elements of each dipole element using the scaling factor technique. The highest length dipole element determines the lowest resonance operating frequency and vice-versa. Table 1 shows all dimension parameters of the LPSSKDA with a symbol.

$$\tau = \frac{l_n}{l_{n+1}} = \frac{w_n}{w_{n+1}} = \frac{f_n}{f_{n+1}} = \frac{d_n}{d_{n+1}} \quad (1)$$

The spacing factor σ is calculated using the following equation. The antenna bandwidth B_s is defined to determine the number of element N.

$$\alpha = tan^{-1}\left[\frac{1-\tau}{4\sigma}\right] \qquad N = 1 + \frac{\ln(B_S)}{\ln(\frac{1}{\tau})} \qquad (2)$$

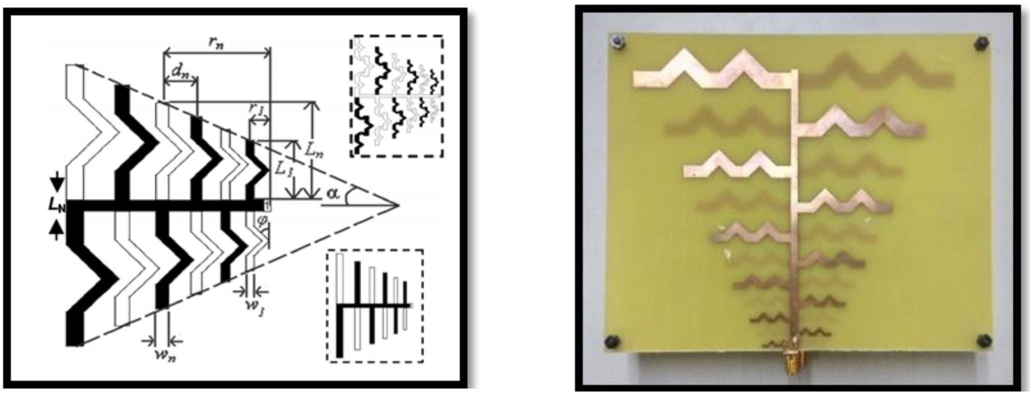

Figure 2. Log-periodic second series koch dipole array design and prototype

Table 1. Dimension parameter of printed log-periodic second series koch dipole array (LPSSKDA)

Parameter	Symbol	mm
Scaling factor	τ	0.8
Angle Factor	α	34
First Spacing Element	d_1	21.6
First Length Element	l_1	140.0
First Width Element	w_1	6.9

3. RESULTS AND ANALYSIS

3.1. Printed log-periodic second series koch dipole array (LPSSKDA)

The LPSSKDA antenna prototype has been fabricated and measured to recognize the simulation design validity. Figure 3 shows the simulation result of the reflection coefficient of the simulated and measured LPSSKDA with a flare angle of 45 degrees. The log-periodic antenna with an optimized eleven dipole element performs well with the bandwidth of 2400 HZ. The reflection coefficient of the fabricated LPSSKDA antenna performs well and valid with the simulation operating frequency between 0.8 - 3.2 GHz. The multiple Koch dipole elements form numerous deep resonant in the frequency range. Figure 4 shows the surface current distribution for two different resonant frequencies at 1 and 3 GHz. At the low operating frequency of 1 GHz, the surface current propagates well at the second, third, and forth the dipole elements. At the high operating frequency of 3 GHz, the surface current consistently flow with high density at the small element of ninth, tenth and eleventh element.

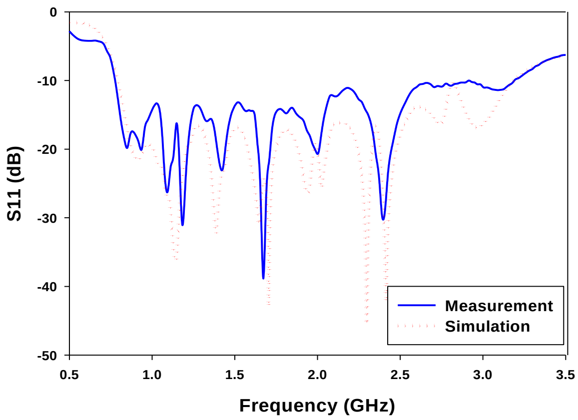

Figure 3. Simulation and measurement result of the reflection coefficient the log-periodic second series koch dipole array

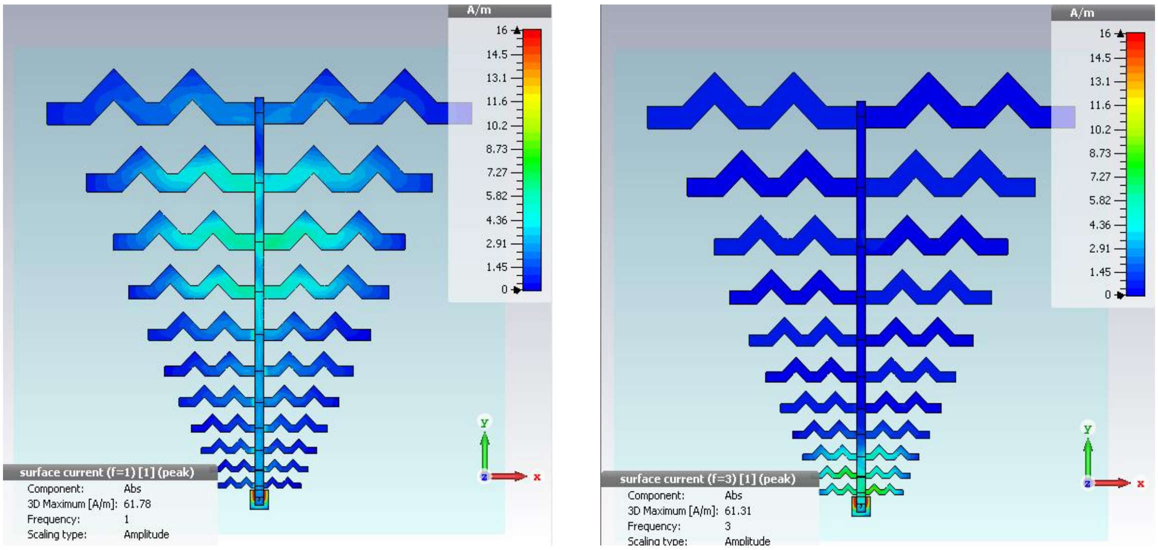

Figure 4. The current distribution of log-periodic second series koch dipole array antenna at 1 GHz and 3 GHz

3.2. Double element of printed log-periodic second series koch dipole array (LPSSKDA)

The double element of LPSSKDA antennas is placed with a vertical position by connecting with the planar power divider to improve the gain enhancement of antenna, as shown in Figure 5. Initially, the LPSSKDA antenna has gain between 5.2-6.1 dB in range frequency between 1-3 GHz with the backward directional pattern. The arrangement of two elements of LPSSKDA improves the antenna gain to 6.9-7.9 dB with maintaining an average half-power beamwidth pattern of 69 degrees. Figure 6 depicts the E-field radiation pattern of the LPSSKDA antenna with the single and double element at 1 and 3 GHz. For a single element, the front-to-back (FTB) ratios are around 11.8 dB at 1 GHz and 13.3 dB at 3 GHz. The FTB has been changed around 14.0 dB at 1GHz 13.0 dB at 3GHz by adding a double element of the LPSSKDA antenna. Table 2 shows the comparative performance between the first and double elements of the LPSSKDA at 1, 2 and 3 GHz. The double element of the LPSSKDA improve the antenna gain and reduce the half-power beamwidth at 1-3 GHz with maintaining FTB compared to the first element of the LPSSKDA.

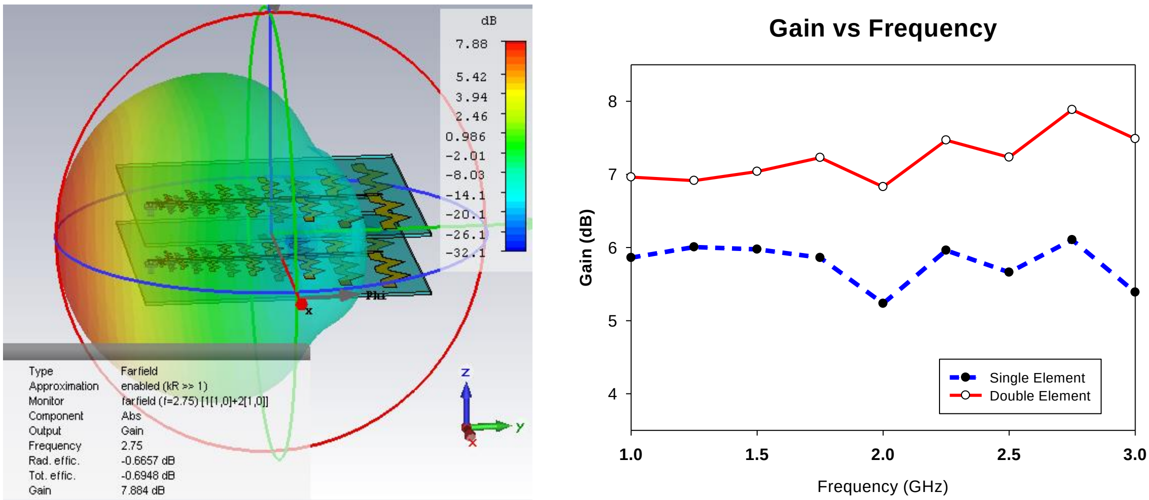

Figure 5. 3D radiation pattern of double element log-periodic second series koch dipole array and gain comparison of single and double element of log-periodic second series koch dipole array

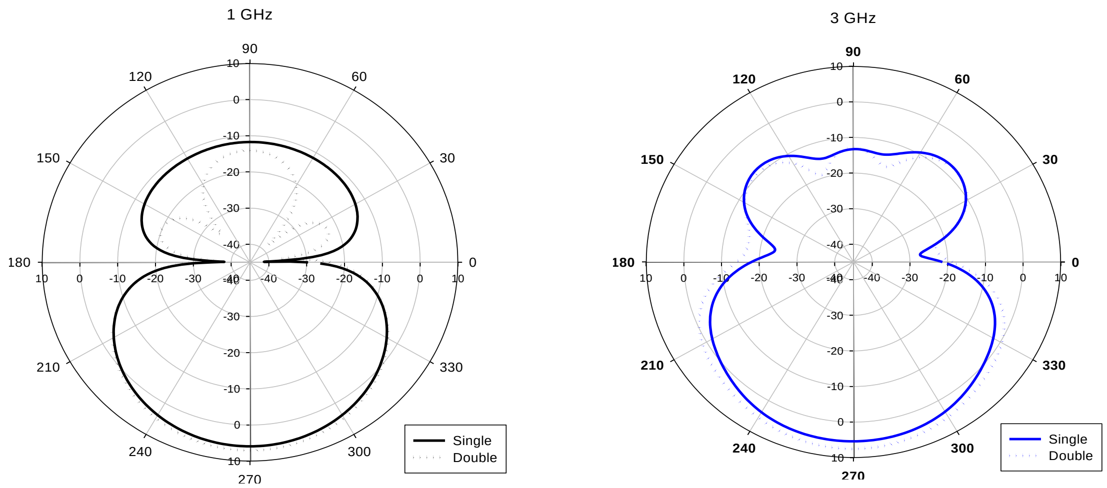

Figure 6. The simulated radiation pattern of E-plane of single and double element log-periodic second series koch dipole array at 1 GHz and 3 GHz

Table 2. Comparison between a single and double element of the LPSSKDA antenna

Element		Single	Double
Operating Frequency		0.77-3.18	0.80-3.15
Gain (dBi)	1 GHz	5.86	6.96
	2 GHz	5.23	6.83
	3 GHz	5.38	7.49
Front-to-back ratio (dB)	1 GHz	11.75	14.05
	2 GHz	14.73	11.73
	3 GHz	13.03	13.31
Half-power beam width (degree)	1 GHz	71.2	68.6
	2 GHz	73.1	70.8
	3 GHz	76.2	74.4

The simulated and measured pattern of LPSSKDA with the double element is very similar and directive, as shown in Figure 7 for E-plane pattern and Figure 8 for the H-plane pattern. The half-power beamwidth is about in the range of 68-74 degrees from 1 GHz up to more 3 GHz. Measured side lobe level ranges from -15 dBi to less than -35 dBi at 1 GHz and from -7dBi to less than -20 dBi as expected the same trend with the simulated result. The presence of a power divider for connecting two LPSSKDA antennas interrupted the central radiation portion of the antenna, causing a difference in the sidelobe level in measurement and simulation.

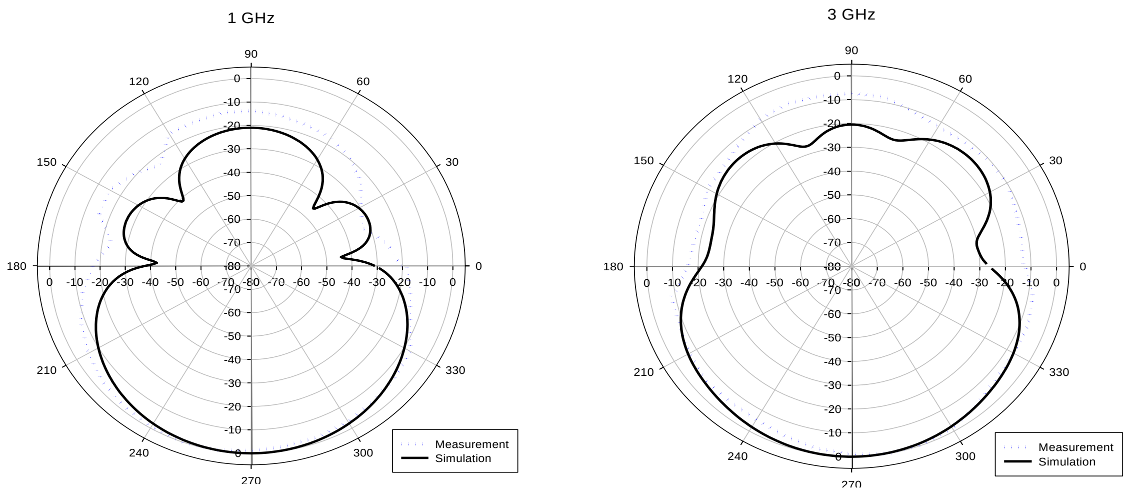

Figure 7. Simulated and measured E-plane result of normalized radiation pattern result at 1 GHz and 3 GHz

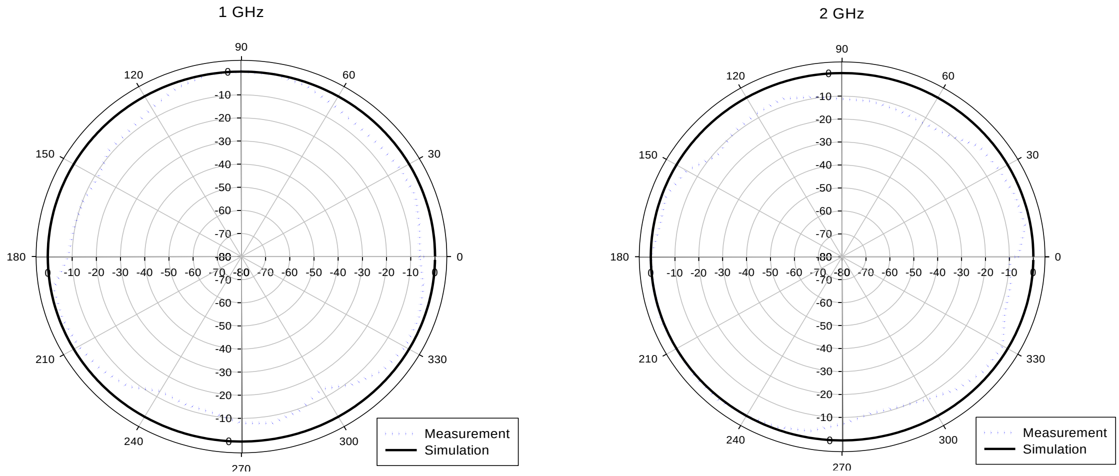

Figure 8. Simulated and measured H-plane result of normalized radiation pattern result at 1 GHz and 3 GHz

Figure 9 shows the measured radiation pattern of the LPSSKDA antenna with a different resonant frequency. The main beamwidth has a similar radiation pattern with different resonant frequencies at 1, 2, and 3 GHz. However, the side lobe range for the low frequency is less than -14 dB compared to the high frequency of less than -5 dB.

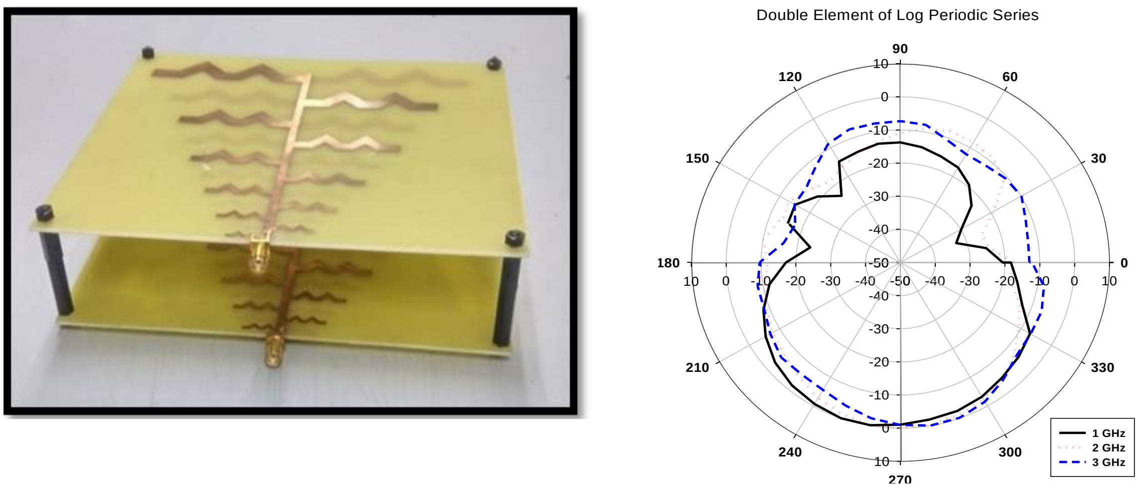

Figure 9. The double element of log-periodic second series koch dipole array and measured E-plane radiation pattern of the double element of the log-periodic second series koch dipole array

4. CONCLUSION

A high gain, high bandwidth, and miniaturized Koch Fractal Log Periodic Antenna with eleven elements have been designed, simulated, and fabricated to miniaturize 15% of the length of the conventional straight dipole log-periodic antenna. Then, the miniaturized double element of the log-periodic antenna series. This paper proposes the double elements of the Log-Periodic Second Series Koch Dipole Array with the gain between 6.8-7.9 dB in the range between 1-3 GHz as a chipless reader antenna. For future work, two of the log-periodic Koch Fractal with the double element are positioned with opposite directions each other to identify the data information of chipless RFID tag based on the transmission coefficient between the two antennas

ACKNOWLEDGEMENTS

The authors would like to thank the Ministry of Education (MOE), School of Postgraduate Studies (SPS), Research Management Centre, Advanced RF and Microwave Research Group, School of Electrical

Engineering and Universiti Teknologi Malaysia (UTM), Johor Bahru, for the support of the research under Grant 06G15 and 04G67. The authors also would like to acknowledge all members of the Advanced RF and Microwave Research Group (ARFMRG).

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