A T-Type Fractal Boundary Single-Feed Circularly Polarized Microstrip Antenna

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ABSTRACT: A single-feed T-type fractal boundary microstrip antenna is presented. It is established that a very good circular polarization is realizable with 3-dB axial ratio bandwidth of 1.27% at the center frequency of 2446 MHz by changing the electrical length in two directions of the square patch by using T-type fractal curve as boundary. Further it is shown that the surface area occupied by the antenna is reduced compared to the Euclidean shaped patch antenna without much degradation in gain of the antenna. Experimental results are compared with simulated results and a very good agreement is obtained. © 2008 Wiley Periodicals, Inc. Int J RF and Microwave CAE 19: 285–291, 2009.

Keywords: T-type fractal boundary; electrical length; axial ratio; circular polarization

I. INTRODUCTION

Low profile, conformal, compact size, multiband, and broadband are the desirable characteristics of antennas used in both commercial and military applications. There are many methods developed over the years to achieve the aforesaid attributes [1]. One such possibility in achieving the said qualities is to use fractal concept in microstrip antennas. Fractals are space-filling contours which can be packed efficiently into small areas. Since the electrical lengths play an important role in antenna design, this efficient packing can be used as a viable miniaturization technique [2].

Circularly polarized (CP) antennas are used in many applications like GPS, mobile satellite communications, radio frequency identification (RFID) applications etc. In these applications it is required to design the CP antenna which gives 3-dB axial ratio (AR) bandwidth of at least 1% and almost 0-dB AR at the frequency of operation. The change in electrical length in two directions of the square patch is a key point in obtaining circular polarization. There are many methods reported in the literature with single-feed CP antennas using square patch. The first single-feed CP antenna is reported by Sharma and Gupta [3] using square patch with truncated corners and with inclined slot. But the reported 6-dB AR bandwidth is only 0.831 and 1.134%, respectively with those antennas. Wong et al. [4] presented a different method to get circular polarization mainly aiming for compact size by incorporating slots and adding tails to the square patch. But with that method the impedance and 3-dB AR bandwidths are 1.61 and 0.381%, respectively. Row and Ai [5] have proposed a compact design of single-feed circular polarized antenna by cutting a crossed slot on the circular patch backed by square-shaped ground plane with crossed slot, but the peak gain is very low which is in the order of 1.8 dBi and 3 dB AR bandwidth of around 0.9%. Elsdon et al. [6] have reported a single-feed star-loaded patch antenna for circular polarization with 3-dB AR bandwidth at 2.4 GHz around 1.1% and the input impedance of the patch around 245 to 705 ohms. So, it is not matched to

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Figure 1. Generation of T-Type fractal curve.

the line. Further the AR at the center frequency is around 1 dB. Chen et al. [7] have proposed a novel compact CP square microstrip antenna. The gain with that antenna is only 1.4 to 3.5 dBi. Wong and Wu [8] have proposed a single-feed CP microstrip antenna by providing two pairs of narrow slits in the x and y directions of the square patch. The minimum AR obtained at the center frequency is about 0.5 dB [8]. In all these antennas the AR bandwidth is low and minimum AR is not close to 0 dB.

But in this article, a novel technique is used to obtain circular polarization by using a fractal curve as boundary to the square patch. The method proposed here is replacing the straight sides of square patch by a T-type fractal curve with slight difference in electrical length in two directions of the patch so that two orthogonal modes will be excited. The excitation of these two near degenerate modes is a prerequisite for obtaining circular polarization. As there are two parameters in hand-like indentation depth and indentation angle of the prefractal boundary, the designer has more flexibility to fine tune the patch for exciting two near degenerate modes.

When a fractal curve is used as boundary for the square and triangular patches it is always possible to reduce the size and surface area. For a given resonant frequency this fractal boundary antenna has a smaller area. This is an interesting feature when it is necessary to minimize conductor losses or expensive materials such as superconductor materials that are employed in the construction of the patch. This area reduction results in a higher quality (Q) factor, and hence lower bandwidth when the indentation depth is high [9].

For easy understanding, the case of linear polarization is discussed first. To get linear polarization, the patch is fed along the centerline of the patch. Its resonant behavior is modeled by a parallel RLC circuit. For circular polarization, the antenna is fed along the diagonal to equally excite two orthogonal modes. A series combination of two parallel RLC circuits is used to model the resonant behavior of the single-feed CP microstrip antenna. This arises from the fact that the feed independently excites two orthogonal modes, each of which is modeled as a single RLC circuit [10].

II. ANTENNA GEOMETRY

The proposed fractal boundary CP antenna can be obtained by replacing each pair of straight lines of square patch by a T-type fractal curve with different indentation depths and keeping indentation angle constant. The generation of the T-type fractal curve and the geometry of the antenna are shown in Figures 1 and 2. When the sides are replaced with the proposed prefractal curve, the length will be increased just by changing the indentation depth or indentation angle or both. This increase of the electrical length of the patch will help in controlling the resonant frequency in two directions of the patch, so that it is very simple to excite two orthogonal modes within the patch. The antenna is fed along the diagonal as shown in Figure 2. With the feed positions indicated, it is possible to get right- and left-hand circular polarizations. The specifications of antennas for simulation are: size of the patch (L) as 40 mm × 40 mm, thickness (h) of the substrate as 3.2 mm, relative permittivity (ε_r) = 2.33, and loss tangent = 0.0018.

III. RESULTS AND DISCUSSION

In this article, two cases have been considered.

A. Case I: Linear Polarization

Linear polarization is obtained by replacing each side of square patch with a T-type fractal curve as boundary having different indentation depths and indentation angles, keeping electrical length same in both directions of the patch and feeding the antenna along

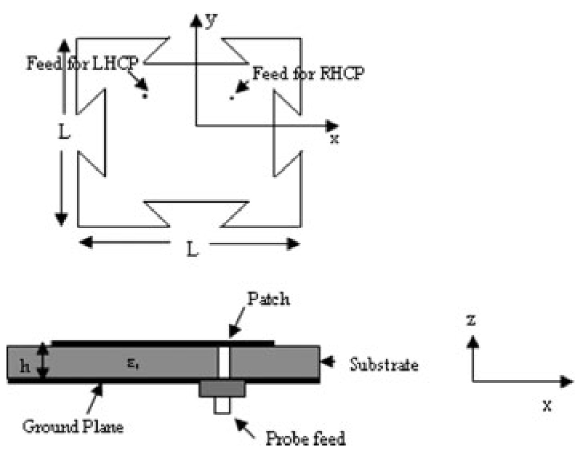

Figure 2. Geometry of the proposed antenna (L = 40 mm, 3.2 mm, ε_r = 2.33, loss tangent = 0.0018).

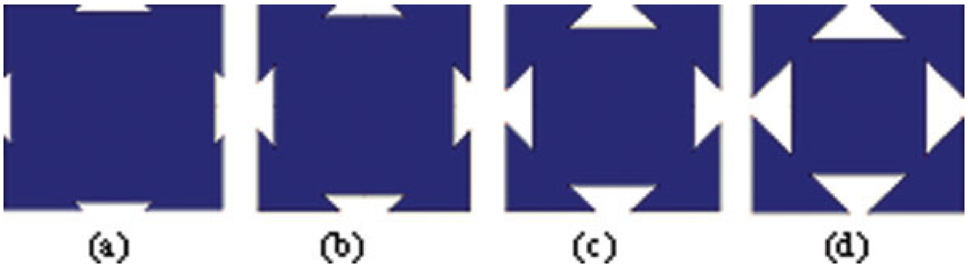

Figure 3. Geometry of the T-type fractal boundary antennas with indentation depth factor of (a) 0.1, (b) 0.2, (c) 0.3, and (d) 0.4. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

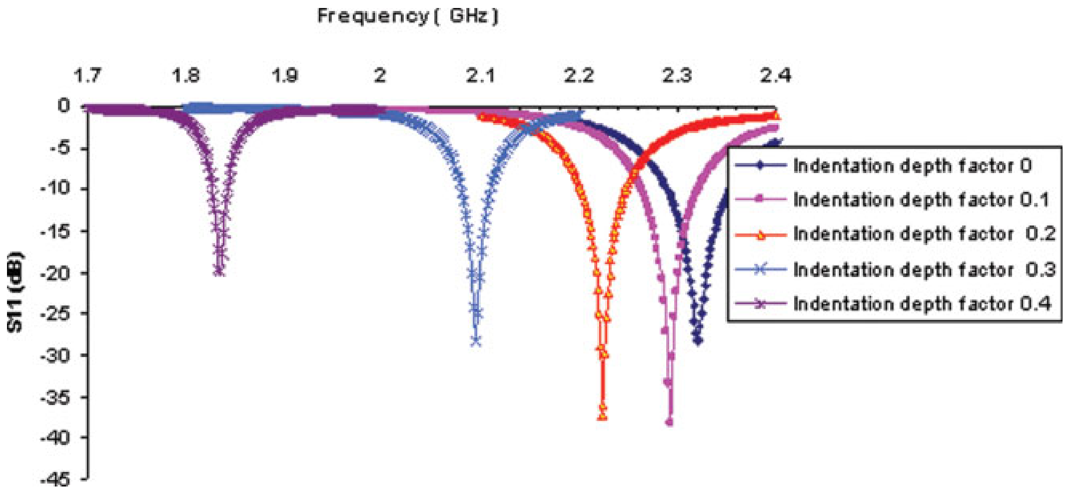

Figure 4. Simulated return loss characteristics of proposed antenna giving linear polarization for an indentation angle of 45° for different indentation depths. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

TABLE I. Resonant Frequency and Bandwidths of T-Type Fractal Boundary Linearly Polarized Antenna (End-to-End Dimension of the Patch is 40 mm and Indentation Angle as 45°)

Indentation Depth Factor	Resonance Frequency (GHz)	Band Width (MHz)	Gain (dBi)	Area (mm^2)	Perimeter (mm)
0 (square patch)	2.32	64	6.8	1600	160
0.1	2.292	57	6.8	1526	187
0.2	2.224	45	6.76	1447	219
0.3	2.094	30	6.34	1366	256
0.4	1.833	16	6.4	1282	300

TABLE II. Parameters of the Antennas Operating at the Same Frequency of 2.45 GHz

Indentation Depth Factor	Resonance Frequency (GHz)	Band Width (MHz)	Gain (dBi)	Area (mm^2)	% of Area Reduction Compared with Square Patch
0 (square patch)	2.45	64.8	6.8	1427	–
0.1	2.45	63.6	6.8	1320	7.5
0.2	2.45	56.4	6.74	1184	17
0.3	2.45	42	6.63	971	32
0.4	2.45	31	6.47	718	50

y-axis. The geometry of the antennas for various indentation depth factors is shown in Figure 3. As the indentation depth changes, the resonance frequency shifts toward origin because of increase in electrical length, this is clearly evident from Figure 4. When indentation depth factor is changed from 0 to 0.4 (keeping the indentation angle as 45°), the resonance frequency is changed from 2320 to 1833 MHz, i.e., 20% reduction in the resonance frequency, which can be observed from Table I. To assess the amount of size reduction of the patch, the antenna is made to operate at a frequency of 2.45 GHz for different indentation depth factors. The surface area of the patch is reduced from 1427 to 718 mm^2 when depth factor is changed from 0 to 0.4 while operating at the same frequency. At the same time it is observed that the impedance bandwidth is decreased from 64.8 to 31 MHz. This decrease in bandwidth is because of increase in Q factor of the antenna. As the impedance bandwidth of the patch antenna is proportional to the volume of the patch [11], the decrease in impedance bandwidth is expected with the fractal boundary microstrip antennas. The details are listed in Table II. The resonance frequency not only varies with indentation depth but also with indentation angle because electrical length changes with indentation angle also. This almost linear variation of resonance frequency with electrical length for different indentation depth factors is shown in Figure 5.

B. Case II: Circular Polarization

As it is mentioned in the earlier sections, circular polarization can be obtained by changing the electrical length in two directions. The variation in electrical length in two directions can be achieved either by changing the indentation depth or angle. But here only the change in indentation depth is considered for simulation and keeping indentation angle as 45°. Various indentation depth factors in two directions considered for obtaining circular polarization are mentioned in Table III. When the antenna is fed along the diagonal, the feed independently excites two modes. Figures 6 and 7 show the return loss characteristics and variation of AR with frequency. For all the cases, the AR at the center frequency is very close to 0 dB. Further the frequency at which the antenna matched to the line is exactly same as the frequency at which the minimum AR is obtained. As the indentation depth changes the center frequency of the antenna decreases which can be observed from Figure 7. For example, for the Antenna 1 the center frequency is 2267 MHz and for the Antenna IV (same end-to-end dimension of 40 mm) the resonance frequency has been decreased to 1881 MHz. This shows that there is a reduction of 17% in resonance frequency as can be seen from Table III.

IV. EXPERIMENTAL RESULTS

As a sample, a fractal boundary antenna having end-to-end dimensions of 36.4 mm with indentation depth factor (0.3,0.2) and indentation angle 90° is fabricated using RT Duroid substrate with relative permittivity (ε_r) of 2.33, thickness (*h*) 3.2 mm, and loss tangent 0.0018. The first number in the parenthesis indicates the indentation depth factor along *x*-direction and second one gives the same along *y*-direction. Photograph of the antenna is shown in Figure 8. The antenna is fed along the diagonal at a position where the impedance is 50 ohms. Measured return loss characteristics, radiation pattern, and rotating linear pattern are shown in Figures 9 and 10. The width on any position on the plot of the rotating linear pattern is an indication of AR. Table IV lists the details of resonance frequency, impedance, and AR bandwidth of the fabricated fractal boundary CP antenna. Zeland IE3D Electromagnetic simulator is used to analyze the antenna. Very good agreement is obtained between measured and simulated results. The perfect circular polarization is also verified with the help of Smith chart, where the variation of input impedance with frequency displays a loop with area zero. The area of the loop indicates the closeness of the two frequencies corresponding to orthogonal modes [12].

TABLE III. Various Parameters of Proposed Circular Polarized Antennas with Indentation Angle as 45° (Simulated)

Antenna	Indentation Depth Factor Along *x* and *y*	Center Frequency (MHz)	10-dB Impedance Bandwidth (MHz; %)	3-dB Axial Ratio Bandwidth (MHz; %)
Antenna 1	(0.105,0)	2267	126 (5.5)	31 (1.31)
Antenna 2	(0.2,0.13)	2238	108 (4.8)	27 (1.2)
Antenna 3	(0.3,0.26)	2120	80 (3.8)	21 (1)
Antenna 4	(0.4,0.382)	1881	44 (2.33)	10 (0.6)

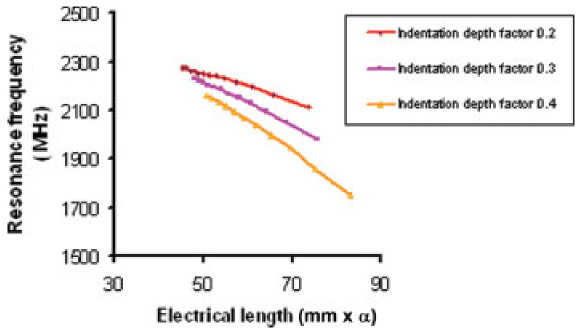

Figure 5. Variation of resonance frequency with electrical length for various indentation depths. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

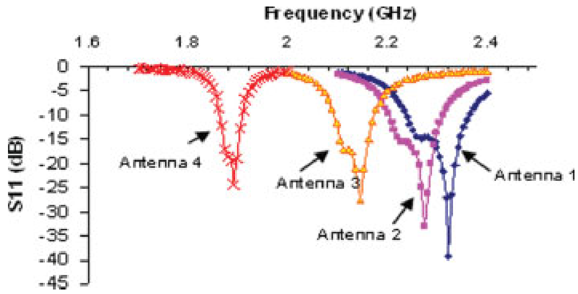

Figure 6. Simulated return loss characteristics of proposed CP antennas with different indentation depths. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

The Impedance and AR bandwidths of single-feed CP antennas can be expressed in terms of voltage standing wave ratio (VSWR) and Q factor of the antenna [10]. The bandwidth of linearly polarized antenna can be calculated using the relation

$$BW_{LP}^{IMP} = \frac{VSWR_{max} - 1}{\sqrt{VSWR_{max}}Q} \quad (1)$$

where Q is the quality factor of the antenna and $VSWR_{max}$ is the maximum allowable VSWR (here it is taken as 2). Similarly the impedance bandwidth of a single-feed CP microstrip antenna is given by

$$BW_{CP}^{IMP} = \frac{\sqrt{2(VSWR_{max} - 1)}}{Q} \quad (2)$$

The impedance bandwidth of the CP patch antenna is always greater than that of the same linearly polarized patch antenna by at least a factor of 2. And the 3-dB AR bandwidth of a CP microstrip antenna is given by

$$BW_{CP}^{AR} = \frac{AR_{max} - 1}{\sqrt{AR_{max}}Q} \quad (3)$$

where AR_{max} is the maximum allowable AR (here it is taken as $\sqrt{2}$).

According to equations given above, the impedance bandwidth of CP antenna will always be greater than that of corresponding linearly polarized antenna. Further the 3-db AR bandwidth is always less than half of the impedance bandwidth of the corresponding linearly polarized antenna for typical values of $VSWR_{max}$ and AR_{max}. Using the concept of fractal curve as boundary to obtain circular polarization there are three advantages: (1) increase of electrical length within the given space so that size is reduced,

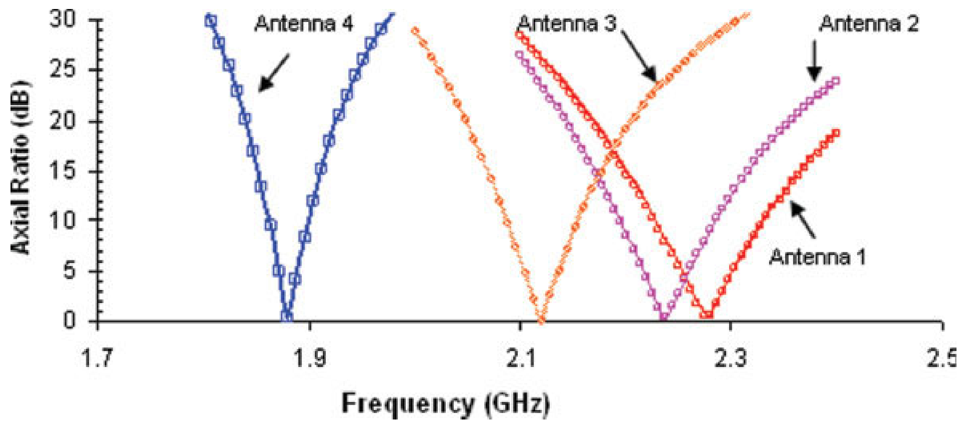

Figure 7. Simulated axial ratio versus frequency characteristics of proposed CP antennas with different indentation depths. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

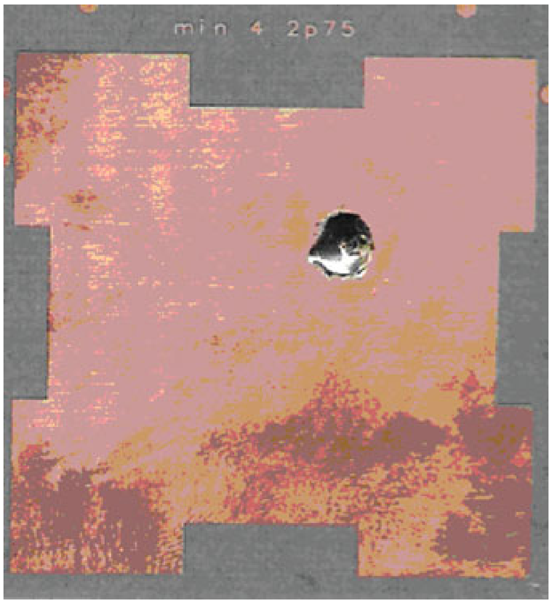

Figure 8. Photograph of fabricated fractal boundary CP antennas with indentation depth factor (0.3,0.2) and indentation angle 90°. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

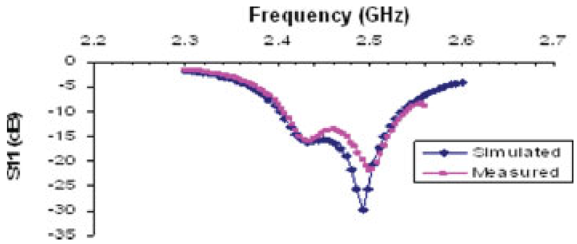

Figure 9. Measured return loss characteristics of the CP antenna with indentation depth factor (0.3, 0.2) and indentation angle 90°. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

(2) additional parameter such as, indentation angle and depth factor to design the antenna apart from patch length, relative permittivity, and thickness of the substrate, and (3) multiband operation. In addition, a very good circular polarization with AR close to 0 dB can be obtained.

V. CONCLUSIONS

A T-type fractal boundary single-feed CP microstrip antenna is presented. By choosing a proper indentation angle and indentation depth in two directions of the antenna it is shown that, it is very simple to get circular polarization. Further as the indentation depth factor changes, the resonance frequency decreases almost linearly since the electrical length increases linearly. With the proposed fractal boundary antenna the 3-dB AR bandwidth of about 1.27% is obtained.

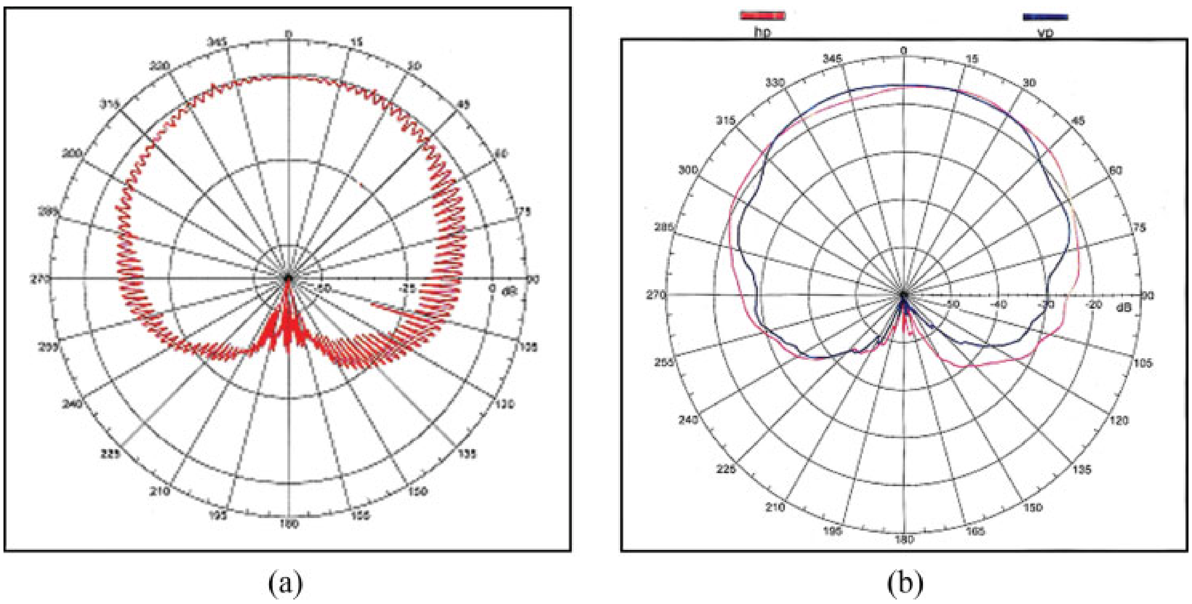

Figure 10. (a) Measured rotating linear pattern. (b) Measured radiation pattern (in *xz* and *yz* planes) at 2446 MHz. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

TABLE IV. Measured Parameters of Proposed CP Antenna

Indentation Depth Factor Along *x*	Indentation Depth Factor Along *y*	Center Frequency		3-dB Axial Ratio BW (%)	Minimum Axial Ratio (dB)
		f_o (MHz)	Imp BW (%)		
0.3	0.2	2446	5.43	1.27	0.1

The resonance frequency is varied by 20% when the indentation depth is changed from 0 to 0.4 for linear polarization. With this type of fractal curve as boundary, additional parameters such as, indentation depth, indentation angle, and iteration of the fractal curve, are available for the designer.

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