Progress In Electromagnetics Research Letters, Vol. 63, 107–113, 2016

On the Miniaturization of Log Periodic Koch Dipole Antenna Using Split Ring Resonators

Jolly Rajendran[1, *] and Sreedevi K. Menon[2]

Abstract—In this paper, a printed split ring resonator (SRR) loaded log-periodic Koch dipole antenna (SLPKDA) is proposed. Koch-shaped dipoles when being loaded with split ring resonator (SRR) yielded a compact antenna, still preserving the radiation properties of log-periodic dipole antenna (LPDA). Measurement results show that the proposed antenna has a wide bandwidth, good impedance match and gain of 4 dBi over the band of frequencies from 0.9 GHz to 2.5 GHz. Both vertical and horizontal dimension reductions are achieved by loading Koch dipoles with SRR.

1. INTRODUCTION

Invented by Isbell, log-periodic dipole antenna is a wideband, directional antenna which can be modified to several variants [1–6]. For wideband hand-held devices which requires a compact miniaturized antenna, LPDA is a suitable choice. Several miniaturization techniques for LPDAs are found in the literature [7–10]. A log periodic Koch dipole antenna (LPKDA) [8] has been reported with a vertical reduction in length up to 17%. A fractal tree dipole [9] has achieved a lateral size reduction of 61%.

Split ring resonators (SRRs) are used to design antennas with multiple resonant frequencies [11–13]. The present paper attempts the size reduction of LPDA using Koch fractal and SRR. Dipoles modified as Koch fractal lead to a vertical reduction in length while the inclusion of SRR could generate multiple resonances reducing the horizontal dimension. Koch fractal is used since fractals show benefits in antenna size reduction [16–19]. The detailed design procedure of split ring resonators (SRR) loaded log-periodic Koch dipole antenna (SLPKDA) is presented in Section 2. The antenna was then modelled and simulated in Ansoft HFSS. The simulation results are discussed in Section 3. The simulation results were then validated by conducting experiments. The experimental validation is presented in Section 4. The compact, low cost, split ring resonator (SRR) loaded log-periodic Koch dipole antenna (SLPKDA) presented is easily integrable in handheld devices. Simulated and experimental results show the miniaturization results in minimum degradation in antenna performance.

2. ANTENNA CONFIGURATION

To start with, a printed log periodic dipole antenna (PLPDA) was designed by the standard design procedure [1–3]. The LPDA used an FR-4 substrate, which has a relative permittivity ($\epsilon_r = 4.4$) and loss tangent (0.008). In the LPDA design, the lowest and highest resonant frequencies are chosen as 0.622 GHz and 2.504 GHz, respectively. τ and σ are chosen as 0.87 and 0.2, respectively. The approximate gain for this design is 6.5 dB [5]. The half angle α is calculated [1] and found to be 9.2°. Then the number of dipoles (N) required in the design is calculated which is 11 [1–5]. Then the length, spacing and thickness of each dipole of LPDA is calculated [1–5]. The calculated values are shown in Table 1 (‘n’ is the number of the dipole arm in the design).

Received 4 September 2016, Accepted 18 October 2016, Scheduled 4 November 2016

* Corresponding author: Jolly Rajendran (r_jolly@cb.amrita.edu).
[1] Department of Electronics & Communication Engineering, Amrita School of Engineering, Coimbatore, Amrita Vishwa Vidyapeetham, Amrita University, India. [2] Department of Electronics & Communication Engineering, Amrita School of Engineering, Amritapuri, Kollam, Amrita Vishwa Vidyapeetham, Amrita University, India.

Table 1. Calculated value of length, spacing and thickness of dipoles in LPDA.

n	Guided Wavelength (λ_g) [mm]	Length [mm]	Spacing [mm]	Thickness [mm]
1	253.9	63.5	25.4	4.4
2	220.9	55.2	22.1	3.8
3	192.2	48.1	19.2	3.3
4	167.2	41.8	16.7	2.9
5	145.5	36.4	14.5	2.5
6	126.6	31.6	12.7	2.2
7	110.1	27.5	11.0	1.9
8	95.8	23.9	9.6	1.7
9	83.3	20.8	8.3	1.5
10	72.5	18.1	7.3	1.3
11	63.2	15.8	-	1.1

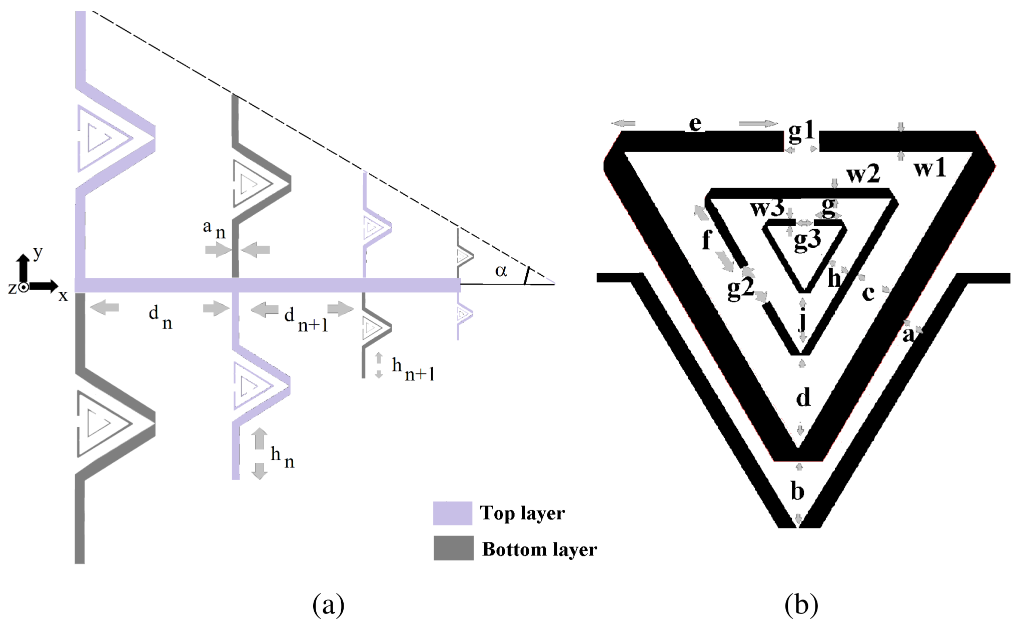


Figure 1. (a) Design parameters of a log periodic Koch dipole antenna. (b) SRR loaded Koch dipoles in SLPKDA.

Size reduction is achieved by bending the dipoles into first iteration Koch curves [9]. All the four arms of Koch dipole are of the same length. The length of each dipole arm (h_n), spacing d_n and thickness a_n of each Koch shaped dipole of LPKDA are listed in Table 2. The acute interior angle made by adjacent dipole arms in all Koch dipoles is 60°. This completes the design of log periodic Koch dipole array (LPKDA). A size reduction of 12% is achieved for LPKDA compared to LPDA. Higher iterations of Koch curves were not applied because the antenna gain and front-to-back ratio degraded with a higher iteration of Koch curves [8].

Only vertical size reduction is achieved by forming the dipoles into Koch dipoles. Further, the horizontal dimension reduction is achieved by omitting alternate dipoles and compensating the same by loading the Koch dipoles with split ring resonators (SRRs). This results in SLPKDA which has six dipoles. The layout of SLPKDA is shown in Fig. 1(a). Fig. 1(b) shows the different parameters of SRR loaded Koch dipole (SKD). All Koch dipoles except the third are loaded with one SRR. The third Koch dipole is loaded with two SRRs. The design parameters of each SKD are optimized using Ansoft HFSS.

Table 2. Calculated value of length, spacing and thickness of Koch dipoles in LPKDA.

n	Guided Wavelength (λ_g) [mm]	Length (h_n) [mm]	Spacing d_n [mm]	Thickness a_n [mm]
1	253.9	15.9	25.4	4.4
2	220.9	13.8	22.1	3.8
3	192.2	12.0	19.2	3.3
4	167.2	10.5	16.7	2.9
5	145.5	9.1	14.5	2.5
6	126.6	7.9	12.7	2.2
7	110.1	6.9	11.0	1.9
8	95.8	6.0	9.6	1.7
9	83.3	5.2	8.3	1.5
10	72.5	4.5	7.3	1.3
11	63.2	3.9	-	1.1

Table 3. Length, spacing and thickness of SRR loaded Koch dipoles in SLPKDA.

n	Guided Wavelength (λ_g) [mm]	Length (h_n) [mm]	Spacing d_n [mm]	Thickness a_n [mm]
1	253.9	15.9	25.4	4.4
2	192.2	12.0	19.2	3.3
3	145.5	9.1	14.5	2.5
4	110.1	6.9	11.0	1.9
5	83.3	5.2	8.3	1.5
6	63.1	3.9	-	1.1

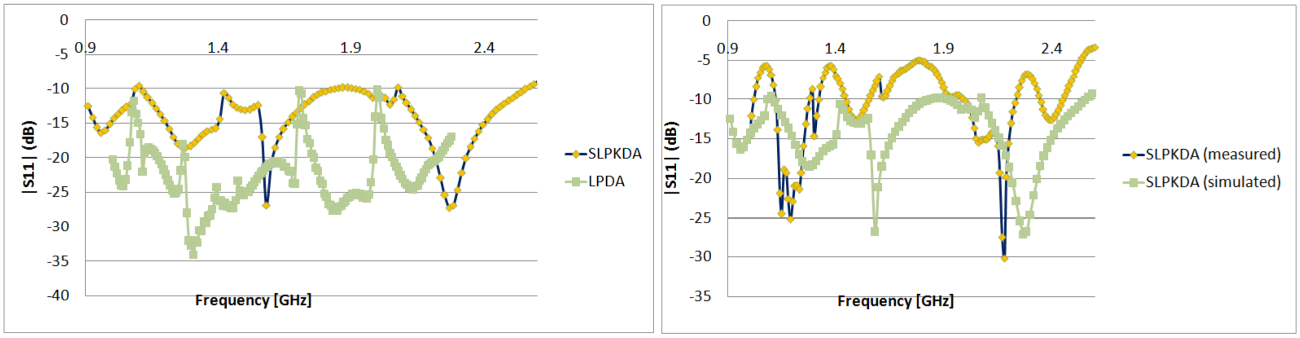
Table 4. Parameters of SRR, loaded in Koch dipoles of SLPKD.

n	w_1 [mm]	g_1 [mm]	e [mm]	w_2 [mm]	g_1 [mm]	f [mm]	a [mm]	b [mm]	d [mm]
1	1.5	1.0	9.6	-	-	-	0.1	2.4	-
2	1.1	1.0	7.2	-	-	-	0.2	2.1	-
3	0.8	1.0	6.0	0.4	1.0	4.7	0.1	1.4	0.9
4	0.6	1.0	4.1	-	-	-	0.1	1.1	-
5	0.5	1.0	3.7	-	-	-	0.1	0.9	-
6	-	-	-	-	-	-	-	-	-

The values of the optimized design parameters of each SKD used in design of SLPKDA are shown in Table 2, Table 3 and Table 4 ('n' is the number of the dipole arm in the design).

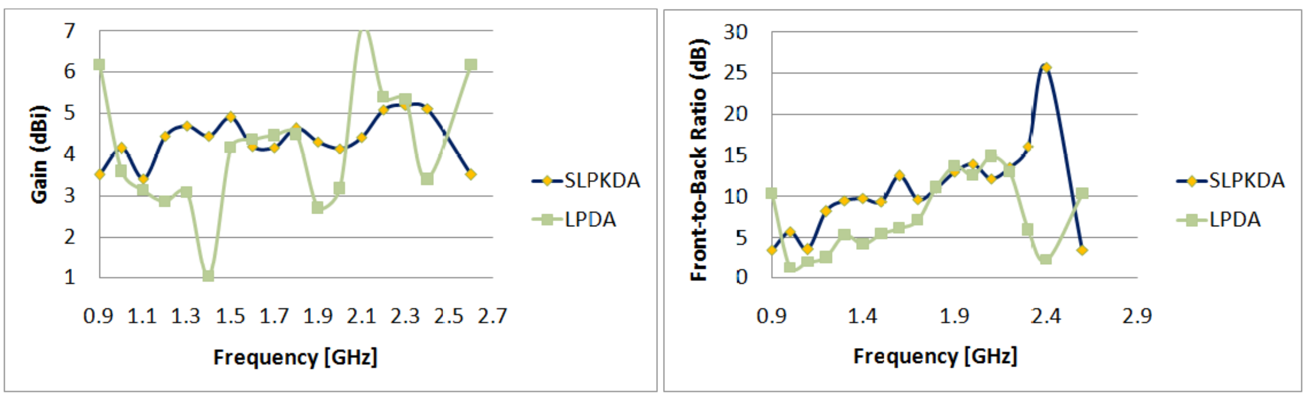
3. MODELLING & SIMULATION

The proposed SLPKDA is fed by a coaxial cable based on an RG 316 SMA connector. Different parameters, such as S_{11} and VSWR, are analysed using Ansoft HFSS. Fig. 2(a) shows the plot of S_{11} with frequency. The antenna return loss is below -10 dB in the desired frequency range and is thus well matched with respect to impedance in the frequency range. It is noted that, from 0.9 GHz to 2.6 GHz, the antenna is well matched with a VSWR ≤ 2, giving an operating bandwidth of 1.7 GHz.



(a) (b)

Figure 2. (a) The simulated response of S_{11} of the LPDA and SLPKDA. (b) The measured return loss of fabricated SLPKDA prototype.



(a) (b)

Figure 3. (a) The simulated gain of LPDA and SLPKDA. (b) The simulated response of front to back ratio for LPDA and SLPKDA.

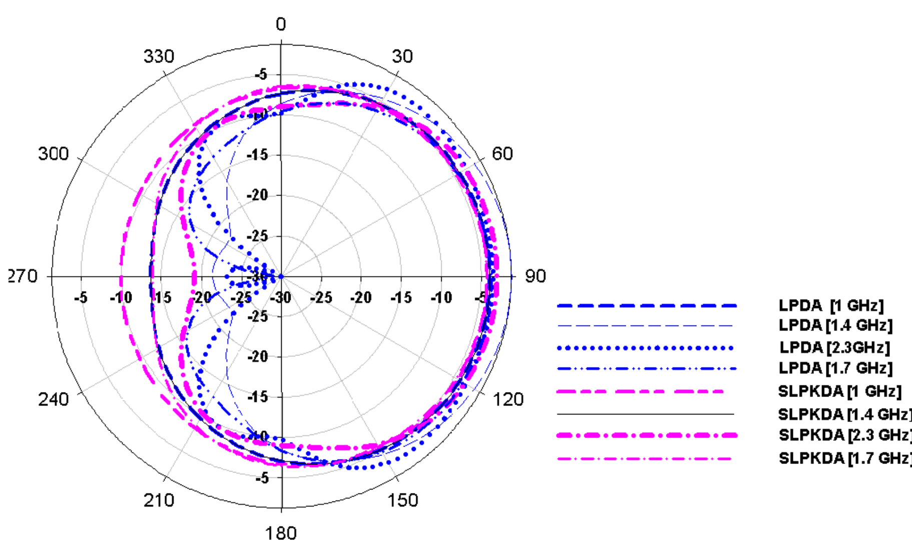


Figure 4. The simulated response of electric field for LPDA and SLPKDA.

The real part of the impedance is almost 50 ohm at resonant frequencies. The imaginary part of input impedance is almost zero at resonant frequencies. The frequency variation of input impedance is not drastic for the proposed SLPKDA. The peak gains of LPDA and SLPKDA are compared in Fig. 3(a). The peak gain is low at low frequencies (below 1.2 GHz) as only a few elements radiate because their characteristic frequency is above 1.2 GHz. Across the operating bandwidth, the peak gain varies from 3.5 dBi to 5 dBi. It is noted that SPLPKDA has a better gain than the normal LPDA. Fig. 3(b) shows the front to back (F/B) ratio of LPDA and SLPKDA. The front to back ratio is better for SLPKDA than LPDA. The E-field plot shown in Fig. 4 provides a better insight to this improvement in F/B ratio. The E-field pattern of regular LPDA is compared with that of SLPKDA. SLPKDA has a backfire pattern. The back lobe levels of LPDA are more prominent than that of SLPKDA, especially at high frequencies (2.3 GHz and above), compared to low frequencies. It is observed that the radiation pattern is stable over the operating bandwidth. The main beam points towards the backfire direction and for most of the frequencies the beam (pattern) overlaps. A directional pattern is obtained for SLPKDA, which is similar to LPDA. For analysis of the radiation of SLPKDA, the antenna is considered as locally periodic structure [15]. The active region is the one that radiates, which is often considered as a uniform array [15]. As per floquet wave expansion and spatial harmonic theory, the array should radiate in backfire direction towards apex [15]. In agreement with the theory, simulations show that SLPKDA has a backfire directional pattern directed towards the apex.

4. EXPERIMENTAL VALIDATION

The antenna was fabricated on a 1.6 mm thick FR-4 substrate with dielectric constant 4.4 and loss tangent 0.008. The proposed SLPKDA was fed by a coaxial cable based on RG 316 SMA connector. An infinite balun was realized by soldering the outer mesh of the coaxial cable to the lower transmission line feeding the dipoles, and the inner conductor of the coaxial cable was connected to the upper central feed line via a hole drilled in the substrate. This infinite balun [14] does the unbalanced to balanced impedance transformation which is required to reduce the current flowing on the outer shield of the coaxial cable. As this infinite balun, together with the solder joints, was difficult to model in Ansoft HFSS, a differential port was placed at the shorter dipole side. But the fabricated prototype is fed from the larger dipole side as shown in the photograph. Fig. 5 shows a photograph of the fabricated antenna prototype. Due to these reasons, the measured results slightly vary from the simulated ones. To characterize the antenna with respect to the return loss, S-parameter measurement was carried out using Rhode & Schwartz ZNB20 network analyser. Fig. 2(b) shows the measured S_{11} compared with simulation results. The simulated results show a -10 dB bandwidth from 0.9 GHz to 2.6 GHz. This corresponds to an impedance bandwidth of 97% with center frequency of 1.75 GHz. The measured results slightly vary from the simulated one, because the relative permittivity of substrate

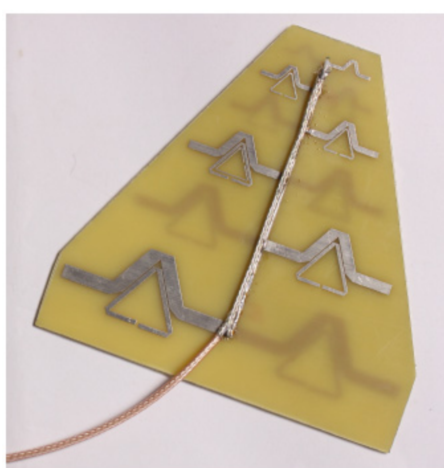


Figure 5. The fabricated antenna prototype.

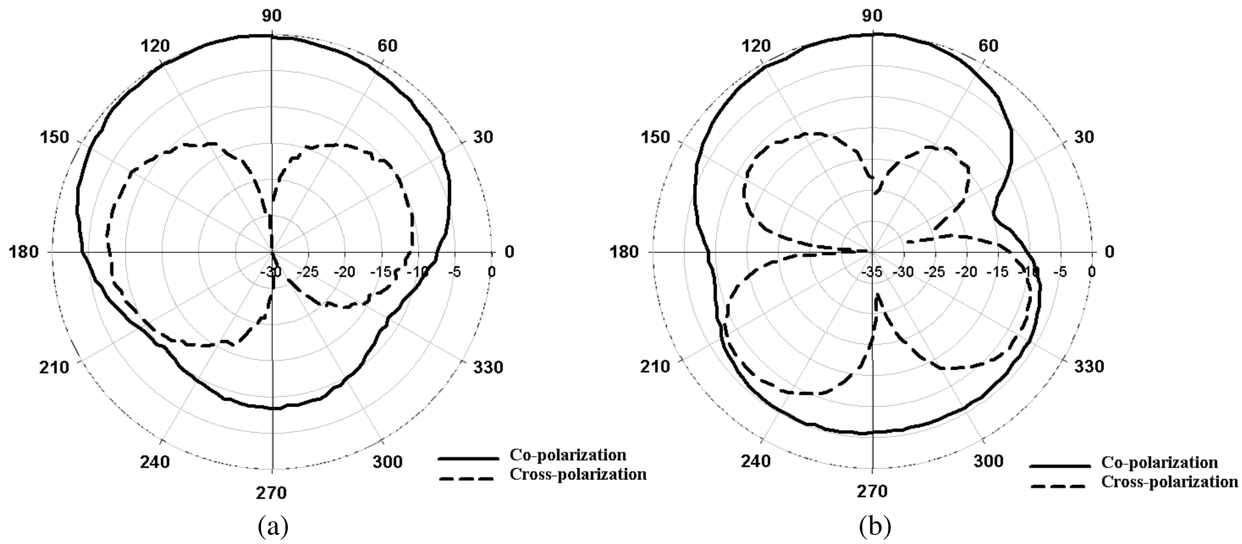


Figure 6. The measured far field pattern in the E-plane (a) at 1 GHz, (b) at 2.3 GHz.

varies with frequency. Also the wideband balun and external feeding structure were not included in the simulation. Far-field radiation patterns were measured for a continuous sweep of frequencies. Co- and cross-polarization levels were measured to evaluate antenna's polarization purity in the frequency of interest. Fig. 6 depicts the measured far-field pattern in E-plane of the SLPKDA prototype. The measured and simulated beamwidths are 95° and 100° respectively at 2.3 GHz.

5. CONCLUSION

In this paper, a novel antenna, SRR loaded log periodic Koch dipole antenna is proposed. Log periodic Koch dipole antenna (LPKDA) is miniaturized by adding SRRs. The antenna design procedure and the simulated and measured results have been discussed. The designed antenna has a good impedance bandwidth of 97% and an average gain of 4 dBi. The return loss is better than 10 dB in the desired bandwidth. There is a significant improvement in F/B ratio for SLPKDA compared to LPDA. The main beam is directed along the back fire direction.

ACKNOWLEDGMENT

The authors would like to thank Dr. Aanandan, Cochin University of Science & Technology [CUSAT], for his support which was indispensable for this work. Authors warmly acknowledge Mr. K. K. Mukundan, Head, Antenna Design & RF Facilities Division [ADRFD], Avionics Entity, Vikram Sarabhai Space Center [VSSC] and all the lab faculty of ADRFD lab for their help in antenna testing. The authors are thankful to Mr. Rakesh Peter, Visiting Faculty, Centre of Excellence in Computational Engineering & Networking [CEN], Amrita University for his support.

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