MULTI ELEMENT FRACTAL RECTANGULAR CURVE PATCH ANTENNA FOR INDOOR ACCESS POINTS

G. TSACHTSIRIS, M. KARABOIKIS, C. SORAS, V. PAPAMICHAEL AND V. MAKIOS
Electrical & Computer Engineering Department
University of Patras
Laboratory of Electromagnetics, 26500, Rio Patras
GREECE

Abstract: - In this paper the diversity performance of several multi element antenna configurations consisting of a novel fractal rectangular curve patch antenna is studied. The fractal rectangular curve microstrip antenna was chosen due to its very good size reduction ability without compromising significantly on the bandwidth and efficiency. The evaluation of the diversity performance was conducted by means of calculating the envelope correlation coefficient, the mean effective gain and the effective diversity gain of the proposed configurations.

Key-Words: - Fractals, fractal rectangular curve, multi element patch antenna systems, diversity, MIMO

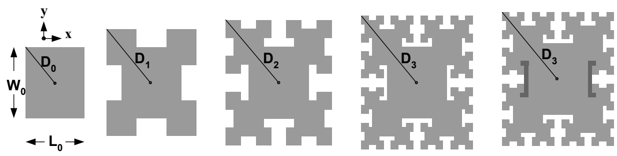
1 Introduction

Miniature antennas are of prime importance in wireless communications due to the available space limitations on the devices and the oncoming deployment of diversity and MIMO (Multiple Input Multiple Output) systems to mitigate the effects of the channel and increase the total received power. The microstrip patch antenna though very popular due to its low profile, ease of fabrication and low cost could not be considered as a good candidate for such applications owing to its large physical size.

In this paper a novel Fractal Rectangular Curve (FRC) patch antenna is proposed for use in multi element systems for indoor access points applications, due to its compact size and its ability to maintain good bandwidth and efficiency [1]. The FRC was employed for the realization of three diversity antenna systems; a two element co-polarized, a two element cross-polarized and a four element with mixed polarizations. In section 2 the construction of the FRC patch antenna and the multi element configurations are illustrated along with the computed input return losses. In section 3 the criteria for the evaluation of the diversity performance are presented and the proposed configurations are evaluated.

2 The Multi element FRC Patch Antenna System

The shape of the proposed configuration is a generalization of the "Squares Curve" [2], using a rectangular initiator instead of a square one. The FRC is constructed by applying a geometric transformation on the rectangle FRC0 of Fig. 1a. By producing four more rectangles of a quarter of the area of FRC0 and placing them at the four corners of the initiator as depicted in Fig. 1b, the pre-fractal FRC1 is obtained. Repeating this adding procedure one more time at each rectangle placed at the four corners, results in the pre-fractal FRC2 (Fig.1c). The ideal fractal curve would be obtained by applying this iterative procedure an infinite number of times. However, for antenna applications a few iterations would suffice.



a) b) c) d) e)

Fig. 1. Construction of the pre-fractals, a) FRC0, b) FRC1, c) FRC2, d) FRC3, e) modified FRC3.

The dimensions of the initiator are W_0 by L_0, while the semi-diagonal D_0, the perimeter Π_0 and the enclosing area A_0 can be expressed as:

$$D_n = 2D_0\sum_{i=0}^{n}\frac{1}{2^{i+1}} \ , \ \Pi_n = 2^n\Pi_0 \ , \ A_n = \left(\frac{2^{n+1}-1}{2^n}\right)^2 A_0 \quad (1)$$

Theoretically as n goes to infinity the semi-diagonal of the FRC is doubled, the perimeter goes to infinity, while the enclosing area increases four times.

The element that was chosen for the implementation of the two and four branch diversity system is the modified FRC3, which stems from the FRC3 by merely adding two metal patches as depicted in Fig. 1e with a darker colour. According to [1], this simple modification has proven to enhance the bandwidth of the element. The patch antennas are mounted on top of a 6.35 mm-thick substrate with relative permittivity ε_r=2.2 and loss tangent tanδ=0.0007. The thickness of the antenna's copper layer is 35 μm and the copper's conductivity is σ=5.8e7 S/m. The ground plane, which is mounted at the bottom of the dielectric slab, is assumed to be infinite. Initially two element configurations were considered, a co-polarized and a cross-polarized one, as depicted in detail in fig. 2 and 3 respectively. The patch's width and length is 35.5 and 29.7 mm respectively, with a corresponding ratio a=W/L=1.19. The inter-element spacing is λ_0/8 (15.3 mm at 2.45 GHz), while the antennas are excited through a probe feed as illustrated. The configurations were simulated using the IE3D Method of Moments based electromagnetic field solver [3].

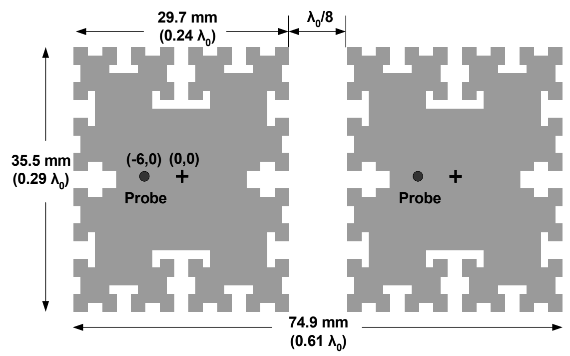


Fig. 2. Details of the co-polarized two branch antenna diversity system.

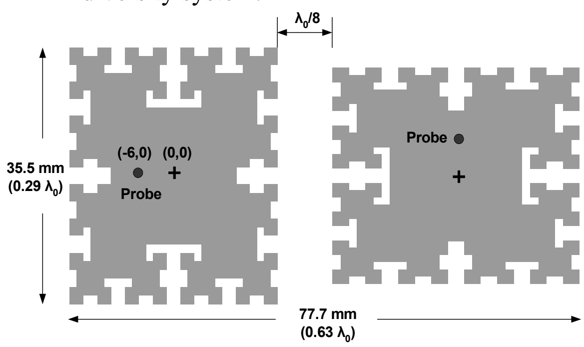


Fig. 3. Details of the cross-polarized two branch antenna diversity system.

The computed input return losses (Sii and Sij in dB) for both cases are shown in fig. 4, where it can be seen that the elements are well-tuned in 2.45 GHz ISM (Industrial Scientific and Medical)band achieving a 100 MHz bandwidth (4%). It can also be observed that in the cross-polarized case the mutual coupling between the antennas is reduced relative to the co-polarized one, since the Sij parameters do not exceed -27 dB in the band of operation.

In fig. 5 the four element case is depicted, where the patches are placed in such a way, so that each is next to a cross-polarized one, except for the diagonal elements.

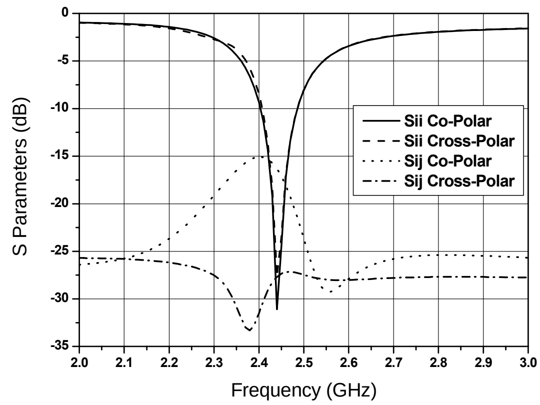


Fig. 4. The S parameters of the two element antenna systems.

The input return losses of the system are illustrated in fig. 6. It is clear that the diagonal placed antennas exhibit a stronger mutual coupling.

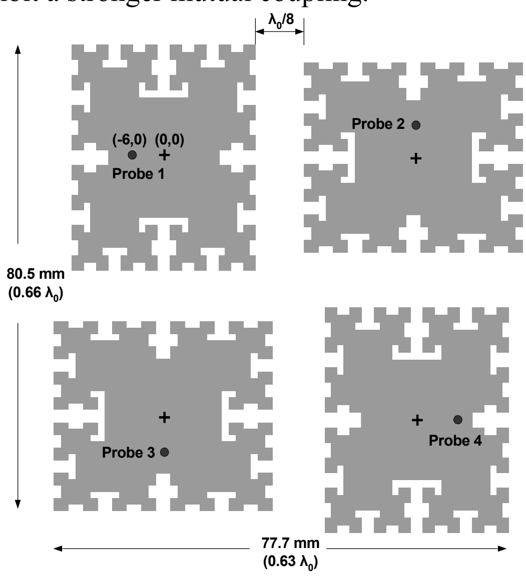


Fig. 5. Details of the four element antenna diversity system.

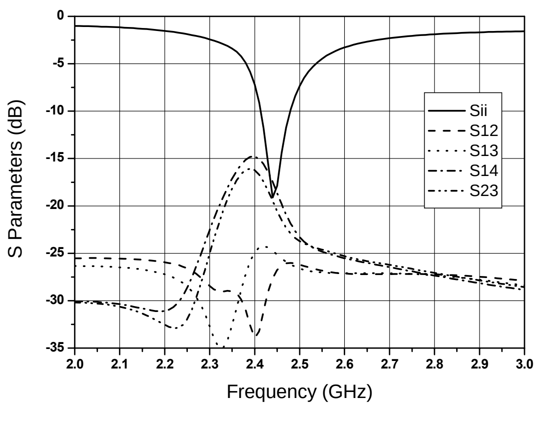


Fig. 6. The S parameters of the four element antenna system.

3 Evaluation of Diversity Performance

Diversity gain is the amount of improvement obtained from a multiple element antenna system relative to a single element one. It depends on the correlation coefficient and the relative mean power levels between the signals delivered from each antenna branch. In general, diversity gain increases when the correlation coefficient and the power imbalance between the diverted signals decrease.

The envelope correlation coefficient of the diverted signals can be calculated from Eq. 2 [4], where E_θ and E_φ are the θ and φ polarized electric field patterns of the antennas at the azimuth plane and Γ the cross polarization discrimination (XPD) of the incident field. The asterisk denotes the complex conjugate.

The mean power P_i received from each antenna branch, can also be obtained from the radiation patterns and the statistics of the channel using the concept of the Mean Effective Gain (MEG). The MEG of an antenna, which is defined as the ratio of the mean received to the mean incident power at that antenna, can be calculated from [4]:

$$MEG = \oint \left[\frac{\Gamma}{1+\Gamma} P_\theta(\Omega) G_\theta(\Omega) + \frac{1}{1+\Gamma} P_\varphi(\Omega) G_\varphi(\Omega) \right] d\Omega \quad (3)$$

where, G_θ and G_φ are the θ and φ polarized components of the antenna power gain pattern , Ω is the solid angle (θ,φ) and P_θ, P_φ are the θ and φ components of the angular density functions of incoming plane waves expressed as:

$$P_\theta(\theta,\varphi) = A_\theta \exp\left[- \frac{\left\{ \theta - [\frac{\pi}{2} - m_V] \right\}^2}{2\sigma_V^2} \right] \quad (0 \le \theta \le \pi) \qquad (4)$$

$$P_\phi(\theta,\varphi) = A_\phi \exp\left[- \frac{\left\{ \theta - [\frac{\pi}{2} - m_H] \right\}^2}{2\sigma_H^2} \right]$$

where it is assumed to be Gaussian distributed in elevation and uniform in azimuth [5]. The radio propagation environment used for calculating the incident power at the antennas is assumed to be an indoor picocell one as reported in [6]. Hence, the XPD is taken equal to 7dB and the m_V, m_H, σ_V and σ_H equal to 3.8^0, 1.9^0, 8.7^0 and 10.7^0 respectively.

Diversity gain can be achieved when the signals received from two antennas satisfy the following criteria [4]:

$$\rho_{eij} < 0.5 \quad \text{and} \quad P_i \cong P_j \qquad (5)$$

Assuming that the mean incident power on each antenna is the same, the equality criterion between P_i and P_j reduces to equality between MEG_i and MEG_j.

Apart from the traditional definition of diversity gain, Kildal et al. [7] defined the effective diversity gain (EDG), which is an absolute measure of the diversity performance between different antenna systems. According to this definition, the effective diversity gain is expressed mathematically from:

$$G_{effdiv} = \frac{P_{div}}{P_{ideal}} \qquad (6)$$

where P_{div} is the received power level of the combined signal and P_{ideal} is the received power level of a single antenna with unit radiation efficiency operating in the same environment. P_{div} and P_{ideal} are read at the same probability level in a cumulative probability density versus power level plot. In this paper the cumulative density function of P_{div} is computed as a function of the envelope correlation coefficient and mean effective gain for the maximum ratio combining case [8] and P_{ideal} follows the Rayleigh distribution [9].

The envelope correlation coefficient and the mean effective gain ratio of the three systems are shown below in Table 1 and 2. It can be easily observed that in cases where the antennas are co-polarized the correlation coefficient is increased significantly and in the two element system the accepted limit is exceeded (0.637>0.5), unlike the cross polarized case, where the antennas are highly uncorrelated. Regarding the MEG ratio, it is obvious that in all cases is almost unity, indicating that the mean power delivered from each antenna branch is nearly the same.

$$\rho_{eij} \approx \frac{\left| \oint (\Gamma \cdot E_{\theta i}(\Omega) \cdot E^*_{\theta j}(\Omega) \cdot P_\theta(\Omega) + E_{\phi i}(\Omega) \cdot E^*_{\phi j} \cdot P_\phi(\Omega)) d\Omega \right|^2}{\oint (\Gamma \cdot G_{\theta i}(\Omega) \cdot P_\theta(\Omega) + G_{\phi i}(\Omega) \cdot P_\phi(\Omega)) d\Omega \cdot \oint (\Gamma \cdot G_{\theta j}(\Omega) \cdot P_\theta(\Omega) + G_{\phi j}(\Omega) \cdot P_\phi(\Omega)) d\Omega} \qquad (2)$$

Table 1
The envelope correlation coefficient and mean effective gain ratio of the two element systems

	ρe_{12}	MEG1(db)	MEG2(db)	Ratio
co-polar	0.637	-6.705	-7.273	1.065
cross- polar	0.0045	-6.674	-6.774	1.011

Table 2
The envelope correlation coefficient and mean effective gain ratio of the four element system

	ρe_{ij}	MEGi, MEGj(db)	Ratio
1/2	0.001	-7.825, 7.351	0.983
1/3	0.006	-7.825, -7.279	0.969
1/4 co	0.391	-7.825, -7.786	0.993
2/3 co	0.432	-7.351, -7.279	0.986

Fig. 7 illustrates the cumulative probability density function of the SNR of the combined signals for the three cases. The EDG is read at a specific outage probability level comparing the Rayleigh reference curve with the one of the combined signal as shown below. It can be seen that the two element co-polarized case exhibits the lowest value of EDG (3.4dB), which was expected since the two elements are highly correlated. On the other hand, the cross polarized system exhibits higher gain (5.2 dB) attributed to the polarization diversity mechanism which decorrelates the two antenna signals. Finally, the third system (4-element) demonstrates the best diversity performance with 10.8dB of EDG owing to the fact that the diversity gain increases as the number of antenna branches increases.

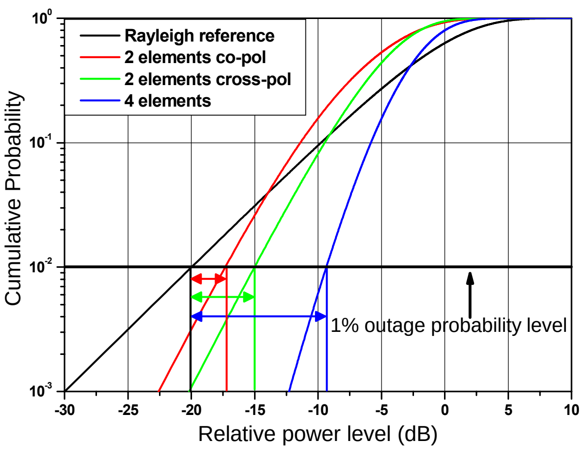


Fig. 7. The cumulative probability density function of the MRC combined signals of the three diversity systems.

4 Conclusions

In this paper a fractal rectangular curve patch antenna is proposed for wireless access point applications. The FRC was employed for the realization of three diversity antenna systems; a two element co-polarized, a two element cross-polarized and a four element with mixed polarizations. The evaluation of the diversity performance was conducted by means of calculating the envelope correlation coefficient, the mean effective gain and the effective diversity gain of the three systems. The cross-polarized system exhibits higher gain relative to the co-polarized one with the four element case demonstrating the highest gain, 10.4 dB.

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