Fractal Spiral Monopoles: Theoretical Analysis and Bandwidth Optimization

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***Abstract* — Spiral antennas are characterized by low resonant frequencies and broadband matching for high frequencies. We present in this work a theoretical analysis and optimization of a special type of spiral antenna, namely the Fractal Spiral Monopole (FSM). In the low frequencies in the range 0<L/λ<1 (L is the height of the monopole and λ the wavelength), variation of the resonant frequencies in function of the monopole's dimensions was investigated. In the high frequencies in the range 0<L/λ<3, the monopole's dimensions were optimized in order to obtain broadband matching. The Method of Moments (MoM) was used for calculations.**

***Index Terms* — Broadband antennas, spiral antennas, monopole antennas, method of moments.**

I. Introduction

During the last years, the achievements in antenna design have been characterized by an exhaustive utilization of different antenna geometries. Broadband antennas are notable examples. Before the 1950s, antennas with broadband pattern and impedance characteristics had the bandwidths not greater than 2:1. In the 1950s, a breakthrough in antenna evolution was made with extended the bandwidth to as great as 40:1 or more. These antennas were referred to as *frequency independent*, and they had special geometries, for example spiral one [1]. Analysis of single-arm and two-arm printed spiral antennas is presented in [2] and [3] respectively. These antennas possess broadband impedance characteristics.

In this work, we discuss a special type of spiral linear antenna, the Fractal Spiral Monopole (FSM). This antenna has a spiral form. It is also a fractal one because the method that is used to produce the geometry of the antenna similar to the methods of construction of fractal curves.

We analyze the characteristics of these monopoles in the low frequencies and optimize their bandwidths in the high frequencies. The calculated parameters are the resonance frequency, input impedance, reflection coefficients, gain, and radiation diagrams. The Method of Moments (MoM) [4] is used for the numerical calculations and some theoretical results are compared with the existent data in the literature.

II. Antenna description

The Fractal Spiral Monopole is constructed as follows. N_s orthogonal segments are added successively to the conventional monopole of the height L. Fig. 1 shows the process of successive iterations for this antenna. The length of a generic segment is calculated by $L_n=(K_f)^n L_0$, where n=1, 2, 3, ..., N_s, and L_0<L is the initial length, and K_f is the reduction factor (0<K_f<1). An example of the FSM with N_s=19, K_f=0.9, and L_0=0.9L is given in Fig. 2.

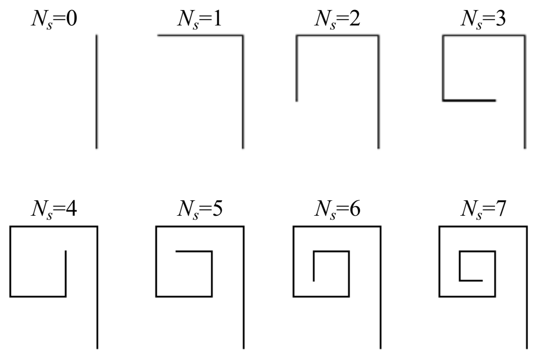


Fig. 1. Examples of successive iterations of the FSMs.

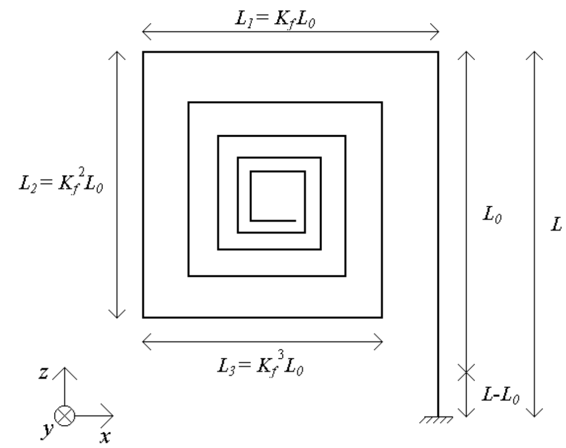
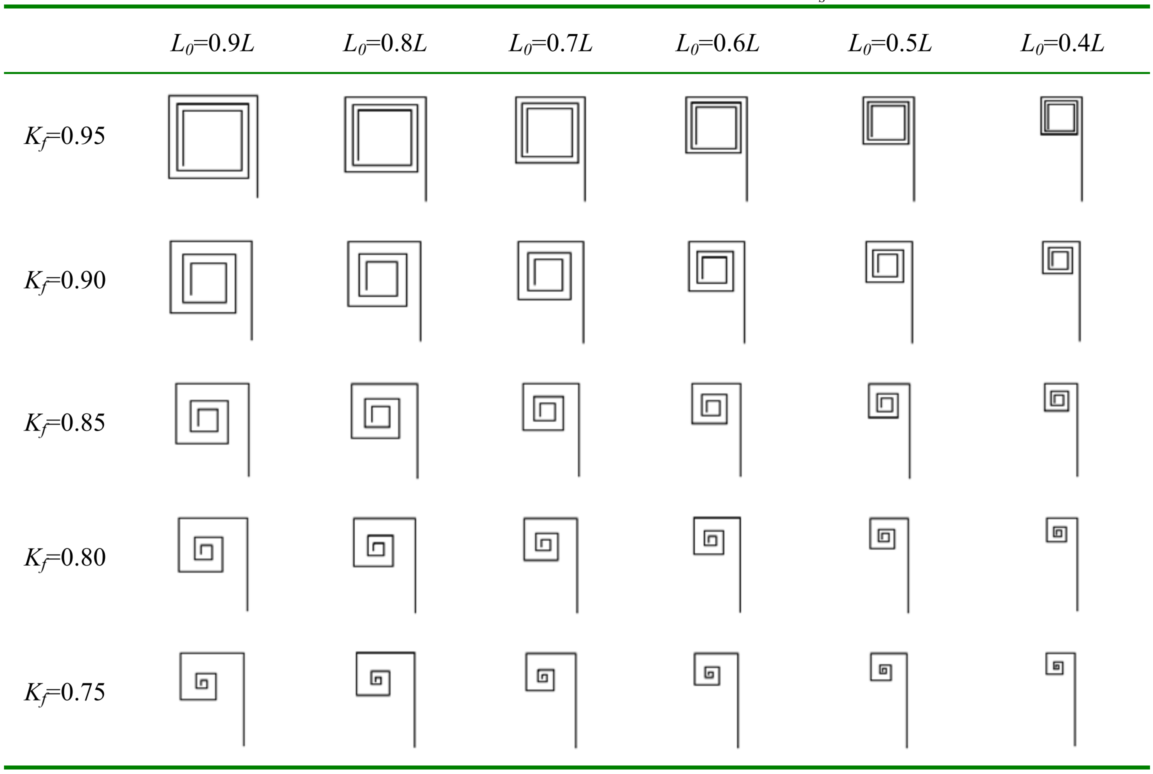


Fig. 2. Geometry of the Fractal Spiral Monopole.

TABLE I
EXAMPLES OF FRACTAL SPIRAL MONOPOLES WITH N_s=10



The parameters L, L_0, K_f, and N_s define the FSM. The radius of the conductors used in numerical calculations is $a=L/200$. Table 1 shows several examples of the FSM with different values of the parameters. The number of segments is N_s=10.

III. ANALYSIS FOR LOW FREQUENCIES

In order to analyse the FSMs, a MoM code was developed. In this code, we used pulse and Dirac's delta functions for basis and test functions, respectively. All the antennas shown in Table 1 were analyzed with N_s varying from 1 up to 8. The time of each simulation was around 5 minutes (computer Pentium IV). In these simulations, the length L was divided in 15 segments, and the lengths L_1, L_2, ..., were divided in 8 segments.

Firstly, we present a comparison of the resonant frequency calculated here and in [5] for the monopole in the form of L. The discretization and the dimensions of this monopole are shown in Fig. 3.

The resonant frequency obtained by MoM code developed here is 531 MHz and the frequency obtained in [5] by the software EZNEC [6] is 528.7MHz. The difference between these values is 0.44%. This result shows a good agreement between our MoM code and the commercial software EZNEC.

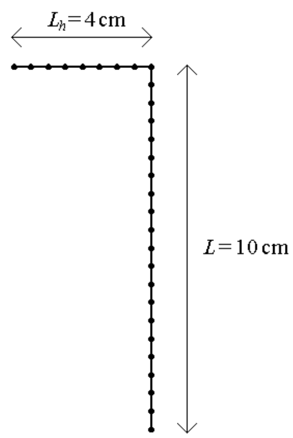


Fig. 3. Geometry and discretization of the L monopole.

A. Resonant Frequencies

The resonant frequencies of the FSMs are reduced when the parameters K_f, L_0, and N_s are increased. Fig. 4 shows an example of the dependence of the resonant frequency on the parameters K_f, and N_s for the monopole with L_0=0.9L. The reduction of the resonant frequencies is asymptotic and the values of the resonant frequencies converge in a few iterations (N_s=4). The lowest value obtained was L/λ=0.0471 for the antenna with L_0=0.9L, K_f=0.95, and N_s=6. This value corresponds to a reduction of 80% of the length L in comparison with a conventional monopole with the same resonant frequency.

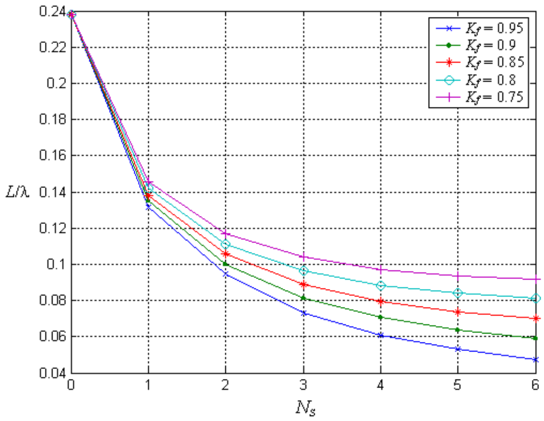


Fig. 4. Variation of the L/λ in function of K_f and N_s, at the first resonance, L_0=0.9L.

B. Input Impedance

Fig. 5 shows the input impedance of the FSMs with L_0=0.9L, K_f=0.9, and N_s=0, 1, 2, and 3. In this figure, the dependence of the input impedance (Z_{in}=R_{in}+jX_{in}) on the number of segments N_s is presented. We can see that when N_s is increased, the variation of the Z_{in} is increased too. This means that the bandwidth matching in the low frequencies is decreased for large N_S. The bandwidth is diminished for larger values of the L_0 and K_f.

C. Radiation Diagrams

Fig. 6 shows the radiation diagrams in the planes *xz* and *yz* for the FSMs with L_0=0.9L and N_s=4. The gain in these diagrams was calculated for the first resonance. In these diagrams, *co* means vertical polarization or co-polarization, and *cross* means horizontal polarization or cross-polarization. All the diagrams calculated at the first resonance have a similar form.

The antennas analyzed here have a significant radiation in the *z* direction. This is explained by the presence of the horizontal segments of conductors, which radiate in *z* direction. The radiation magnitude of the cross-polarization in the plane *yz* is less then 0dB at the first resonance, and more then 0dB at the second resonance.

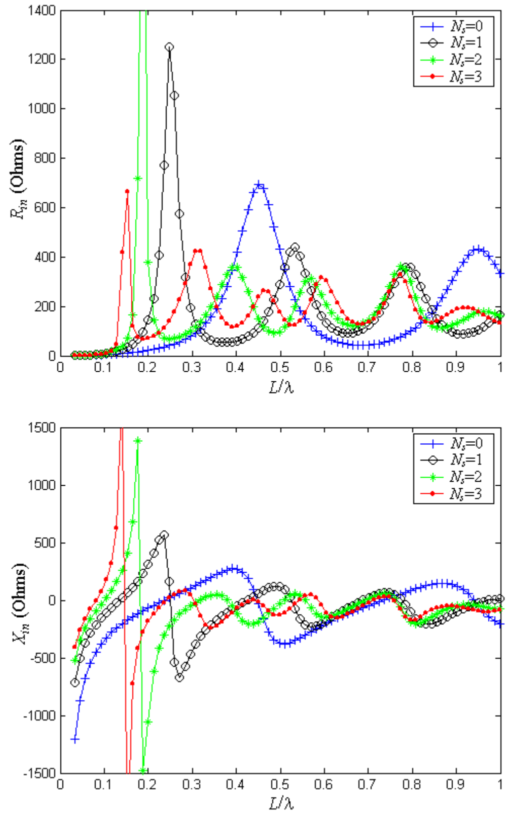
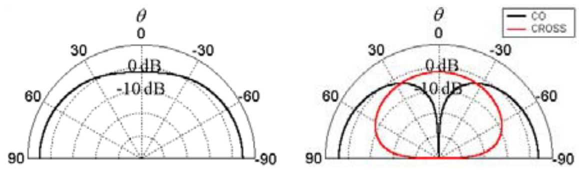


Fig. 5. Variation of the Z_{in} in function of N_s for the FSMs with L_0=0.9L and K_f=0.9.



(a) (b)

Fig. 6. Radiation diagrams of the FSM with L_0=0.9L, K_f=0.9, and N_s=4 at the first resonance. (a) plane *xz*. (b) plane *yz*.

IV. ANALYSIS FOR HIGH FREQUEQUENCIES

For all the antennas shown in Table 1, the best results in terms of bandwidth matching were the cases with L_0=0.8L and L_0=0.7L. Only these results are presented here.

A. Input Impedance

An example of the input impedance Z_{in} calculated in the range 0<L/λ<3 is presented in Fig. 7. It is observed that with increasing the number of segments (N_s=1, 2 and 3), the variation of Z_{in} in function of L/λ becomes smaller. The real part of Z_{in} (R_{in}) possesses the values around 200Ohms, and the imaginary part of Z_{in} (X_{in}) remains close to zero.

For $N_s>3$, there is no significant change of Z_{in} in the range $0<L/\lambda<3$. This means that it is sufficient to use a small number of segments to obtain broadband matching. A transmission line with characteristic impedance Z_0=200Ohms can be used for feeding the antenna.

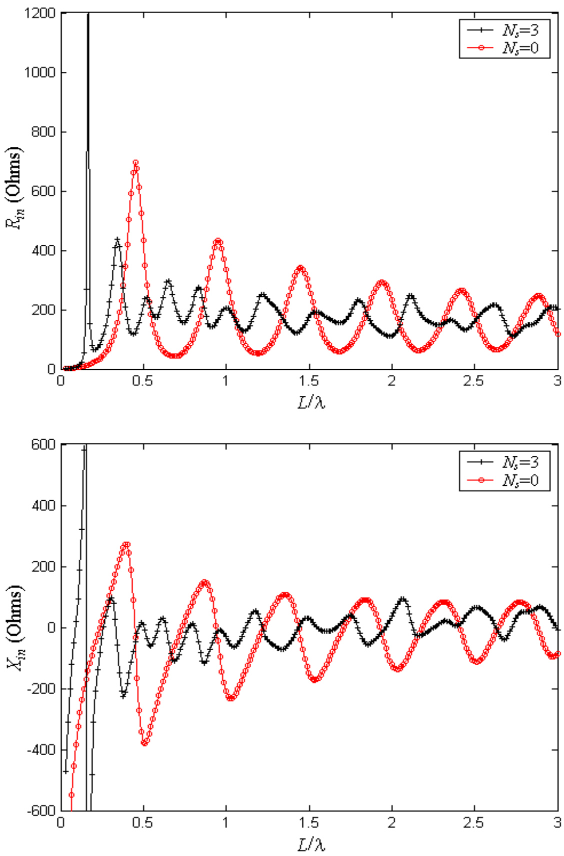


Fig. 7. Input impedance for the FSM with N_s=3, L_0=0.8L, and K_f=0.9. The conventional monopole is N_s=0.

B. Reflection Coefficient and Gain

Fig. 8 shows a typical example of reflection coefficient $|\Gamma|$ and gain G for the FSM. The input transmission line has the characteristic impedance Z_0=200Ohms. The gain shown in Fig. 8 is in z direction.

The broadband matching is in the range $0<L/\lambda<3$, where for $L/\lambda>0.5$ this antenna has $|\Gamma|<-10$dB. The FSMs with L_0=0.8L and L_0=0.7L and with different values of K_f have characteristics to those show in Fig. 8.

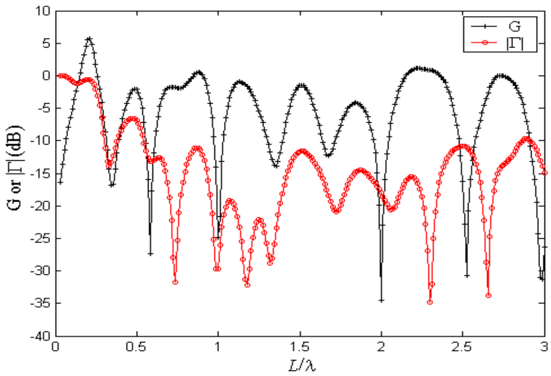


Fig. 8. Reflection coefficient $|\Gamma|$ and gain G in function of L/λ for the FSM with L_0=0.7L, K_f=0.85, and N_s=4.

V. Conclusion

We have presented in this work the analysis and broadband optimization of the FSMs in low and high frequencies, respectively. In low frequencies, these monopoles are resonant, and the reduction of L in comparison with the conventional monopole is about 80%.

In high frequencies ($0<L/\lambda<3$), these antennas have frequency independent characteristics. The FSMs with L_0=0.8L and L_0=0.7L possess better impedance matching. It was also shown that for broadband operation, it is sufficient to use the small number of segments (N_s=3).

Acknowledgement

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