THE MINIATURE INVERTED KOCH SQUARE MICROSTRIP PATCH ANTENNA

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Abstract:

Novel kind of miniature and broadband fractal patch antenna based on inverted Koch square fractal with variable indentation angle is studied. L-System generator was advantageously used to create desired geometry with possibility of adjusting its properties. Impedance and radiation behavior of proposed antennas are numerically investigated with IE3D MoM simulator and partially by modal analysis as well.

Introduction

Miniaturization of patch antennas is a recent topic, interest is particularly on those offering wideband properties. Numerous methods were introduced to decrease the microstrip patch antennas size such as shorting pins and planes, introducing of U-slots, using of high permittivity materials [1]. Using of fractal shapes is a quite new way to design promising miniature antennas. Recently, there is a paper on so called Fractal Clover Leaf [2] with considerable size reduction of the patch. We did a parametric study on another fractal structure called Inverted Koch Square (IKS) with variable indentation angle (60, 80, 85 and 88 degrees, see Fig. 1). All the studied antennas through the paper are scaled to have the same edge dimensions 31.31mm $\times$ 31.32mm for easy comparison of performance. All the antennas are feeded using L-probe with an airgap to obtain wideband behavior. For quick evaluation of surface currents on fundamental mode we have used fast modal analysis calculated with FEMLAB. Accurate solutions was then obtained by IE3D Method of Moment simulator.

L-System fractal generator

L-System (Lindenmayer System) [3] is a very useful tool for generating the fractal geometry. We have developed [4] a MATLAB script able to generate plenty of L-System fractals and export them to several state-of-art EM simulators. We will not repeat here the whole L-System principle, let us show only the needed alphabet used for creating our antenna set.

L-system alphabet

Alphabet needed to create the desired set of Inverted Koch Square antennas consists of the the letters described below:

F move forward a step of length f

+ turn left by a specified angle α

$-$ turn right by a specified angle α

$<$ turn left by a specified angle β

Inverted Koch square with variable indentation angle

Inverted Koch Square (IKS) fractal with variable indentation angle is defined by L-System algorithm as follows: seed: F<F<F<F, rule: F→ F−F++F−F.
Indentation angle α (see Fig. 1) is defined within operators + and $-$, as described above. The

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seed (initial set) is a rectangle, the angle for < operator is thus β=90°. In the paper, we will denote Inverted Koch Square by notation IKSn-α, where n is number of performed iterations and α is the indentation angle.

Modal analysis

Modal analysis was employed as the first step to quickly estimate resonant frequencies and current distributions. We have used FEMLAB Finite Element package and calculated the performance of third iteration fractals (n=3) with indentation angles 60, 80, 85 and 88 degrees (IKS3-60, IKS3-80, IKS3-85 and IKS3-88). IKS3-60 was included because it's one of the "tabelled" and well-known fractals and partially was studied in [5]. First we have to anticipate that agreement between modal and full-wave analysis isn't perfect like one could expect. Main reason is strong coupling inside the IKS structure, caused by triangular slots. Obviously, such coupling can't be included within cavity model. Also the L-probe is moving the structure behavior little far from cavity model presumptions. Calculated resonant frequencies are show in Tab. 1, where *FRF* states for Frequency Reduction Factor, considered to be 100% for a rectangular patch with the same dimensions (31.31mm × 31.32mm) which plays role as a reference or say, "standart antenna". From the results in Tab. 1 it's clearly observed that as the indentation angle α increases, resonant frequency significantly decreases. This could be very likely addressed to number of arised thin triangle shaped slots. For higher indentation angles with low resonant frequency, the current is forced to intensely concentrate along both diagonals of the shape, see arrows in third picture in Fig. 1. Full-wave analysis (IE3D) fully proved this result (see Fig. 5), moreover both current paths are in-phase, producing linear polarization.

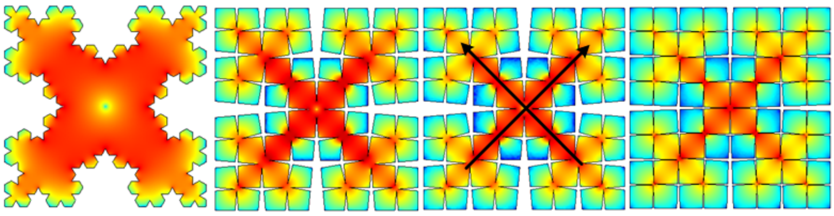

Fig. 1: Modal currents $|\mathbf{J}_e|$, 1^{st} mode of IKS3-60, IKS3-80, IKS3-85 and IKS3-88, log scale

antenna	resonant frequency [GHz]	FRF [%]
IKS3-60	4.25	88.7
IKS3-80	1.716	35.8
IKS3-85	1.308	27.3
IKS3-88	1.307	27.3

Tab. 1: Resonant frequencies of IKS with variable indentation angle α

Another study was performed to investigate behavior with fixed indentation angle α=85° and increasing iterations (iteration 0 is a rectangle obviously, iterations 1-4 are shown at Fig. 2). Again, the forming of the diagonal current paths is clearly observed. Resonant frequencies decrease with iterations, however it's not fully clear like the case when changing the angle. Frequency of the fourth iteration, IKS4-85, is slightly higher compared to previous iteration, IKS3-85 and we unfortunately haven't found satisfactory reason. One explanation could be impropriate meshing used in FEMLAB because of high computer memory demand.

Full-wave simulations

Full-wave simulation was performed using IE3D Method of Moments simulator. The antennas are considered to have infinite ground plane and air substrate. Set of antennas IKS3-60, IKS3-80, IKS3-85 and IKS3-88 was simulated using L-probe feed, adjusted for every case. Main parameters are summed up in Tab. 3, Fig. 3 shows reflection coefficient RL_{dB} for reference impedance Z_0=50Ω.

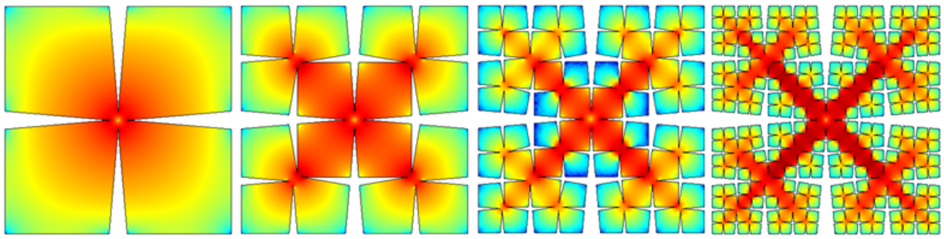

Fig. 2: Modal currents $|\mathbf{J}_e|$, 1^{st} mode of IKS1-85, IKS2-85, IKS3-85 and IKS4-85, log scale

antenna	resonant frequency [GHz]	FRF [%]
IKS0-85	4.78	100
IKS1-85	2.55	53.3
IKS2-85	2.0	41.8
IKS3-85	1.308	27.4
IKS4-85	1.566	32.7

Tab. 2: Resonant frequencies of IKS with constant indent. angle α=85° and variable iterations

Radiation patterns was calculated for middle of the band of each antenna. Radiation patterns (see Fig. 4) suffers mainly from the currents on vertical portion of L-probe. Particularly the cross-polarization level in H-plane may be unwanted for certain applications. However, by decreasing the height of the air-gap the cross-polarization level could be significantly improved. Final geometry configuration for IKS3-85 is shown at Fig.4, calculated gain varies from 4.1 to 6.3 dBi inside the working band.

antenna	f_0 [GHz]	FRF [%]	BW [%]	G [dBi]
IKS3-60	2.2	45.9	11.8	∼3.5
IKS3-80	2.1	43.8	24.5	3.12 - 5.5
IKS3-85	2.0	41.8	21	4.1 - 6.3
IKS3-88	1.95	40.7	8	3.2 - 6.3

Tab. 3: IE3D results for IKS3-60, IKS3-80, IKS3-85 and IKS3-88

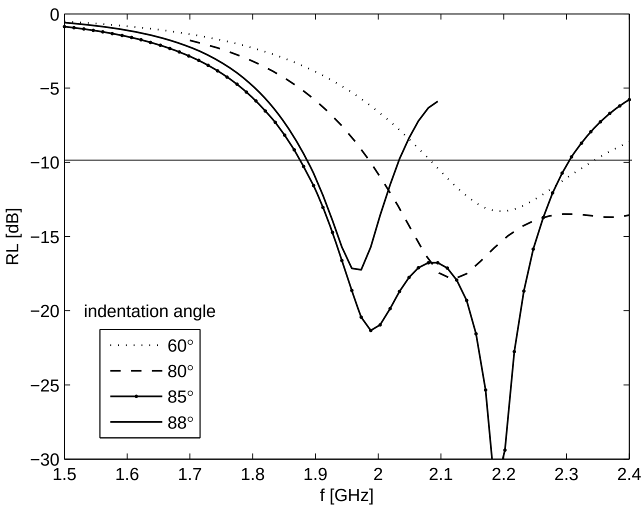

Fig. 3: Module of reflection coefficient for IKS3-60, IKS3-80, IKS3-85, IKS3-88

Improvement on radiation properties

In order to improve radiation properties, IKS3-85 with lower air-gap (h=10mm $\sim 0.06\lambda$) and adapted L-probe parameters (L_h=22mm, L_e=5mm) was introduced. Indeed, bandwidth in now much smaller, only 1.5%, but cross-polarization level in H plane is improved by approximately

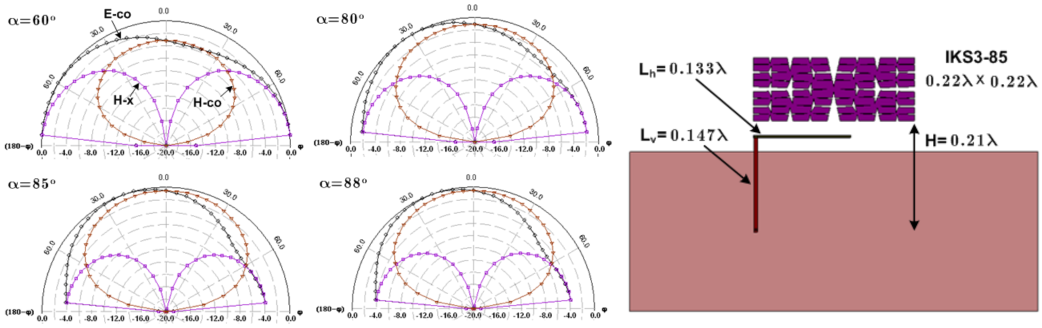

Fig. 4: Pattern cuts for IKS3-60, IKS3-80, IKS3-85, IKS3-88 and geometry layout for IKS3-85

12dB in turn and the gain now reaches 8dBi. Symmetry of radiation pattern is improved also (see Fig. 5).

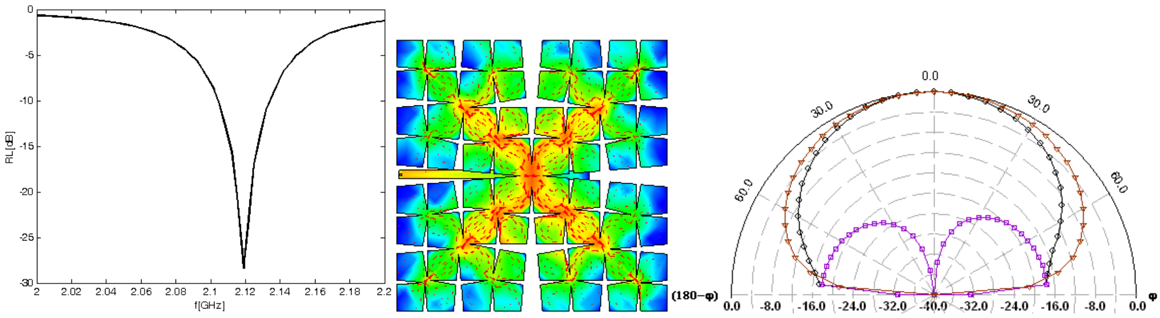

Fig. 5: Improved IKS3-85 antenna - return loss, surface currents and radiation pattern

Conclusion

Set of miniature patch antennas based on Inverted Koch Square was studied using numerical simulation, both modal and full-wave. It has been found that IKS structure with proper indentation angle offers considerable miniaturization (edges of the IKS3-85 have dimensions $0.22\lambda \times 0.22\lambda$). Bandwidth around 20% makes possible to cover PCS band and use such antennas for mobile communication purposes. However, vertical portion of L-probe causes high cross-polarization level in H plane which may be unwanted for certain applications. In order to improve the radiation behavior, air-gap and thus the vertical L-probe portion length has been decreased. Indeed, the bandwith consequently decreased, but cross-polarization level improved by approximately 12dB and gain by 3dB.

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