Compact Log-Periodic Dipole Antennas using Peano Fractal Cuvres

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Abstract—**In this paper, novel compact planar log-periodic dipole antennas (LPDA) using two types of Peano fractal curves are designed. Designs procedure consists of two minimization approaches: in the first approach radiating elements are minimized using two different types of Peano curves while in the second one, an evolution of the first, minimizing the interconnecting feed elements are performed. Four proposed variations of log-periodic antennas realized on FR4 substrate are designed to operate in the frequency range between 1 and 4 GHz. The characteristics of proposed fractal antennas are compared with a conventional LPDA. Improvement of up to 49% reduction in occupied surface area is obtained while gain and directivity achieved with fractal antennas remain constant.**

Keywords-log-periodic antenna, Peano fractal;miniaturization

I. Introduction

Log-periodic dipole antennas (LPDAs) are attractive for different communication applications such as commercial broadcast and radio signal detection. LPDA has high directivity and high front-to-back ratio over a very wide frequency range, [1-3]. Modern communication systems usually require smaller size of antenna in order to meet the miniaturization requirements of mobile units. The size of planar LPDA can be reduced significantly by reducing antenna dipoles using different shapes: 2D or 3D meandered lines, [4-5], Koch fractal, [6-7] or tree fractal structure, [8].

The idea of this paper is to illustrate a way to decrease the size of a LPDA by experimenting with different shapes of Peano fractal dipoles while trying to maintain the directivity and gain of a conventional LPDA. Configurations based of two type of Peano fractal, depicted in Fig. 1, have been analyzed. Designs procedure consists of two minimization approaches: in the first approach radiating elements were minimized while in the second one feed elements were also bended. The characteristics of proposed fractal antennas are compared with a conventional LPDA. All antennas have been designed using 1.575mm thick FR4 substrate with a permittivity of 4.3 and a tangent loss equal to 0.025. Simulations were performed using CST Microwave studio.

II. Convetional LPDA

The design theory behind designing the conventional LPDA that is made of a certain number of dipoles, *N*, each resonating at a certain frequency is well explained in the past. Fig. 2 shows the well-known shape of the conventional log-periodic planar antenna while the design parameters are given in Table I. All LPDA elements are carefully optimized in order to obtain antenna that operate in frequency range between 1 and 4 GHz. From the return loss shown in Fig. 3 we can see that the antenna is operating within set bandwidth. Radiation patterns at 1, 2, 3 and 4 GHz are shown in Fig. 4. Proposed designs based on Peano fractal dipoles will be compared to this conventional antenna.

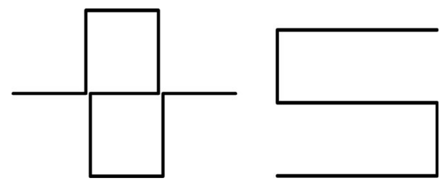

Figure 1. Constructions of Peano fractal curve: a) type1, b) type2.

III. Fractal LPDA using Peano curves

A. *Peano LPDA type 1*

Fig. 5 shows the proposed shape of the first antenna topology with the normal radiating elements substituted with Peano fractal curve - type1. Design parameters for proposed antenna are given in Table II. It can be seen in Fig. 5 that the end part of the fractal element is shorter than the one connecting to the feed line. Optimal distance of Peano dipole from the feed line is set to P_1 = 12 mm for best performance. The optimal spacing that is separating the curve from making a square is set to P_2= 1.2 mm. It is noticeable that the number of elements has increased by two but the overall length of the antenna is shorter approximately 2.3 cm in comparison to conventional antenna. However, the occupied surface area is reduced by 19%. Simulated return loss has shown that the bandwidth meets the required specification, Fig. 6, while radiation patterns, Fig. 7, show that the directivity is almost maintain constant.

B. *Peano type 2 LPDA*

Fig. 8 shows the LPDA that uses Peano fractal curve-type2 as radiating elements. Design parameters for this type of antenna are given in Table III. In this case there are 14 elements but the antenna is now 1.6 cm shorter. Surface area is reduced by 32% although the width of the feed line and the elements is slightly increased to insure the antenna 50 Ω input impedance. For this type of Peano dipoles optimal distance from the feed line is set to P_1=20 mm due to more parallel overlapping of the fractal curve with the straight feed line. The optimal spacing that is separating the curve from making a square is now P_2= 2.65 mm because of wider elements then in case of type 1. Fig. 9 shows simulation results of the return loss, while Fig. 10 shows that the radiation patern in E- and H-plane.

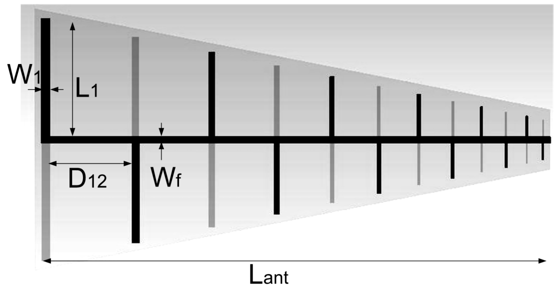

Figure 2. Conventional LPDA

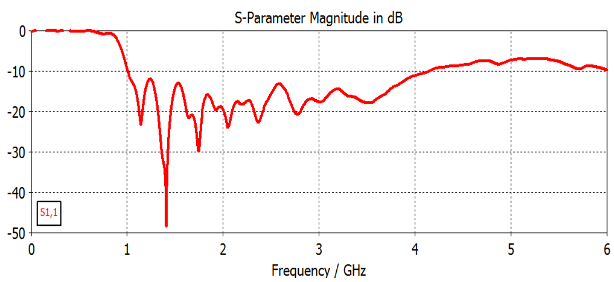

Figure 3. Simulated return loss for the conventional LPDA.

TABLE I. DESIGN PARAMETERS FOR THE CONVENTIONAL LPDA

Scaling factor	0.85
Length of the first element L_1 [mm]	52.55
Spacing between 1st and 2nd element D_{12} [mm]	36.72
Number of dipoles	12
Length of the antenna L_{ant} [cm]	23.01
Antenna surface area [cm^2]	166.122
Width of the first element W_1 [mm]	3.8
Width of the feed line W_f [mm]	2.9

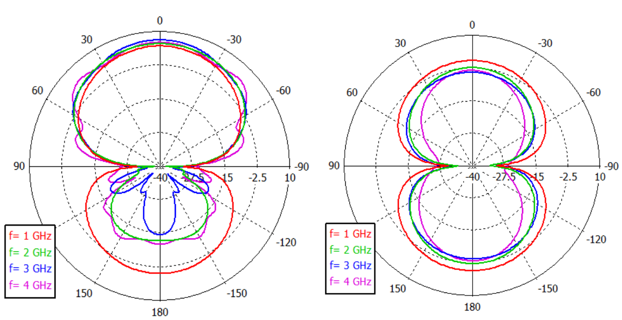

Figure 4. Radiation paterns at 1, 2, 3 and 4 GHz for the conventional LPDA in E- and H-plane.

C. *Peano type 1 LPDA with fractal feed line*

Further minimization of the Peano type 1 LPDA was realized by replacing the conventional feed line with type 1 fractal curve, Fig. 11. Design parameters for this type of antenna are given in Table IV. From the table we can see that antenna just has one additional radiating element, *N*=13 but the antenna is approximately 7 cm shorter. Surface area is

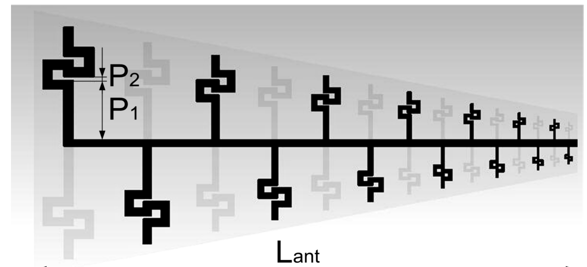

Figure 5. LPDA using Peano fractal curve - type1.

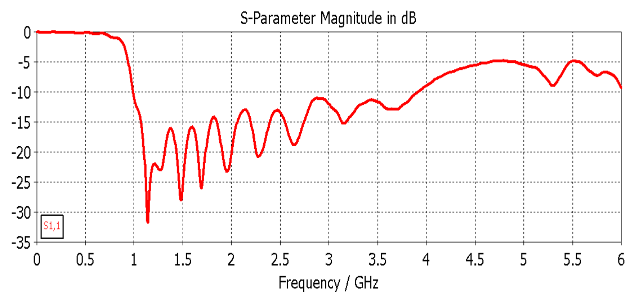

Figure 6. Simulated return loss for the Peano LPDA – type1.

TABLE II. DESIGN PARAMETERS FOR THE PEANO LPDA -TYPE 1

Scaling factor	0.865
Length of the first element L_1 [mm]	78
Spacing between 1st and 2nd element D_{12} [mm]	26.52
Number of dipoles	14
Length of the antenna L_{ant} [cm]	20.8
Antenna surface area [cm^2]	134
Width of the first element W_1 [mm]	3.8
Width of the feed line W_f [mm]	2.78

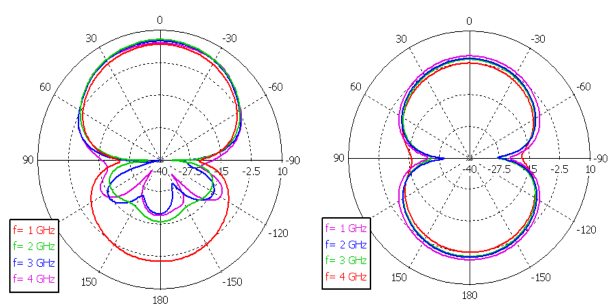

Figure 7. Radiation paterns at 1, 2, 3 and 4 GHz for the Peano LPDA type1 in E- and H-plane.

reduced for almost 41% because of the fractal feed. The distance of the Peano dipoles from the feed line is the same as with original type 1 (P_1= 12 mm) while spacing that separates the curve is set to P_2= 1.9 mm. Notice from Fig. 12 that the feed line is not straight anymore but has also scaled down with the scaling factor τ as dipoles. This means that the start of the fractal feed line is wider than in the case of the smallest element. In order to obtain good impedance matching of the antenna to the 50 Ω port tapper line was used. Fig. 13 shows the the return loss while Fig. 14 shows the radiation patterns.

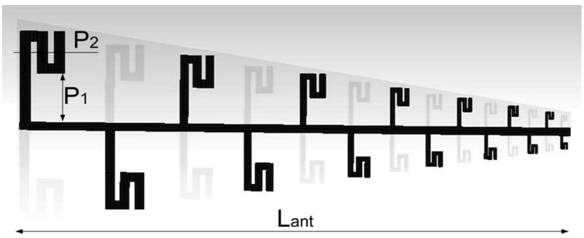

Figure 8. LPDA using Peano fractal curve – type2.

TABLE III. DESIGN PARAMETERS FOR THE PEANO LPDA - TYPE 2

Scaling factor	0.865
Length of the first Peano element L_1 [mm]	78
Spacing between 1st and 2nd element D_{12} [mm]	29.41
Number of dipoles	14
Length of the antenna L_{ant} [cm]	21.5
Antenna surface area [cm^2]	111.5
Width of the first element W_1 [mm]	4
Width of the feed line W_f [mm]	3

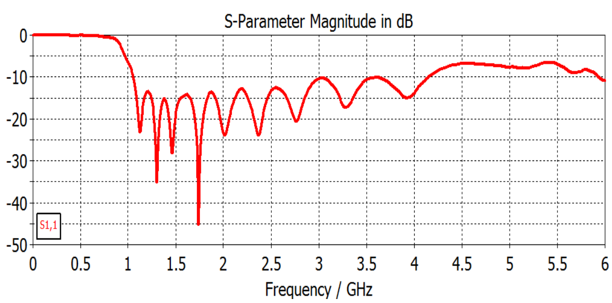

Figure 9. Simulated results los for the Peano LPDA type2.

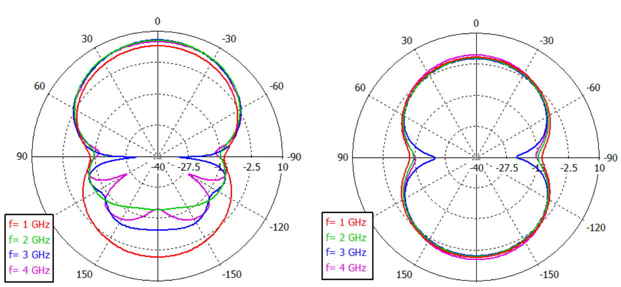

Figure 10. Radiation paterns at 1, 2, 3 and 4 GHz for the Peano LPDA – type2.

D. *Peano type 2 LPDA with fractal feed line*

Fig. 14 shows the evolution of the Peano LPDA type2 in witch the feeds are substituted with type1 fractal curve. Design parameters for this type of antenna are given in Table V. This topology requires 14 dipole elements to meet the bandwidth specifications, but the total length of the antenna is 8 cm shorter than in the case of conventional one. Starting width of the elements is the same with the previous antenna but the Peano dipoles needed to be further apart (20 mm) from the feed line due to larger overlapping area. Fractal feed line is

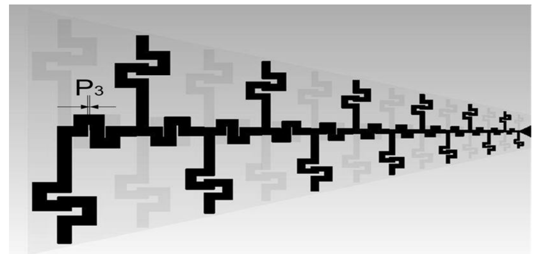

Figure 11. Variation of Peano LPDA type 1with fractal feed line.

TABLE IV. DESIGN PARAMETERS FOR THE PEANO LPDA TYPE1WITH FRACTAL FEED LINE

Scaling factor	0.854
Length of the first Peano element L_1 [mm]	78
Spacing between 1st and 2nd element D_{12} [mm]	20.6
Spacing between fractal segments P_3 [mm]	0.65
Number of dipoles	13
Length of the antenna L_{ant} [cm]	16
Antenna surface area [cm^2]	97.81
Width of the first element W_1 [mm]	4.5
Starting width of the fractal feed line W_f [mm]	4.5

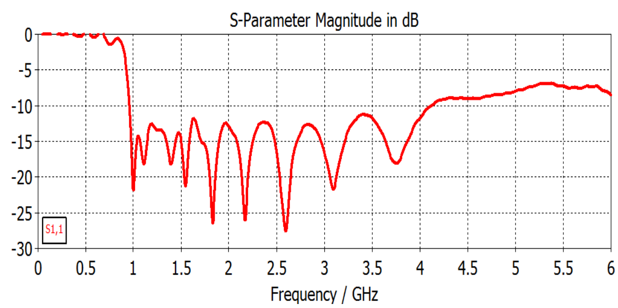

Figure 12. Simulated results for the Peano LPDA type1with fracted feed line.

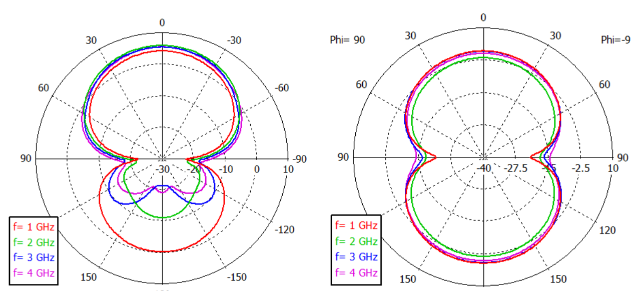

Figure 13. Radiation paterns at 1, 2, 3 and 4 GHz for the Peano LPDA type1 with fractal feed line.

again made up of segments with length of two times the starting element width (2 x 4.5 mm). The spacing that separates the segments can now be made smaller (0.42 mm) because the higher scaling factor. The same taper line is used to obtain good impedance matching to 50 Ω. Results for the S_{11} parameter are presented in Fig. 15 while the radiation patterns are illustrated in Fig. 16.

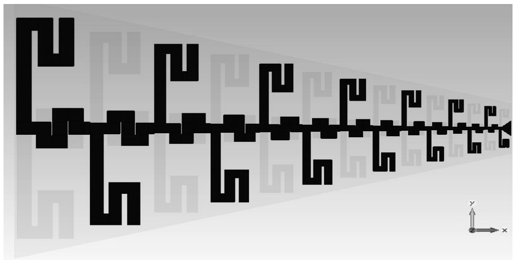

Figure 14. Variation of Peano LPDA type2 with fractal feed line.

TABLE V. DESIGN PARAMETERS FOR THE PEANO LPDA TYPE2 WITH FRACTAL FEED LINE.

Scaling factor	0.874
Length of the first Peano element L_1 [mm]	78
Spacing between 1st and 2nd element D_{12} [mm]	17.69
Spacing between fractal segments from shorting P_3 [mm]	0.42
Number of dipoles	14
Length of the antenna L_{ant} [cm]	14.97
Antenna surface area [cm^2]	83.56
Width of the first element W_1 [mm]	4.5
Starting width of the fractal feed line W_f [mm]	4.5

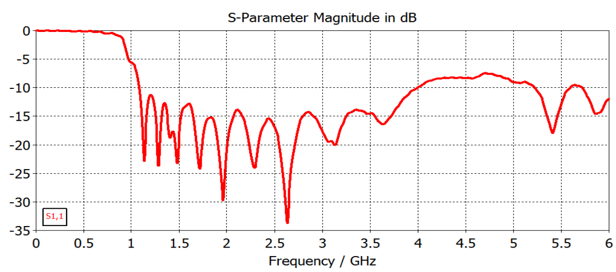

Figure 15. Simulared return loss for the Peano LPDA type 2 with fractal feed line.

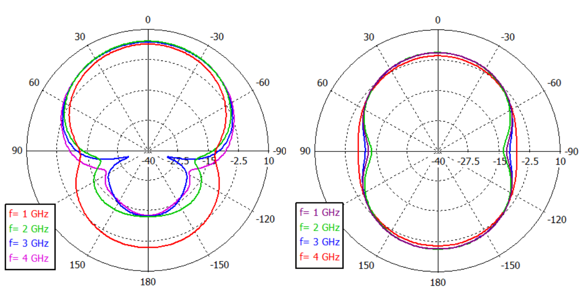

Figure 16. Radiation paterns at 1, 2, 3 and 4 GHz for the Peano LPDA type 2 with fractal feed line.

IV. COMAPRISON OF PROPOSED AND CONVENTIONAL LPDA

The proposed fractal LPDA antennas are compared with conventional one. The characteristic parameters are summarized in the Table VI, where L_{ant} denotes total length of antenna and Z_{ant} shows the variation of the characteristic impedance in the operating range. Although, fractal antennas require addition dipoles to satisfy bandwidth specification, 32 % size reduction can be obtained using fractal dipoles instead of conventional. Improvement of up to 49% reduction in occupied surface area can be obtained using additional fractal feeds. In the same time gain and directivity achieved with fractal antennas was decreased for 12% for the worst case. Smaller variation of the characteristic impedance is visible in the case of fractal antennas. Characteristic impedance of fractal antennas changes up to 65%, while conventional one has more than 80%.

TABLE VI. COMPARISION OF PROPOSED FRACTAL ANTENNA RESULTS AND CONVENTIONAL LDPA ANTENNA.

FLL is short for fractal feed line

LPDA	Conv.	Type1	Type2	FFL Type 1[a]	FFL Type2
N	12	14	14	13	14
L_{ant} [cm]	23.01	20.8	21.5	16	15
L_{ant} [%]	na	-9.6	-6.56	-30.47	-34.8
Surf. Area [cm^2]	166.12	134	111.5	97.81	83.56
Reduction [%]	na	-19.34	-32.88	-41.12	-49.67
Z_{ant} [Ω]	43 – 80	42 – 62	40 – 65	52 – 84	49 – 81
Gain [dbi]					
1 GHz	4.84	4.93	4.41	4.29	4.17
2 GHz	6.01	6.89	6.52	6.23	5.45
3 GHz	7.15	6.40	6.91	5.83	5.25
4 GHz	6.29	5.98	6.20	5.85	5.51
Half-power beamwidth [°]					
1 GHz	74.9	76.2	79.1	77.7	81.5
2 GHz	87.6	73.4	77.5	81.7	88.7
3 GHz	64.7	77.7	69.4	77.5	94.8
4 GHz	101.3	87.8	79.6	76.3	95.6

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