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Compact Circle-Elliptical Combined Fractal (CECF) Monopole Antenna for Super Wideband Applications

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Abstract

A novel printed circle-elliptical combined fractal (CECF) microstrip-fed monopole antenna is presented for super wideband (SWB) applications. The antenna is composed of a semi-elliptical ground plane and the CECF patch. In comparison to the previous SWB and fractal antennas the entire size of antenna is only 18×24×1.6 mm^3. The simulated results imply that the 2:1 VSWR is from 1.2 to 35 GHz with the 10-dB BW (%) of 190 (%). The simulated and measured result of the designed structure indicates that it is useful for super wideband applications. The simulated and measured results are in good agreement.

Keywords: fractal monopole antenna, circle-elliptical combined fractal, super wideband (SWB), BDR.

INTRODUCTION

For modern wireless systems and devices, the presence of compact and wideband antennas are essential because of space limitation in this systems and devices [1], [2]. The best option for applications in the ultra-wideband (UWB) communication systems are planar monopole antennas due to their wide impedance bandwidth, uncomplicated structure, and omni-directional radiation patterns [4]-[6]. The fractal structures, as it's space filling and self-similarity characteristic, were vastly indent for wide impedance bandwidth, multiband and miniaturized antennas [1], [7].

In 2002, the federal communication commission (FCC) prescribed the frequency band from 3.1 to 10.6 GHz with a ratio bandwidth of 3.4:1 for UWB communication [8], start an exclusive concentration in wideband antennas. SWB antenna with a ratio bandwidth equal or greater than to 10:1 is generally called a super wideband (SWB) antenna in the antenna literature [1]. In the late 1950s and early 1960s, a family of SWB antennas was developed by Ramsey *et al*, which was classified as a class of frequency-independent antenna [9]-[11]. Lately, lots of printed monopole antennas with different structures were suggested for SWB applications. As a case in point, a novel microstrip-fed fractal monopole antenna presented in [1] has a 2:1 VSWR bandwidth of 60:1.

In this letter, a new compact circle-elliptical combined fractal monopole antenna with very insignificant size, wide impedance bandwidth and acceptable radiation characteristics is exhibited. In reality, this letter is the follow-on for SWB fractal antenna that considered in [1]. In like manner, by increasing of the CECF iterations, antenna has a impedance bandwidth of 1.2~35 GHz and can support most of the communication standards such as WLANs, radio location, fixed satellite, UWB operating range and significant bands such as regional networks, satellite TV, police radar, long haul trunk network and a noticeable part of the ka band. This SWB antenna has a greater frequency range in comparison to the antenna referenced in [1] and supporting the higher frequencies than [1] which can be seen in the overall analysis.

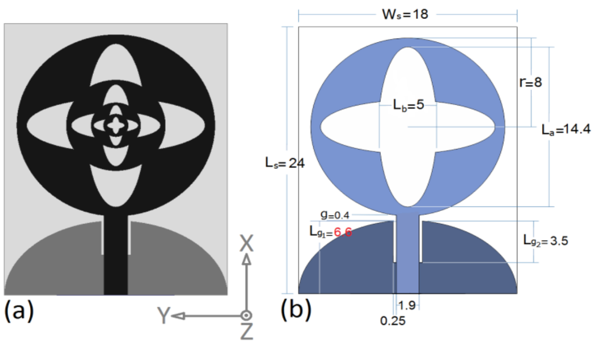

Figure 1. (a) 4th iteration of the proposed final design, (b) Geometry of the proposed CECF antenna.

ANTENNA DESIGN

The final appearance of the CECF antenna with the iteration scale of 0.78 is shown in Fig. 1(a). The geometry of the proposed antenna with parameters defined in it which consist of CECF patch with the modified semi-ellipse shaped ground plane, is illustrated in Fig. 1(b). The designed CECF antenna with compact dimension of $18\times24\times1.6$ mm^3 is printed on a FR4 substrate with loss tangent of 0.02 and relative permittivity of 4.4. To acquire the most accomplishable impedance matching which concluding the bandwidth enhancement, the method of cutting off a rectangular slot with dimension of 2.4×3.5 mm^2 at the feeding position in the ground plane is announced [12]. The width and length of the microstrip feed line to achieve 50 Ω characteristic impedance are fixed at 1.9 and 7 mm respectively [13].

Due to eke out fractal iterations on the fractal patch, it is contemplated that the antenna will face with improvement in bandwidth [1]. The fractal patch has the distance gap 0.4 mm to the semi-ellipse ground plane. The length and width of the ground plane are L_{g1} and W_g, which owning 6.6 and 18 mm quantities respectively.

SIMULATED AND MEASURED RESULTS

To approach the best affirmation of the designed antenna’s result, it was simulated using Ansys HFSS (ver.15). The analysis of the proposed antenna is founded on the effect of parameters that introduced. The procedure analysis is adjusting the effective parameters one by one. The analysis of the antenna for different and the current parameter values has been conducted by altering one of the parameters without modifying others. As a major effect, we have demonstrated the simulated results of the four iteration of CECF antenna, different values of L_g and g based on the fourth iteration of the designed CECF antenna and as a consequence, the radiation outcomes constituted radiation pattern, peak gain and group delay. In the overall analysis, the simulation and measured results of the intended CECF antenna are displayed.

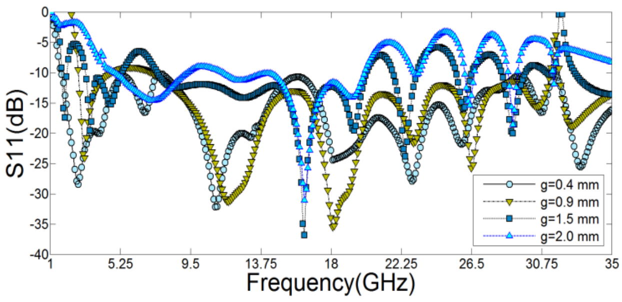

Figure 2. The simulated S_{11} curves for the 4th iteration of CECF antenna with different L_{g1} and g.

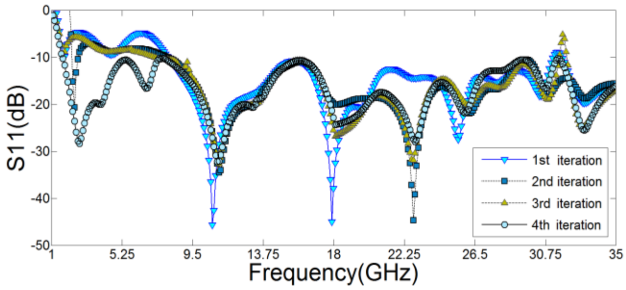

Figure 3. The simulated S_{11} curves for the first four iterations of the CECF fractal.

The best optimal values of parameters of the CECF fractal antenna are presented in Fig. 1. The semi-ellipse ground (GND) plane acting like an impedance matching circuit [1]. The parameters L_{g1} and g, both are noticeable factors to getting the most impedance bandwidth and better impedance matching for proposed CECF antenna's fourth iteration, which are optimized to attain the appropriate value. The simulated S_{11} curves with altered mounts of g are draw up for the whole four iteration of CECF antenna in Fig. 2. As the g parameter increases, the impedance bandwidth decreased down. Also with little altering of the distance of the gap that located between the fractal patch and the ground plane (*g*), the impedance matching of the fractal antenna's fourth iteration experience great alterations. By decreasing *g* down to 0.4 mm, the CECF antenna has the best possible result due to elliptic form of the ground plane.

The simulated S_{11} for the first four iteration of the CECF fractal antenna are plotted in Fig. 3. As it is observed from the simulation results in Fig. 3, that by augment the fractal iteration up to fourth iteration on the fractal patch impedance bandwidth will be increased. Fig. 3 indicates that at the first iteration, the antenna begin to radiating from 8.5 GHz that we cannot us the properties of SWB antennas, retrospectively, the result involves inadequate impedance bandwidth. In the next step, the antenna observes a better impedance matching and the low edge frequency moves to a lower frequency. In step 3, the impedance bandwidth did not have a worthy in attention result. Ultimately, in the fourth iteration of the CECF fractal antenna, the most accessible bandwidth is obtained which covers the 1.2-35 GHz frequency band with good resonance frequencies. It is considerable that in the whole iterations, resonance frequencies did not experience noticeable changes. The S_{11} curve of the simulated proposed CECF antenna with the optimum parameters is presented in Fig. 3. As a result it is worthy in attention that simulated designed antenna has cover lower frequencies than the other iterations besides great compactness size. This phenomena, is because of the space filling characteristics of the fractals [1].

The CECF monopole antenna has been fabricated as a prototype monopole antenna with using customary printed circuit board (PCB) techniques besides it has been simulated (Fig. 4).

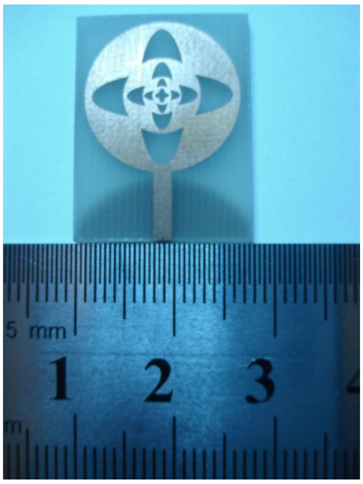

Figure 4. Photograph of the fabricated prototype CECF antenna.

For arranging an intelligent comparison, thoughtful of the other parameters and with using two extremely wideband antennas (particularly SWB antenna), the authors of the presented paper, have used an index term that has been used rarely. This index term will permit the antenna specialists to consider their compact radiator element design (with juxtapose some other designs) that how much their design is compact in size and wide in bandwidth [13]. In exemplification, to ascertain both the compactness and wideband characteristics of an extremely wideband antenna, we use the above mentioned index term that named the bandwidth dimension ratio (BDR) [13]. The mentioned index term will imply how much operating bandwidth (in percentage) can be accommodated per electrical area unit (unit: %/ λ^2) [13]. The equation is written as follows:

$$\mathrm{BDR} = \frac{(\mathrm{BW\%})}{(\lambda_{\mathrm{length}} \times \lambda_{\mathrm{width}})} \quad (1)$$

Where λ is the wavelength of the lower edge frequency of the operating band that meet the 10-dB return loss [1]. Significantly, a greater BDR will point out that the designed antenna is smaller in dimension and wider in bandwidth [13]. Over all, consequences of comparison between the designed CECF and the other previous designs, acquainted in [1], [5], [6], [10], [11] and [13]-[16] (all references antenna cover the UWB spectrum), are summarized in Table I. The performance of different parameters of the antennas such as 10-dB bandwidth (%), electrical dimension (λ^2), ratio bandwidth, BDR (%/λ^2) and f_{low} (GHz) are listed in Table I.

The comparison curves of S_{11} parameter for the simulated and measured results of the proposed antenna is presented in Fig. 5. The 10-dB bandwidth of the designed CECF antenna is 190% (1.2-35 GHz) and 185% (1.7-35 GHz) for the simulated and measured antenna respectively, and a ratio band of 29.2:1 and 20.58:1 respectively calculated. As we can see from the Fig. 5, the final simulated S_{11} and measured S_{11} have an excellent conformity with together. Likewise it is observed, the resonance frequencies are in an extraordinary agreement except in the frequencies 2.4 GHz and 30.75 GHz.

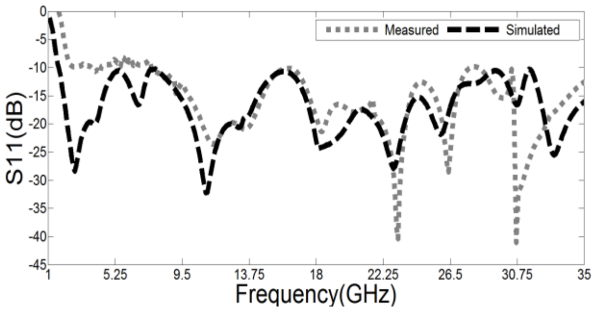

Figure 5. The S_{11} curves of the simulated proposed CECF antenna and measured antenna.

Table 1. 10-dB Bandwidth, Electrical Dimension, Ratio Bandwidth, F_{low} and BDR.

Ant.	10-dB BW(%)	Electrical dimension	Ratio BW	BDR	f_{low} (GHz)
[1]	193	0.033λ×0.033λ	60:1	175818	0.5
[5]	180	0.7λ×0.7λ	20:1	367	2
[6]	185	0.43λ×0.45λ	25:1	956	1.08
[10]	192	0.3λ×0.28λ	50:1	2285	2
[11]	185	0.32λ×0.34λ	25:1	1682	0.64
[13]	172	0.17λ×0.37λ	13.06:1	2735	1.44
[14]	165	0.23λ×0.32λ	10.31:1	2230	2.2
[15]	167	0.37λ×0.24λ	21.25:1	1876	0.79
[16]	175	0.38λ×0.38λ	15.38:1	1250	1.3
Pro.	190	0.06λ×0.08λ	29.2:1	39583	1.2

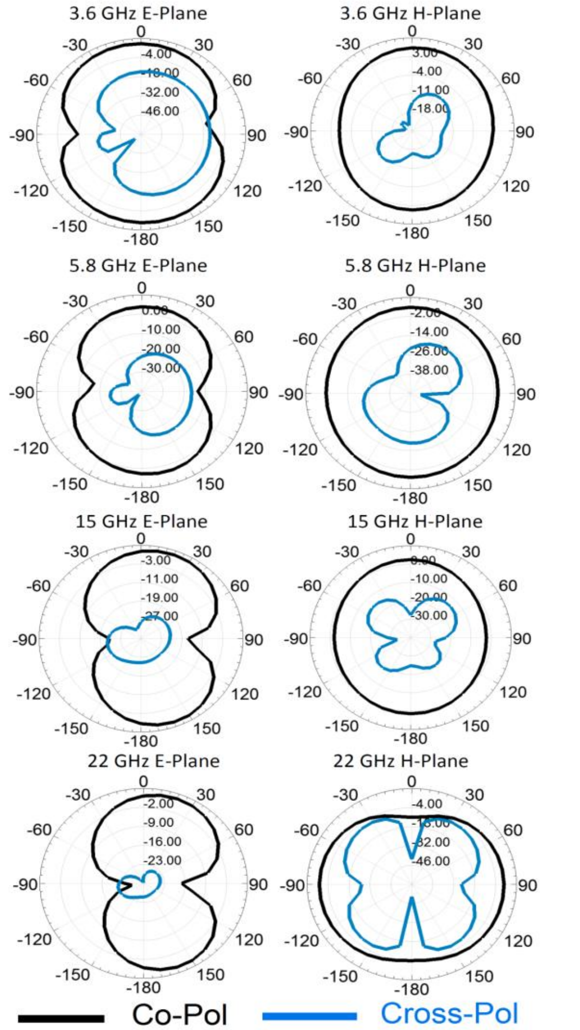

Figure 6. Measured E (xz)-plane and the H (yz)-plane radiation patterns of proposed CECF antenna at 3.6, 5.8, 15 and 22 GHz.

The same as antenna introduced in [1], the 10-dB impedance bandwidth of the CECF designed antenna is one of the best efficacious antenna for SWB applications up to now. The final measured radiation patterns of the prototype proposed CECF antenna at 3.6, 5.8, 15, and 22 GHz are plotted in Fig. 6. It is observed that the CECF antenna contribute omnidirectional radiation patterns in the H-plane (y-z plane) and immutable patterns in the form of figure-eight in the E-plane (x-z plane) without any rotation in the above-mentioned plane. The simulated and measured peak gain diagram of the designed CECF antenna is presented in Fig. 7. Here a raising gain from 15.5 to 18 is unusual for the measured result in comparison to the simulated gain diagram. It can be prompted by fabrication tolerances and non-calibration of VNA. As shown in Fig. 7, the gain is stable along the first half of the plot and has small fluctuations along the second half of operating band. In the overall analysis, we observe a commendable adjustment between the simulated and measured results of CECF antenna that is so desired in the wide bandwidth antennas. In arrangement of UWB and SWB antennas, it is not adequate to judge the antenna performance in accustomed parameters such as S_{11}, gain, radiation patterns [1], and etc. In order to verify the capability of the proposed CECF antenna to operate as a UWB or SWB antenna, it is necessary to achieve a consistent group delay [1]. The group delay needs to be constant over the entire band as well [17], [18]. Measurement of group delay is performed by exciting two prototypes of the CECF antenna kept in the far field for two orientations: side by side and face to face [1]. The separation between the corresponding CECF monopole antenna pairs was 1 m.

Fig. 8 represents the diagram of group delay for side by side and face to face orientations of the CECF antenna. It is observed that the group delay variation is less than 0.5 ns for side by side and 0.1 ns for face to face orientations over SWB. It is also interesting to mention that CECF is designed by authors for the first time and this paper is the first presentation of the CECF fractal. It is observed that in comparison to other fractal and SWB antennas, we have exciting wide bandwidth and radiation results.

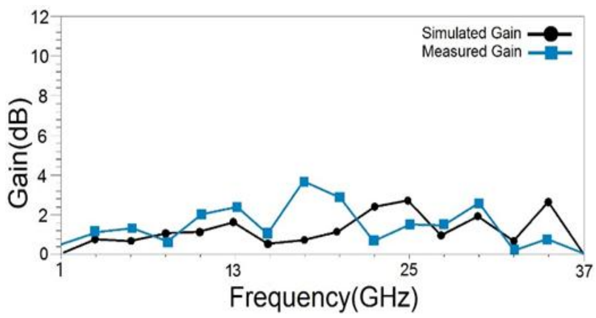

Figure 7. Simulated and measured results of gain variation of proposed antenna.

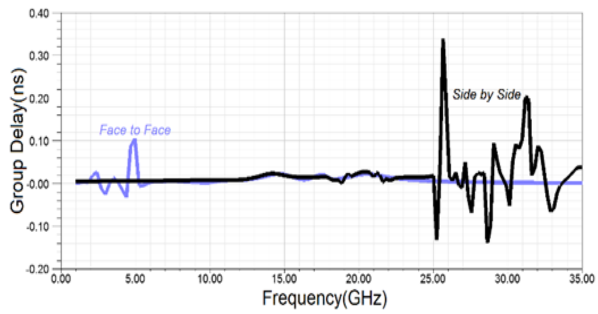

Figure 8. The group delay of the proposed CECF antenna for face to face and side by side configuration.

CONCLUSION

A novel compact CECF monopole antenna with extra compact size was represented and investigated. We showed that by increasing the CECF iteration and optimizing antenna parameters with proper values, an excellent impedance matching and extended bandwidth can be obtained. This results is because of the fractal's space-filling and its special layout properties. The operating bandwidth of the proposed CECF antenna covers the entire frequency band from 1.2 to 35 GHz. The results of CECF antenna's simulation and measurement had been recommended that the proposed CECF antenna can be appropriate for UWB and SWB communication applications.

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