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بالمؤتمر الليبي الدولي للعلوم التطبيقية
و الهندسية
27-28- سبتمبر 2022

Design of Koch Fractal Antenna for Wireless Applications

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الملخص

يقدم هذا البحث تصميمًا لهوائي **كوتش فركتال** للتطبيقات اللاسلكية. حيث تم القيام ببناء نموذج أولي للهوائي باستخدام مخططات كسورية من أجل الحصول على خصائص الأداء المرغوبة مثل الحجم المضغوط ومخطط الإشعاع أحادي القطب. أحد التصاميم السائدة في الأجهزة المحمولة اللاسلكية الحديثة هو التخفيض في الحجم المادي. بالإضافة إلى ذلك، عندما يصبح تكامل التقنيات اللاسلكية المتعددة ممكنًا ، يمكن للأجهزة اللاسلكية العمل في نطاقات تردد متعددة. وبالتالي فإن انخفاض الحجم المادي والقدرة على تعدد النطاقات هما من متطلبات التصميم المهمة للهوائيات في الأجهزة اللاسلكية. يوفر استخدام المخططات الكسورية في تصميم الهوائي طريقة بسيطة وفعالة للحصول على الانضغاط المطلوب وخصائص النطاقات المتعددة. علاوة على ذلك ، تم تقليل حجم الهوائي عن طريق طي 3/2 من المنحنى بمقدار 90 درجة عكس اتجاه عقارب الساعة. كما تم تصميم وبناء هوائي كوتش لإثبات صحة المفهوم. وتم تصميم هوائي مدمج يعتمد على تقنية التغذية المحورية, حيث تمت محاكاة الهوائي لتردد التشغيل البالغ 2.4 جيجا هرتز ، وتألفت عملية التصميم من حسابات نظرية أولية متبوعة بمحاكاة برمجية واسعة النطاق، واستخدمت نتائجها كمبادئ توجيهية لتنفيذ الهوائي المادي. تم إجراء عمليات المحاكاة الكهرومغناطيسية العددية باستخدام برنامج AWR Microwave Office بناءً على تقنية محاكاة طريقة اللحظات (MOM). الهوائي الذي تم تصنيعه عبارة عن هوائي أحادي القطب مطبوع على ركيزة FR–4 واكتشف أنه يعمل وفقًا لتوقعات التصميم. وتمت مقارنة نتائج المحاكاة والاختبار. واستنتج بأنه يمكن استخدام الهوائي المقترح للعديد من تطبيقات الاتصالات اللاسلكية مثل WLAN.

ABSTRACT

This paper presents a design of the Koch Fractal Antenna for Wireless Applications. It was undertaken to construct an antenna prototype by using fractal patterns in order to obtain desired performance properties such as a compact size and monopole radiation pattern. One of the prevailing trends in modern wireless mobile devices is continuing decrease in physical size. In addition, as the integration of multiple wireless technologies becomes possible, the wireless devices can operate at multiple frequency bands. A reduction in physical size and multi-band capability is thus important design requirement for antennas in wireless devices. The use of fractal patterns in antenna design provides a simple and efficient method for obtaining the desired compactness and multi-band properties. Further, the size of the antenna was reduced by folding 2/3 of the Koch curve 90 degrees counterclockwise. A proof-of-concept fractal antenna was designed and built. A compact antenna based on the coaxial feeding technique was designed. The antenna was simulated for the operating frequency of 2.4 GHz the design process consisted of initial theoretical calculations followed by extensive software simulations, the results of which were used as guidelines for the physical antenna implementation. Numerical electromagnetic simulations were performed using the software AWR Microwave Office based on the Method-of-Moments (MOM) simulation technique. The antenna was fabricated as a monopole antenna printed on an FR-4 substrate and was discovered that it performs in agreement with design expectations. The results of both simulation and test were compared. The proposed antenna can be used for various wireless communication applications such as WLAN.

Keywords: Fractal Antenna; Koch curves; return loss; VSWR; WLAN.

1. INTRODUCTION

The development of multi-band internal antennas for handheld devices is in high demand due to the rapid rise in communication standards. With the expansion of wireless communications comes an increase in demand for compact, aesthetically pleasing, lightweight, and curved mobile phones. As a result, mobile phones with hidden or internal antennas are more common. An internal antenna dramatically improves the appearance of the handset. Due to the advancement of modern integrated circuit technology and consumer demands, the dimensions and weights of mobile phones have been quickly reduced. Conventional monopole-like antennas, for instance, have remained somewhat significant about the handset itself. As a result, integrated antennas are developing into exciting candidates for use in mobile devices [1]. Due to its wideband and multiband properties, the fractal antenna is crucial to wireless communications. Because of this, researchers from all around the world have recently focused on the application of microstrip fractal antenna shape [2]. "fractal" refers to a collection of complicated geometries with irregular fragments with self-similarity patterns [3]. Fractal antenna shapes also result in smaller antenna sizes and many resonant bands [4]. Nathen Cohen introduced the fractal antenna idea in 1995. Fractal antennas are suitable for UWB applications due to their self-similarity and space-filling capabilities [5]. Discontinuities are added to the fractal antenna geometry patch to improve the radiation efficiency of antennas [6]. To boost the relative bandwidth of antennas, partial ground planes are used [5]. Multiple Reduction Copy Machines (MRCM), among other iterative methods, are used to create fractal antennas [2]. Minkowski [4], Koch Curves [7], Hilbert Curves, shape fractals, E-shape fractals, and other fractal shapes are examples of constructed fractals [3]. Applications like signal intelligence, electronic warfare, or tactical communications can fall under this category because individuals who create solutions for this branch are interested in features like wideband frequency range or small size. Therefore, by improving dedicated antenna forms, the goals highlighted for antenna design by introducing 5G can be achieved. Fractal-shaped antennas can be used to do these operations. In the future, we plan to design fifth generation (5G) antennas, derived from the principles of small microstrip monopole antenna but with the resonant connection device

[8], integrated into the benefit of familiar fractal Koch geometry, by using an original two or three-iteration binary bionic fractal tree as the pattern in antenna.

2. DESIGN METHODOLOGY

The methods and activities followed to simplify the design and the development procedures can be listed as follows:

1. Pre. Design Stage
   • Literature review.
   • Problem statement.
2. Design and Simulation Stage
   • Optimum antenna that meets specification requirements.
3. Prototype Stage
   • Antenna fabrication.
4. Measurement Stage
   • Return loss and pattern loss at 2.4 GHz.
5. Analysis Stage
   • The measurement and simulation result comparison.

As we can see, figure (1) shows the Flow Chart of Antenna Design and Development.

3. SOFTWARE SIMULATORS

The simulation of antenna parameters is possible with several widely used software programs. The most well-known NEC24 code-based packages include SONNET1, XFDTD2, HFSS3, and others. Professional design tools like XFDTD and HFSS are great because they provide various simulation and analysis possibilities. Unfortunately, these applications don't offer evaluation or academic versions, and their cost would be more than we could afford for this antenna prototype. The MOM AWR microwave office was used to replicate the folded Koch monopole. It is pretty simple to use and makes designing complicated antennas quite simple. For creating complex shapes, the AWR microwave office offers a variety of possibilities, and it has a great inclination to change and modify the designs. The design process includes the following steps:

i. The circuit for the antenna must first be drawn in the circuit schematic before it can be designed.

ii. Next, microwaves can obtain a circuit's schematic layout.

The schematic is then translated to the EM structure.

iv. The antenna simulation is the last phase (for parameters S11, Zin, and radiation pattern)

Folded Koch monopole simulated using AWR microwave office is shown in figure (2.a-2.b).

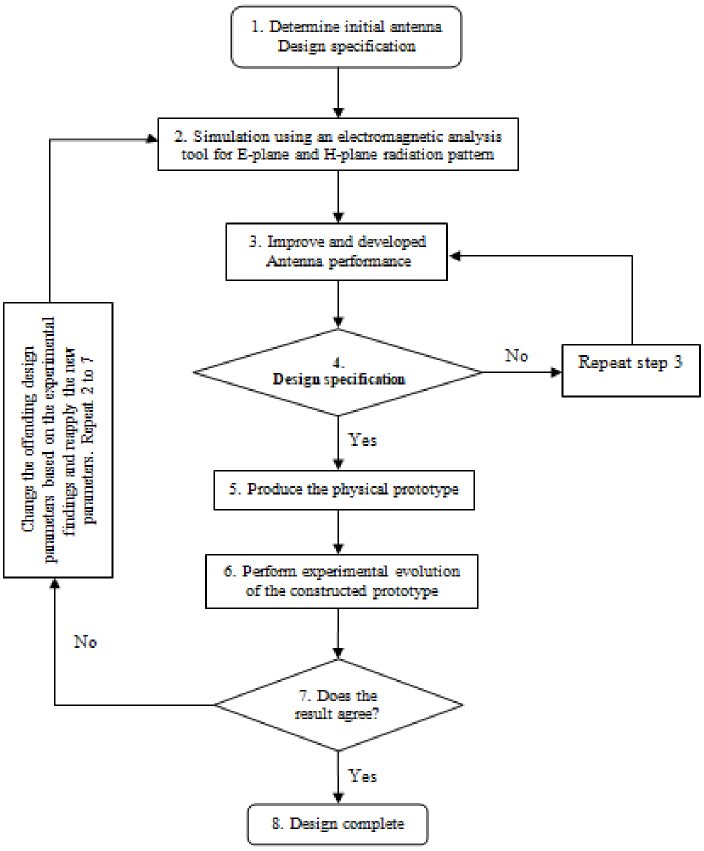
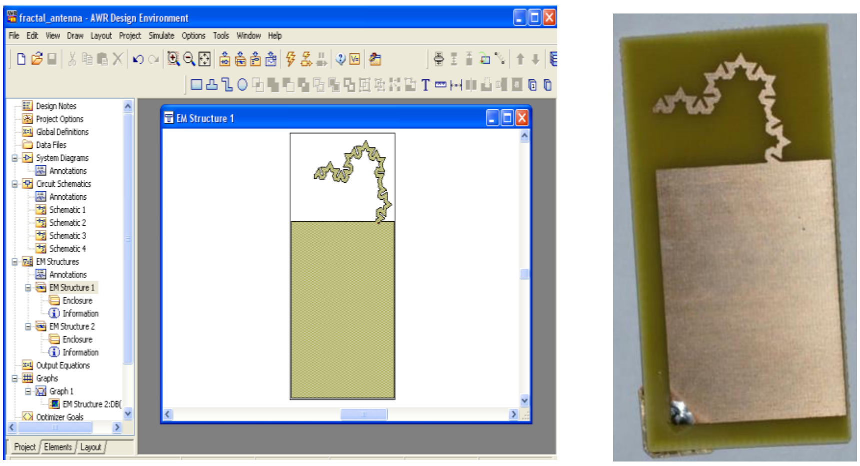


Figure. 1. Antenna Design and Development Flow Chart



(a). Antenna prototype (simulated) (b). Antenna prototype (fabricated)

Figure.2 (a and b). (a). Folded Koch monopole simulated by AWR microwave office
(b). Folded Koch monopole Antenna prototype

The Koch fractal monopole was created with a 2.4 GHz operating frequency. The GSM system utilizes this frequency band for cellular wireless telephony. It is also used for WLAN cards, typically IEEE 802.11, ISM, Industrial Scientific, and Medical band standards used in personal PCs. Additionally, the wavelength is narrow enough at frequencies like 2.4 and 5 GHz to build relatively compact antennas, making the space-filling capabilities of the Koch monopole more favorable at this band [9].

4. HARDWARE DESIGN

Antennas are mounted perpendicular to the ground plane. The ground plane is required to generate an image of the monopole so that an equivalent dipole can be produced. Thus the perpendicular ground plane allows the monopole to function like a dipole antenna by simulating a perfectly conducting ground. The overall Dimensions of the PCB are (5 * 8) Cm. The width of the ground plane is 5.5 cm, while the antenna height is 2.5 cm. The monopole is fed via a coaxial probe as seen in figure (3. a – 3. b).

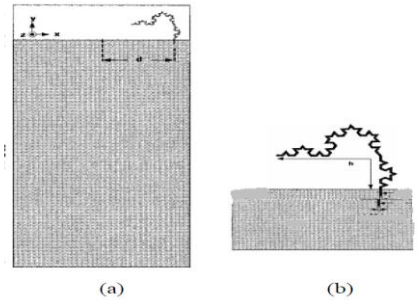


Figure.3 (a & b). The dimensions of the folded Koch curve monopole fed via coaxial probe

5. FINAL DESIGN

A sketch of the final design is shown in Figure (3). The last physical design parameters are given in Table 1.

Table 1: 2.4 GHz Koch monopole design parameters.

Design Parameter	Value
Max. iterations (n)	$n = 3$
Ground plane size	5 * 5.5 cm
Dielectric type	G10-FR4
Total PCB size	5 * 8 cm
Dielectric constant	$\varepsilon_r = 4.7$
Thickness of Dielectric	1.6 mm
Antenna height	2.5 cm

6. SIMULATION AND EXPERIMENTAL RESULTS

The Koch fractal monopole has been fabricated and tested. The simulation and experimental results for the antenna were analyzed and discussed. Software simulations and practical tests were used to evaluate the antenna designs' performance. Some experimental results were compared with simulation performance estimates to verify that the methods performed as intended. Determining the value of the input reflection coefficient of the antenna is necessary to determine the location of the resonant bands. The input reflection coefficient, Γ_{in}, is obtained from the expression:

$$\Gamma_{in} = \frac{Z_{in} - Z_0}{Z_{in} + Z_0} \quad \ldots \quad (1)$$

Z_{in} is the antenna's input impedance, and Z_0 is the characteristic impedance used in the transmission line, used here as a reference. The absolute value of the reflection coefficient can also be expressed as the ratio of the reflected power from the antenna input, P_{ref}, and the power delivered to the antenna, P_{in}. The reflection coefficient will be low at frequencies where the reflected power is small, indicating that power was radiated. In addition, from examining (1), we can obtain the input impedance of the antenna and hence how well we can match it to the transmission line.

The reflection coefficient of the Koch monopole was simulated using the AWR microwave office. A simulated sinusoidal signal was fed to the monopole. The port parameter S_{11}, equivalent to the reflection coefficient, was then calculated as a function of frequency and plotted, as shown in Figure (4). The frequency range used spans from 1 to 3 GHz to match the capabilities of the available experimental hardware. The physical measurement of the reflection coefficient was performed using a network analyzer.

The Koch monopole was connected directly to one port of a Marconi network without using any transmission lines to avoid introducing experimental errors from losses in the coaxial cables. However, an SMA to Type-N adapter was used because only a 50 Type-N calibration kit for the Marconi analyzer was available. Using a reference characteristic impedance of Z_0= 50 Ω, the reflection coefficient variation with frequency was measured in 2 to 3 GHz range.

- **Simulation Return Loss (S_{11}) with coaxial feeding:**

It can be seen from the deep valleys in the plot of the data in Figure (4) that the monopole has a resonant frequency of approximately 2.5 GHz. The accuracy of the simulation is directly related to the mesh element size (more minor is better, resulting in a larger mesh) [10].

BW = 305 MHz, BW%= 12.2%

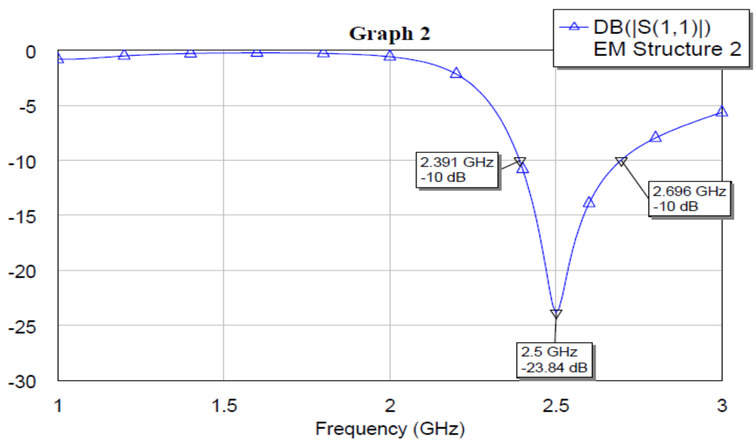
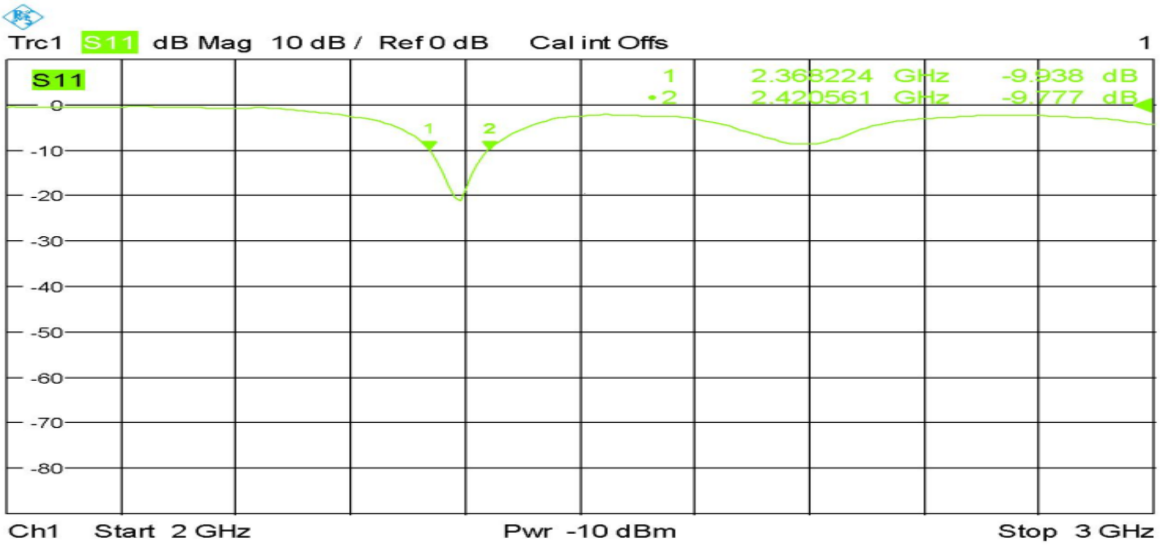


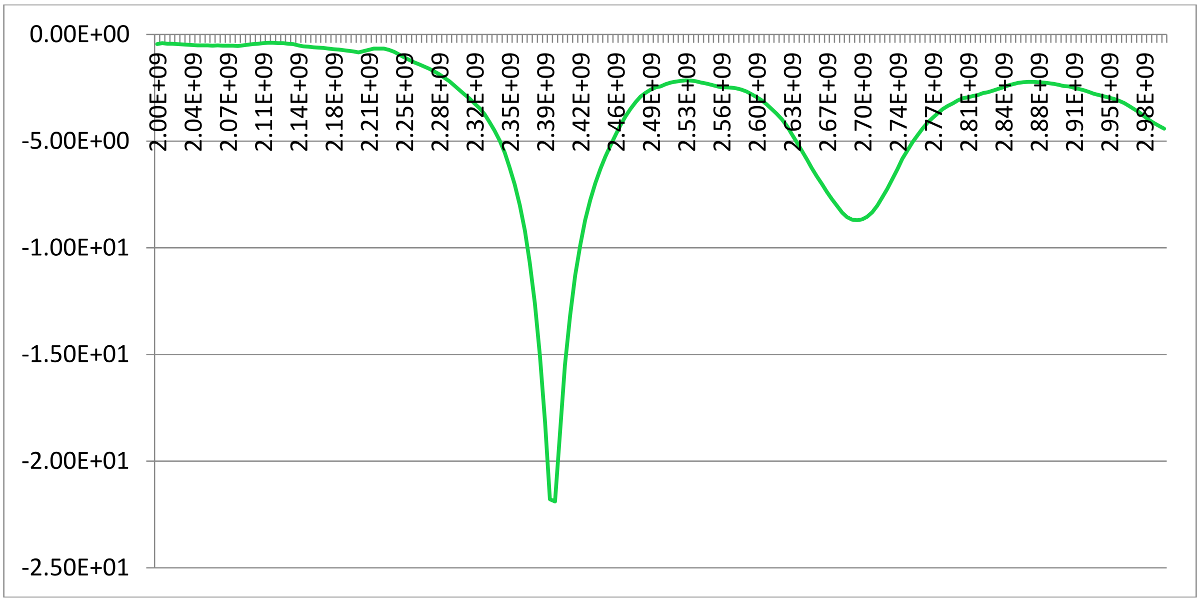
Figure . 4 (S_{11}) simulation result of the antenna fed via coaxial probe

- **Measurement Return loss (S_{11}) with Coaxial Feeding:**

Antenna Resonance Testing Results have been done. From the simulated and measured results, it can be easily seen that there is a slight deviation in the simulation and measurement results. The main peak in the simulated results is resonant at 2.5 GHz, whereas in the measured results, the main peak is at approximately 2.4 GHz. The measured results were taken from 2 to 3 GHz, as shown in figure (5).



(a)



(b)

Figure 5. (a, b): (S_{11}) measurements result of the antenna fed via coaxial probe (BW = 52.4 MHz)

- **Input Impedance**

The input impedance of the Koch curve monopole is approximately Zin = 50 Ω at the 2.5 GHz resonant band, as indicated by the shallow values of the measured and simulated reflection coefficients. This property appears to be inherent in the antenna structure and can help match. Zin is only simulated in the AWR microwave office as discussed above, approximately Zin = 50 Ω as shown in figure (6).[11]

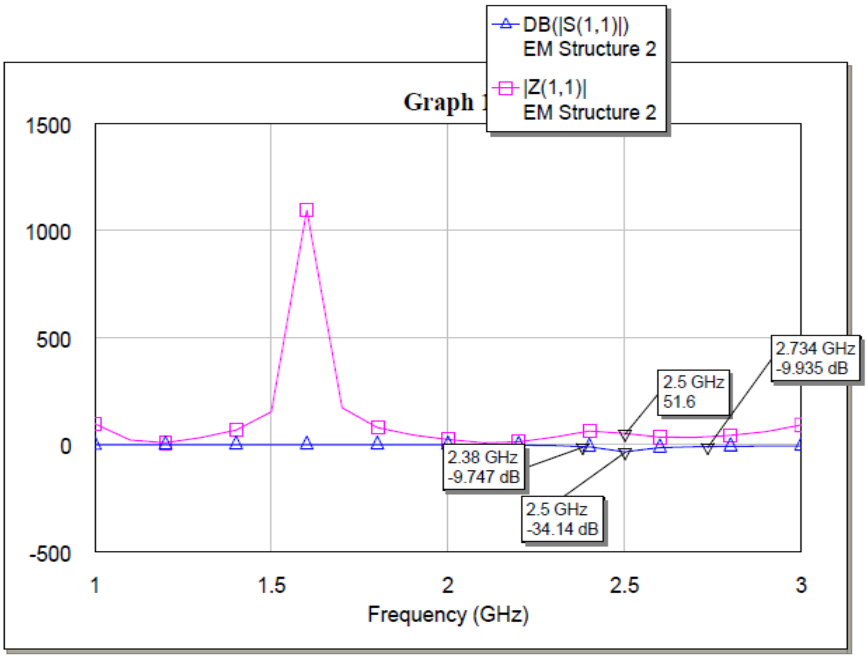


Figure 6. Simulated Input Impedance Z_{in}

Table 2: Performance Parameters of the Antenna

Performance Parameter	Value
(S_{11}) simulated	2.5 GHz @ -23.84 dB
(S_{11}) measured	2.4 GHz @ -22 dB
BW simulated	305 MHz
BW %	12.2%
Simulated input impedance Z_{in}	50 Ohm

- **Simulation result of the radiation pattern**

The 2D radiation pattern in the simulation results is almost perfect in figure (7), where E-CO is the dominant polarization, and E-CROSS is in subscript. The radiation pattern is very uniform in all directions. It is consistent with the classic doughnut shape characteristic of the straight wire $\lambda/4$ monopole and consequently that of the $\lambda/2$ dipole. The measured radiation pattern could not be performed because of inadequate equipment and facilities.

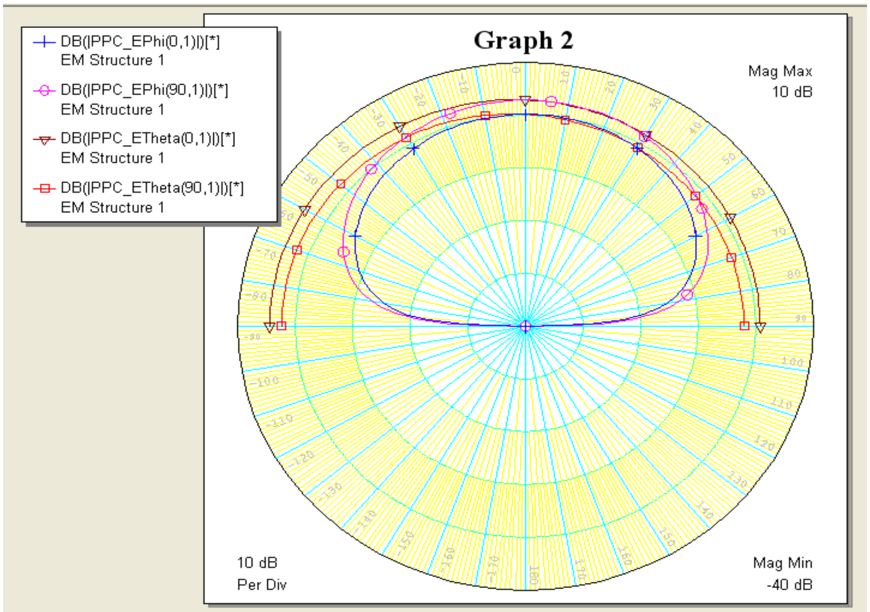


Figure 7. Simulated radiation pattern in terms of (E –CO, E-CROSS, H-CO, H-CROSS)

7. KOCH FRACTAL MONOPOLE ADVANTAGES

The Koch monopole design's initial goal compactness is its most noteworthy benefit. This is very important for applications that frequently use λ /4 monopoles, such mobile phones. It may very easily be fully integrated inside the phone casing, doing away with the protruding monopoles that are frequently found on many mobile phones and WLAN. Comparing the bandwidth to other microstrip antennas, it is satisfactory. Additionally, its broad bandwidth qualifies it as a suitable antenna for wireless communication systems.

In the areas where it might be employed, the Koch monopole design has good frequency flexibility. It could be utilized in almost any wireless communications receiver because the radiation pattern is essentially uniform and identical to a conventional λ/4 monopole. As a result, the Koch monopole offers an excellent compact alternative to the traditional straight-wire monopole.

8. CONCLUSION

The compact Koch fractal monopole designs presented in this paper are an excellent alternative to traditional antenna systems in mobile wireless receivers. The Koch monopole performs adequately at the 2.4 GHz center frequency of the band and demonstrates space efficiency through its self-similar fractal structure. The Koch monopole exhibits good performance at 2.4 GHz and has radiation properties nearly identical to that of traditional, straight-wire monopoles at that frequency.

It has been proven that the Koch monopole has a small size, and it is an efficient omnidirectional radiator. Furthermore, its wide bandwidth makes it an appropriate antenna to support current generation wireless communication systems and future generations more wideband ones. Since reducing the antenna size is an ultimate goal for any wireless applications, the folded Koch monopole could also be a suitable element for diversity or adaptive antennas. The objectives of this design were thus accomplished.

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