Designing Miniaturized Tri-Band Fractal Plane Monopole Antenna

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Abstract
In this study, for the first time, a new structure is presented for the tri-band antenna using a fractal Koch structure in LTE (Low Term Evolution) 850 / 1800/2100 band. This antenna is implemented on the Rogers RO3006 fiber with a thickness of 0.8 mm and the dielectric constant of 6.15 and Co-planar waveguide (CPW) is used to feed the antenna. In this study, the fractal structure of Koch is utilized to shorten the length of the monopole of LTE 850 band. Because the length of the monopoles of the two bands LTE1800/2100 are relatively close, by optimizing the dimensions of monopoles and bringing the frequency of resonances together, the two bands mentioned, become as one and there will be more bandwidth for the superior band. Finally, 27% bandwidth for the upper band and 12.5% width in LTE 850 band is achieved and it can be said that the existing antenna covers all standard 4G (Fourth generation) bands including LTE850 / 1800/2100 and PCS1900 that are available standards in various countries. Antenna's radiation pattern is omnidirectional, radiation efficiency of the three bands LTE 850/1800/2100 are respectively 80% / 91% / 76% which is unprecedented comparing to previous works. Furthermore, the dimensions of the designed antenna, is 0.8*25*55.8 mm3, which is suitable for modern mobile phones.

Key words:
Koch fractal, fractal plane monopole antenna, multi-band antenna, frequency band LTE, coplanar power

Introduction

According to the requirements of the fourth generation of mobile phones, there has always been an endeavor that the antenna designed for these systems, have small and compact dimensions and also cover the essential bandwidth. Therefore, for this purpose, tri-band fractal plane monopole antenna which is downsized by Koch fractal structure, is designed on the Rogers fiber RO3006 with 0.8mm thickness. The design process is that in the first step, the resonant frequency of a simple monopole is calculated and with the obtained dimensions the structure is simulated. In the second step, Koch fractal is used to downsize the length of this monopole (Band LTE 850) which corresponds to the lowest working band and the maximum length of Monopoles. Finally, in the third step, monopoles related to the LTE 1800/2100 band is added to the antenna. Certainly, at this stage various design parameters affecting the simulation will be examined which finally, by optimizing the overall dimensions of the structure and reducing the gap between the working resonances, two upper bands LTE 1800/2100 are combined together and 27% bandwidth at upper band and 12.5 % bandwidth in LTE 850 band has been achieved.

Antenna has always been one of the most important components of wireless telecommunications system, in fact antenna is a gateway that sends electromagnetic energy through the radio waves from the sender (transmitter) to the channel and from channel to receiver, the method in which the electromagnetic energy is emitted into the atmosphere and is received through it. Antennas according to their applications, may have wide bandwidth or low bandwidth or as multiband antennas. Multiband antennas such as antennas used in mobile phones are made in order to remove unwanted signals from adjacent frequency bands which might be designed for multi-band antenna or broadband antennas may be used, but to remove one or more unwanted frequency band, the eliminating forbidden band method is utilized. Wired antennas, one of the oldest and in many cases and in practical terms, are more versatile in various environments and are eco-friendly. Recently, in many wireless applications, these antennas tend to be assembled by plane (surfaced) structures that both in terms of implementation and production are easier and less costly, it occupies a small space and ultimately have the ability to be built on planes with different shapes. A simple method for integrating wired antennas with plate structures, is printing wires on printed circuits. Producing and assembling Antenna on circuit boards in addition to having low costs, has a high manufacturing precision and is also built easily on plate structures.

Among the applications of wireless communications designing antennas with small dimensions has always been an important issue. In this study, a fractal plane monopole antenna capable of simultaneously covering three frequency bands is designed for use in mobile phones of the fourth generation. The antenna used in mobile systems must have omni directional pattern so that the user can receive signals in any position and direction. This will be included in designing the pre mentioned types of antenna. The impedance bandwidth required for fourth-

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generation mobile phones and necessary gains in each band will be satisfied. In order to design the antenna with small physical dimensions, the fractal structures are used.

The purpose of this study is designing plate antennas in LTE 850/1800/2100 bands and miniaturizing it using fractal structures, so that it can cover all necessary bandwidth for fourth-generation mobile phones and also have small dimensions, and be implemented easily on mobile structures. In this study, first and foremost, the fractal structures will be examined and finally, given the size of the antenna and the ability to implement it, a structure will be used that from the viewpoint of antenna frequency characteristics, satisfy the necessary conditions and also the possibility of physically making it. Because in the fourth-generation mobile phones, bandwidth of the antennas is more than previous generations, therefore structures such as monopole plate antennas and other broadband antennas are utilized.

Research Hypotheses

-Fractal structures will be used to implement the monopoles.

-CPW line will feed antenna.

- The software CST Microwave Studio or Ansoft HFSS will be used to simulate the antenna.

Research Methodology

The main objective of the new generation of antennas, is designing and utilizing antennas with compact dimensions so that the functionality needed in these antenna be maintained for the new dimensions. For this purpose, in this study, the fractal structures are used which are the most widely used methods and the most effective in new generation antenna that is a fractal structure and is suitable for the job, and here has been investigated.

CPW structure

CPW is formed from a central strip with S width, W gap width, and substrate height and substrate dielectric material. Among CPW types, including FG-CPW, GCPW and Ungrounded CPW, Ungrounded CPW structure for the proposed antenna are used because it is more standardized than other structures and in which the lateral co-planar waveguide solely provide a return flow path and lower levels of substrate does not need a cover. This structure can be seen in Figure 1-3. The distribution of electric fields in the structure is shown in Figure 2-3 below.

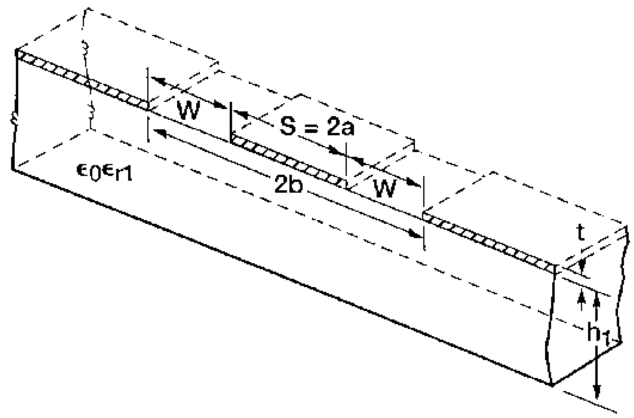

Fig. 1-3 A CPW with dielectric substrate with limited thickness

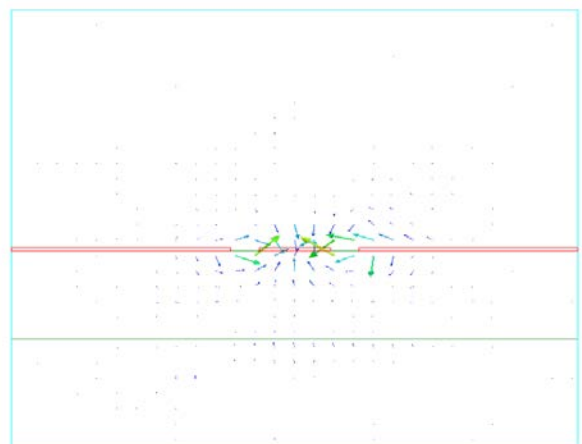

Fig. 2-3 Distribution of the electric field in an Ungrounded CPW

For a better study, the structure of CPW was simulated. In this study, two ports on either side of CPW were devised to study the return and transmission losses, in figure 3-3 intended structure and in figure 4-3 the return losses are shown.

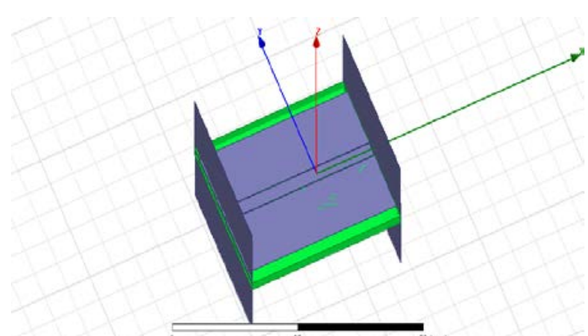

Fig. 3-3 simulated CPW structure

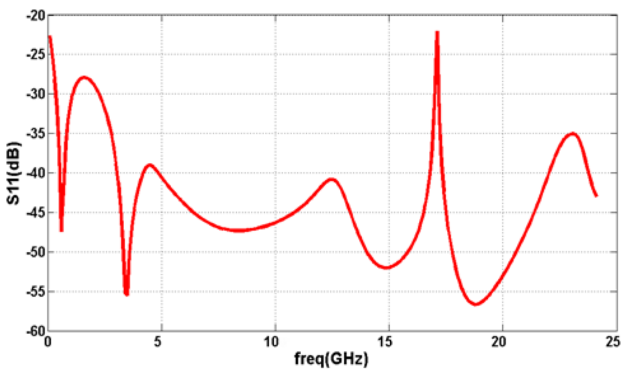

Fig. 4-3 Returning losses for the CPW

In figure 5-3, figure 6-3, figure 7-3, charts of transmission and electric current distribution losses are shown. As it is shown in figure 4-3 to 6-3, return loss of CPW is low on the RO4003 Roger substrate and the curve is under dB30- but S21 (figure 5-3) is almost zero. With each 10 cm length, transmission losses are about dB 0.1. As a result CPW has low radiation losses and in practice this type of feeding structure does not change antenna's radiation patterns. Current distribution on the feed line has the highest density.

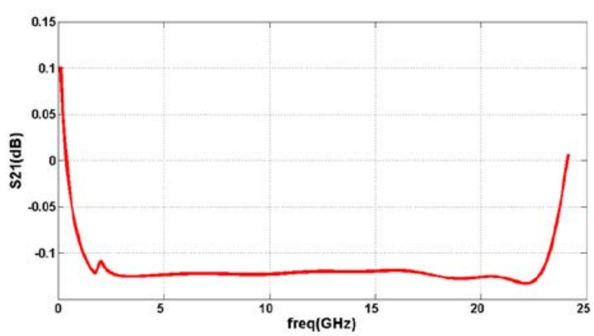

Fig. 5-3 Transmission losses between ports 1 and 2

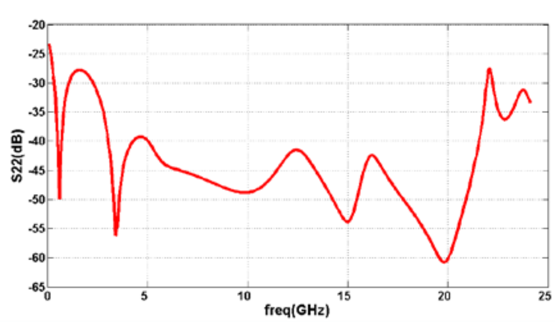

Fig. 6-3 Transmission losses for port 2

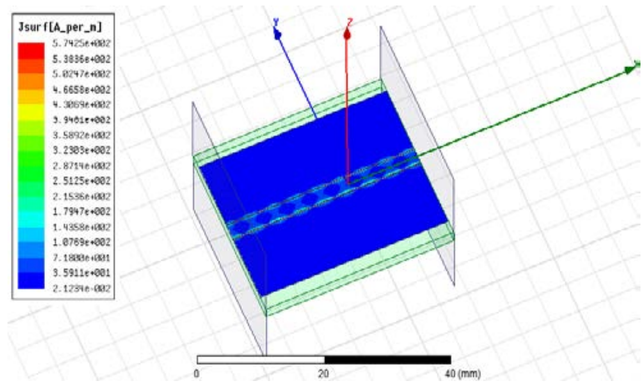

Fig. 7-3 Showing current distribution in CPW

For a conventional CPW on a dielectric substrate with limited thickness, the equations of 1-3 to 11-3 are used.

1.3 $C_{cpw} = C_1 + C_2 + C_{air} C_{cpw}$

C air : Part of CPW capacity in the absence of dielectric

Ccpw : General electric capacity of CPW

C 1 : Part of the CPW capacity with lower dielectric

C 2 : Part of the CPW capacity with higher dielectric

2-3 $=2\,\varepsilon_0\,(\varepsilon_{r1}-1)\,\frac{K(k_1)}{K(k_1')}\,C$

3-3 $k_1 = \frac{\sinh\left(\frac{\pi S}{4h_1}\right)}{\sinh\left\{\frac{[\pi(S+2W)]}{4h_1}\right\}}$ $K_1' = \sqrt{1-K_1^2}$

4-3

$$C_2 = 2\,\varepsilon_0\,(\varepsilon_{r2}-1)\,\frac{K(k_2)}{K(k_2')}\ ,\ \varepsilon_{r2} = 1 \ => \ C_2 = 0$$

5-3 $C_{air} = 2\,\varepsilon_0\,\frac{K(k_3)}{K(k_3')} + 2\,\varepsilon_0\,\frac{K(k_4)}{K(k_4')}$

6-3 $k_3 = \frac{\tanh\left(\frac{\pi S}{4h_3}\right)}{\tanh\left\{\frac{[\pi(S+2W)]}{4h_3}\right\}}$ $K_4 = \frac{\tanh\left(\frac{\pi S}{4h_4}\right)}{\tanh\left\{\frac{[\pi(S+2W)]}{4h_4}\right\}}$

7-3 $k'_4 = \sqrt{1-k_4{}^2}$ $k'_3 = \sqrt{1-k_3{}^2}$

From the above relations (equations) by taking into account h3 = h4 = ∞

8-3 K3=k4=k0= $\frac{S}{S+2W}$ C_{air} =4 $\varepsilon_0 \frac{K(k_0)}{K(k'_0)}$

And finally,

9-3 C cpw =2 ε_0 (ε_{r1} -1) $\frac{K(k_1)}{K(k'_1)}$ + 4 $\varepsilon_0 \frac{K(k_0)}{K(k'_0)}$

10-3 $\varepsilon_{eff} = \frac{C_{cpw}}{C_{air}} = 1 + \frac{(\varepsilon_{r1}-1)}{2} \cdot \frac{K(k_1)}{K(k'_1)} \cdot \frac{K(k'_0)}{K(k_0)}$

11-3 zo = $\frac{1}{cC_{air}\sqrt{\varepsilon_{eff}}} = \frac{30\pi}{\sqrt{\varepsilon_{eff}}} \cdot \frac{K(k'_0)}{K(k_0)}$

In the above equation, C is the speed of light in free space, that finally using the above equations regarding characteristic impedance, relative permeability of the dielectric substrate can be achieved.

CPW in high frequencies has less magnetic flux distribution and offers wider adjustments. CPW structure does not need soldering; its construction is easy and is suitable for combination with MMIC. CPW power not only operates better than the bandwidth, it also has a good radiation pattern. This method of feeding is less expensive than microstrip power (recharge). In supplying power of CPW, Power of antenna and radiator elements are printed on one side of the substrate. By adjusting width S of internal conductor and the width of the gap between the ground plane and the inner conductor 50 ohm impedance matching can be achieved. Furthermore, the impedance matching is dependent on the thickness of the substrate and substrate permeability.

The first step: Calculation of the lowest operating frequency of planar monopole antenna

Considering that the aim of this research is to implement this type of planar (screen) antennas on printed circuit fibers, it is necessary to reexamine equations for wired monopole antennas. Monopole antennas are normally in the form of cylindrical wires that their overall length are considered equal to a quarter wavelength. But in planar monopole antennas total rectangular strip are assembled on the printed circuit fibers and researchers use the same method with wired monopole antennas, analyze and design planar monopole antennas while defining the equivalent radius of the wire antennas for such kinds of structures.

For planar monopole antennas, low frequency corresponding to VSWR = 2 can, by putting the planes on the same level on monopole in two cases of wired monopole, be accounted together with planar monopole. In both cases, the length of monopole is considered equal to L, therefore it can be said that:

1-3 $2\pi rL = WL$

Then the equivalent radius is:

2-3 $r = W/(2\pi)$

As it was previously mentioned, monopole antenna input impedance of the quarter wavelength, is half the impedance of dipole antenna output. It means that the monopole antenna input impedance is 36 + j21.25 ohms. That its impedance is inductive (self-impedance) and resistive, the real impedance is achieved when the monopole is selected slightly smaller than a quarter wavelength. The length of monopole instead of 0.25 wavelength, is selected as 0.24 wavelength.

3-3 $L = 0.24\lambda F$

While

4-3 $F = (L/r)/(1 + L/r) = L/(L + r)$

From the above equation it can be concluded that

5-3 $\lambda = (L + r)/0.24$

Thus, the lower frequency of antenna is equal to

6-3

$$f_L = c/\lambda = (30 \times 0.24)/(L + r) = 7.2/(L + r) \text{ GHz}$$

In the above equations sizes should be set in centimeters.

As the first step toward designing monopole antenna, using the above equations the length and width of the planar monopole antenna in figure 8-3 can be calculated. In the beginning, the width of the antenna should be determined so that the antenna will be capable of implementation. Considering that the outer radius of standard ferrule connectors is equal to 1mm and the outer diameter of Teflon is equal to 4mm, therefore choosing width of 2mm is logical. Then according to figure 8-3, W is chosen equal to 2mm, and its length (L) is selected in terms of lower operating frequency. In LTE bands the lowest frequency belongs to the LTE 850 band, which is equal to 0.85 GHz.

Therefore, using the above equations the equivalent radius and the length are equal to: r=0.32 mm and L=94.4 mm

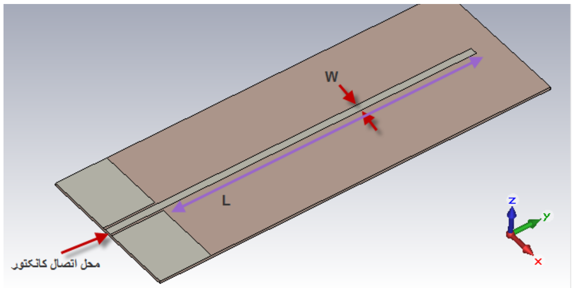

Fig. 8-3 Planar monopole antenna

CPW lines are used for antenna's power, that the set of monopole antenna together with CPW line is implemented on the Rogers standard board RO3006 with dielectric constant of 6.15 and tangent loss of 0.002. Therefore, with the help of calculated length and width and existing substrate, returning losses and antenna pattern in accordance with the following figures are obtained.

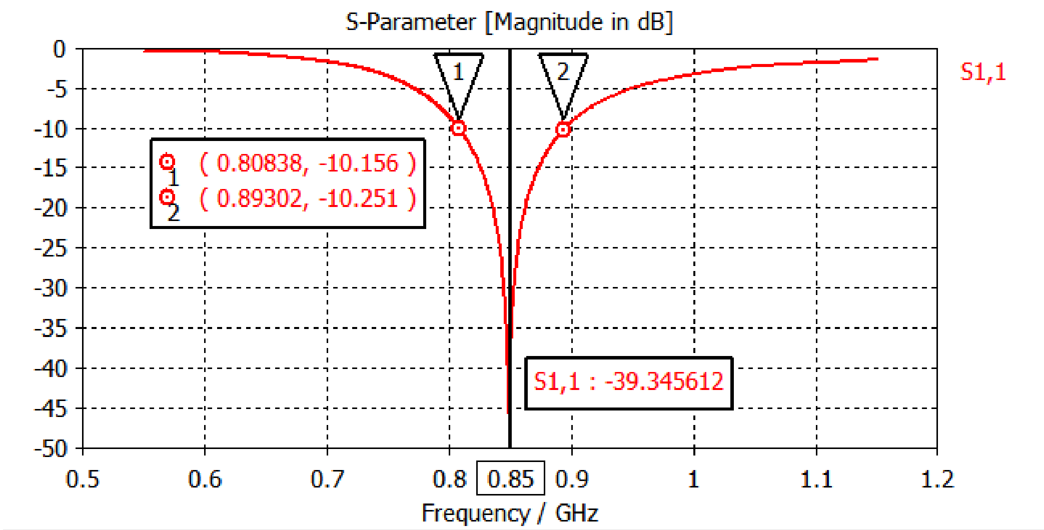

Fig. 9-3 Returning Loss of planar monopole antenna

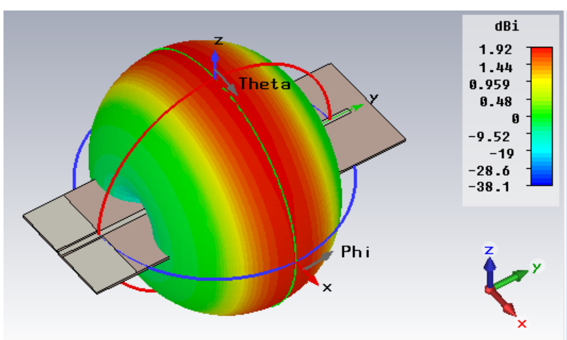

Fig. 10-3 Radiation pattern of planar monopole antenna

The exact specifications of the designed antennas have been calculated in the following table.

Table 1-3: Specifications of planar monopole antenna

Board dimensions(mm)	Monopole dimensions (mm)	Bandwidth (S11<10 dB)	Antenna Gain (dB)
40*115	2*94	10.5%	1.92

Applying Koch fractal on the monopole to compress the antenna

Koch fractal structure

Fractal structures are self-similar structures that depending on the times of repetition, the length per unit area increases. Koch fractal geometry, because of its repetition, is suitable for longitudinal structures and with this method it is possible to effectively reduce the overall dimensions of it. As it can be seen from Figure 11-3, at each step of the repetition, as much the size of 1/3 of the total length, it is added to the length, In fact, for every repetition of its overall length, it will be multiplied by 4/3.

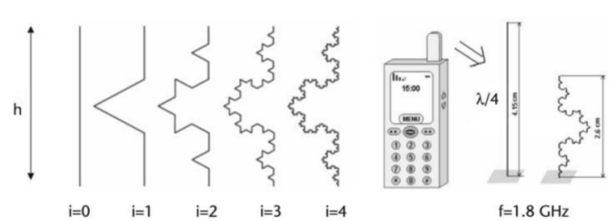

Fig. 11-3 Koch fractal geometry

Fractal structures in recent decades had various applications in the structures of the antenna and microwaves. In many downsizing methods the length of the antenna will usually become shorter, while these methods are mainly dependent on the amount of their miniaturization, they significantly reduce the antenna gain and bandwidth, because the length of the antenna is shortened in those frequencies. But in antenna structures loaded with fractal structures, the length of the antenna will not become smaller in the corresponding frequency. In fact, the overall length of the antenna is the same length as with no fractal structure while in downsizing it refers to a concept which means that it becomes compact in length or volume without being reduced in the electrical length of the antenna, the physical length of the antenna becomes more compact, therefore, we can expect that the antenna performance in a state of benefiting from fractal structures remains almost constant which can be a great advantage for this type of structures.

At this stage, fractal structures have been applied in two stages on fractal monopole antennas, which will be examined in due order.

The first stage of applying fractal structure

The origin of Koch fractal begins where each side of the triangle is being divided into three parts and the fourth part will be added to the middle of the triangle, In fact, every progress of the overall length of 4/3 = 1.333 times multiplies the length of the structure in the previous step (Fig. 12-3). That surely the more this stage is extended and continued, the achieved length will be multiplied in a constant plane (level).

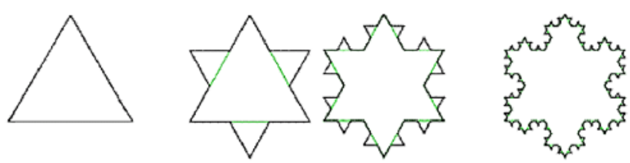

Fig. 12-3 The process of making Koch fractal structure

At this point, according to figure 13-3, Koch fractal structure of the first stage, was applied on the monopole antenna, the length of L1, in fact, determines how much to bend and tilt in a horizontal orientation should be chosen such that the total width of the antenna will not be exceeded. Because the overall goal is to use this antenna for mobile phones and tablets and generally mobile phones' communication modules, it is necessary not to cross the limit of its overall length and width, therefore, it is important to minimize the length and width of the antenna as much as possible. For this purpose, as shown below, the overall length L1 antenna is divided into 9 parts with equal lengths. As we considered in the previous step, the total length of monopole is equal to 94 mm, so we can write 9*L1=94 mm. That is L1=10.44 mm. But with this length, according to the simulations carried out, monopole antenna operating frequency is 100 MHz higher than band frequency of LTE 850 MHz that by modifying the L1 to L1 = 12 mm, the amount of available frequency was corrected and was shifted to the intended band.

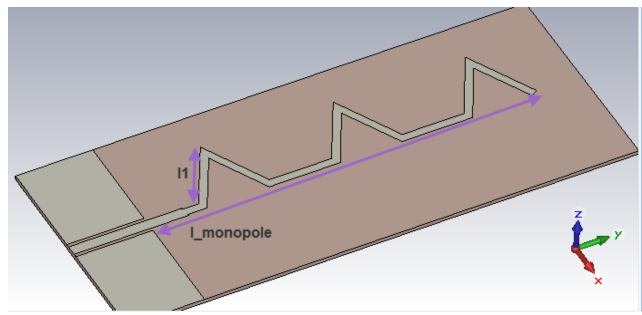

Fig. 13-3 The first stage of applying fractal structure on single-band monopole antenna

Frequency shift is because of imparity of physical length and electrical length of the structure. As stated in the first step of designing in the previous section, in the case that monopole shows a straight line, results of theoretical calculations has a good concordance with the simulated results. But when fractal structure is applied on the antenna, due to the fractures that is created in its curvatures, electric currents that are diffused on the plane of the monopole, in curves, will be disseminated by the shortest route which consequently reduces the electrical length in comparison to the physical length of the structure. Transmission and dissemination of electric current on the loaded monopole with Koch fractal structure is examined in figure 14-3, as noted, in fractures and corners of the structure, flow rate is too low in outer sharp points and subsequently, the current becomes stronger in the direction of bending. Thus, it can be said that fractures are the main cause of low electrical length in proportion to the physical length of it.

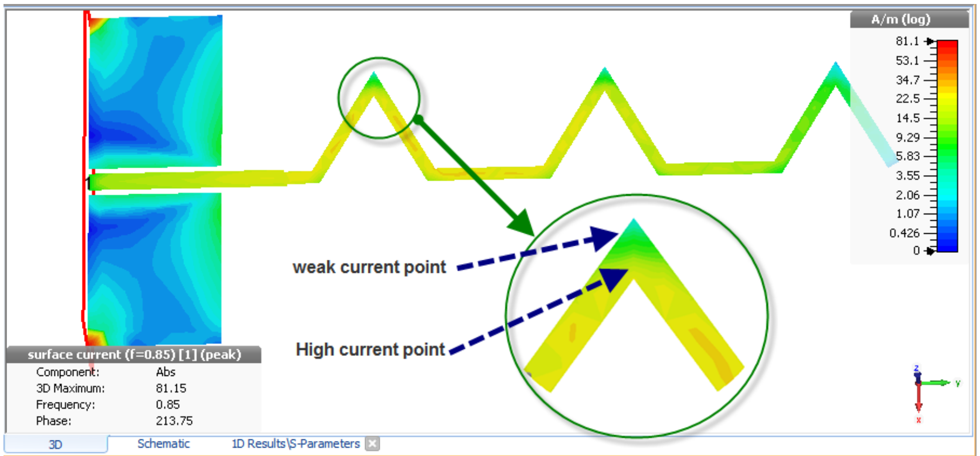

Fig. 14-3 current distribution on the loaded monopole with the first phase of the fractal structure

Respectively in figures 15-3 and 16-3, return loss and radiation pattern of loaded planar monopole antenna have been drawn with Koch fractal structure.

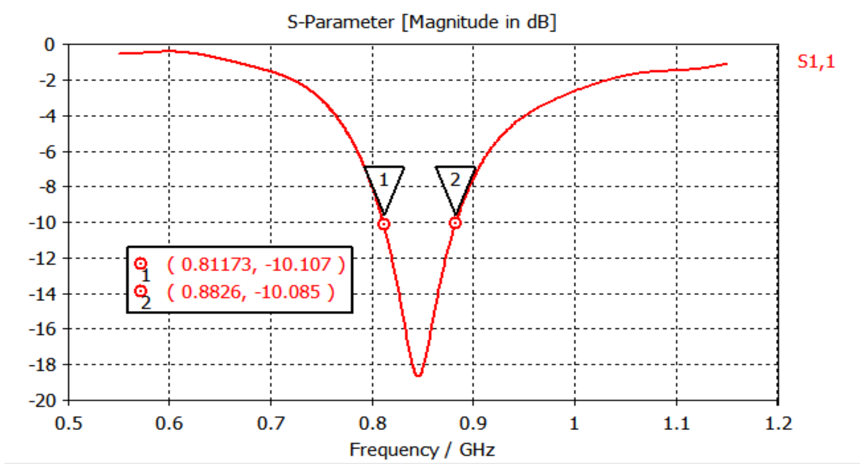

Fig. 15-3 Return loss of the planar monopole antenna with the first stage Koch fractal structure

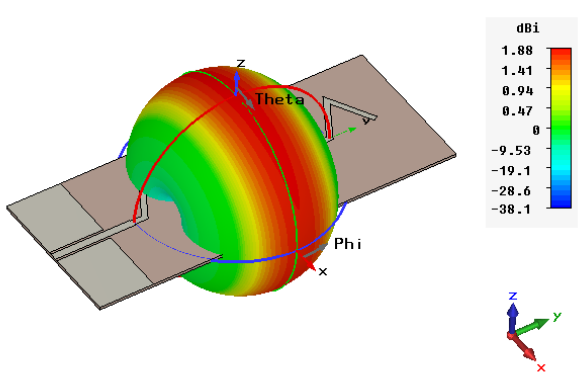

Fig. 16-3 Radiation pattern of monopole antenna with the first stage Koch fractal structure

Bandwidth and antenna gain in comparison to direct monopole antenna, which was discussed in the previous stage, had no significant change. For better comparison of results, the overall antenna parameters are listed in the table. The width of monopole due to the horizontal curvature has become equal to the maximum occupied width of 13.5 mm, and its length according the figure 13-3 begins from the bottom line of CPW with monopole endpoints or L_monopole which is equal to 76 mm. So with these specifications it can be said that the monopole is in this case 22% smaller than before.

Table 2-3: Specifications of planar monopole antenna with the first stage of the Koch fractal structure

Board Dimensions (mm)	Monopole dimensions (mm)	Bandwidth (S11<10 dB)	Antenna Gain (dB)
40*100	13.5*76	8.3%	1.88

The second stage of applying fractal structure

Similar to the first step of applying fractal structure, in this case the second repetition of the fractal structure is applied on this structure as shown in figure 17-3. At this stage, given that length of each line is 4/3 of the previous length, so theoretically it can be said that it gets 25% smaller than before. But as it was previously explained, due to the imparity between physical length and electrical length using the software CST Microwave Studio Suite, the total length of monopole (L_monopole) is obtained.

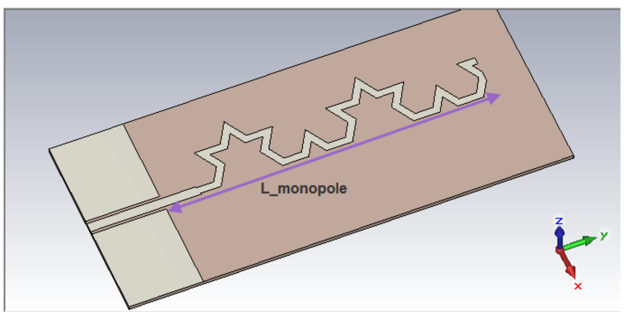

Fig. 17-3 The applied planar monopole antenna with two stages Koch fractal

At this stage in comparison to previous stage, according to the dimensions obtained through simulation software the length of the antenna is 14% smaller. In two recent phases that fractal structure was applied on the antenna, monopole width was considered 1.5 mm, that if we apply the third iteration of a fractal structure on the antenna, the lines come very close to each other and practically the electrical length of the structure will not be extended, That is why the next iteration has been refused. Moreover, we could by reducing the width of monopole apply the second iteration fractal structure, in which case the problem of lines being crossed would have been resolved, However, due to reduced bandwidth and antenna impedance matching problems, it has been refused. In the following sections, the effects of monopole width on the antenna impedance matching and bandwidth, will be examined.

Similar to previous cases, at this stage, scattering parameters and radiation pattern at a frequency of 850 MHz, respectively, are drawn in Figure 18-3 and 19-3.

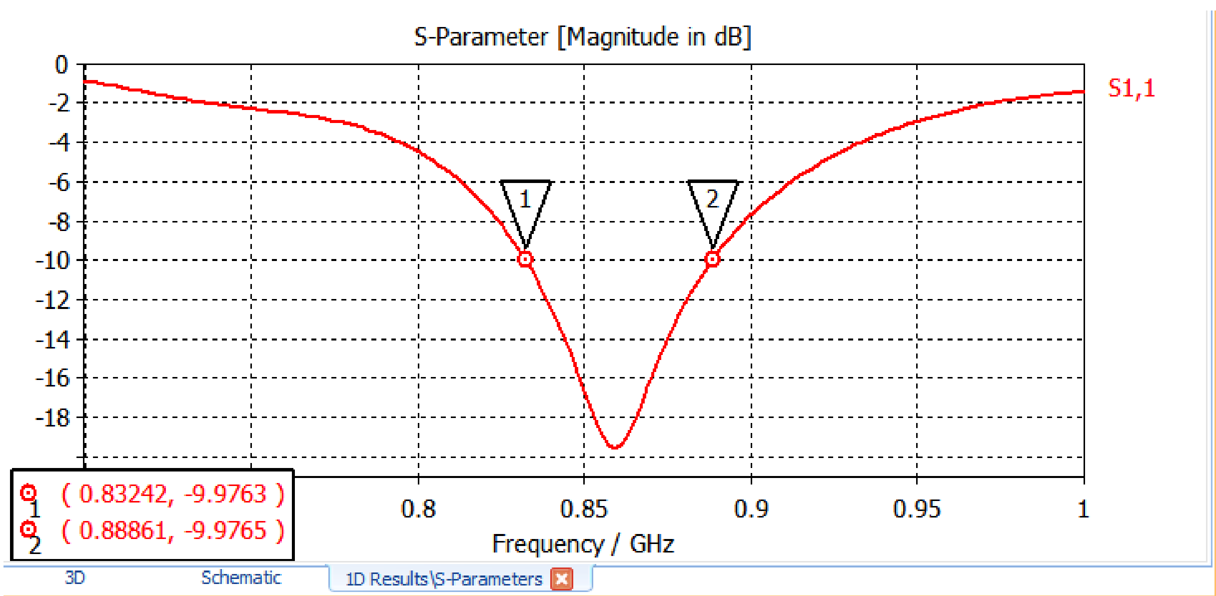

Fig. 18-3 Return losses in monopole antenna with two phase repetition of Koch fractal

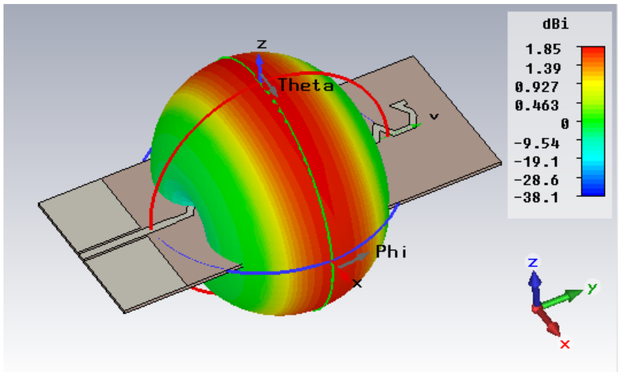

Fig. 19-3 Radiation pattern in monopole antenna with two phase repetition of Koch fractal

General specifications of antenna are given in the table below.

Table 3-3: Planar monopole antenna specifications with second repetition of Koch fractal structure

Board Dimensions (mm)	Monopole dimensions (mm)	Bandwidth (S11<10 dB)	Antenna Gain (dB)
40*90	13.5*66	7.1%	1.85

Third Step: Adding two monopole related to the band LTE 1800/2100 to fractal shaped monopole

In two previous stages, we saw that adding a fractal structure to direct monopole does not make a big change in frequency characteristics such as Return loss and antenna pattern and almost has no effect on the performance of the antenna. But at this phase two other monopoles which are related to the upper bands of LTE, when they are added to the antenna, given that each of these lines at the confluence point of the three Monopoles create a parallel impedance causes significant changes in the input impedance of the antenna. According to figure 20-3, the antenna results are surveyed in three stages, at first, the single-banded antenna that had been previously simulated and then second monopole related to the band LTE 1800 and finally the third monopole of the band LTE 2100 is added to the latter monopole. The return loss of three modes can be seen in Figure 21-3.

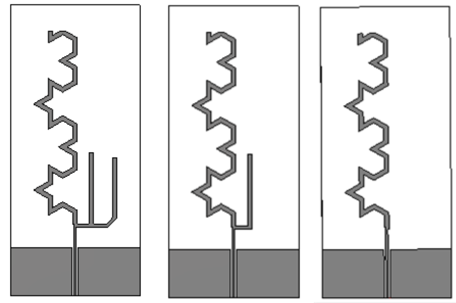

Fig. 20-3 Fractal monopole antenna in due order from left to right: Single-band, dual-band and tri-band

In the first case the antenna only has one monopole, it is resonant only in the low band (frequency f1). In the second case that other monopole is added to the low band fractal monopole the second resonance (frequency f2) also appears. In the end, by adding the third monopole, the third band (frequency f3) is added to the frequency bands. Obviously, by adding any monopole to them, there will be yet more resonances to be added. But as mentioned, the interesting point is that adding monopole on LTE 1800/2100 bands on the low band were almost ineffective, and the reason behind this factor is that the monopole with smaller length has an impedance with larger amounts, That is why when the difference in the size of Monopoles are larger than a limited extent, if the smaller and bigger monopole are parallels to each other in terms of impedance (e.g., a condition that occurred in this study) smaller monopoles on the bigger monopole will be ineffective.

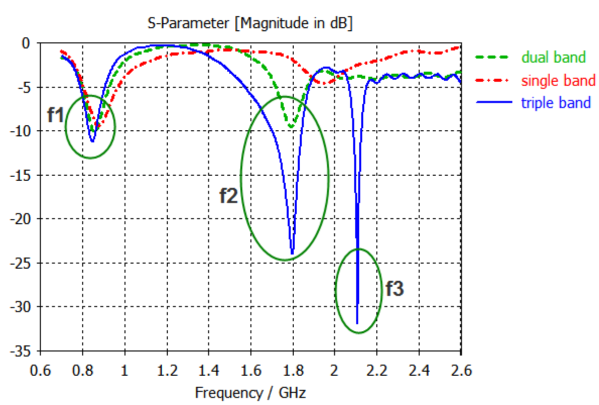

Fig. 21-3 Return loss of single band, dual-band and tri-band monopole antenna

But in the cases that the size of monopoles are somewhat similar to each other impedance effect becomes evident, as it can be seen from Figure 21- 3 in the dual-band antenna return loss in band LTE 1800 is not very good, while by adding the third band the monopole returning losses can be significantly improved in the second band which shows that although the third monopole does not have much impact on the lower band LTE but is very effective for the upper band.

Step Four: 90 degree bending of the monopole regarding the band LTE 850

It was mentioned in the previous section that sizes and dimensions of each monopole affects the other monopoles greatly, thus optimization of antenna at each stage, does not guarantee improved results in the following stage. Therefore, we briefly discuss the final stages of design regarding all the antenna parameters.

Assessing antenna design parameters

The antenna has various parameters such as length and width of the ground plane, the strip width of center line CPW, the gap between the ground plane and strip, monopoles' width and the gap between them, and for the better and the more optimal design of the antenna, it is necessary to consider the impact of each of these parameters.

The impact of monopole width on scattering parameters

As noted, adding second and third monopoles had no effect on the lower band and also replacement of the fractal structure with direct Monopole in accordance with the results of the first step designing, has no significant effect on simulation results, thus, the only parameter that can change the bandwidth of the antenna in the band LTE 1800, is the monopole's width and feed line dimensions. At this stage of the simulation, the main strip width CPW line is equal to lower band monopole width (Figure 22-3).

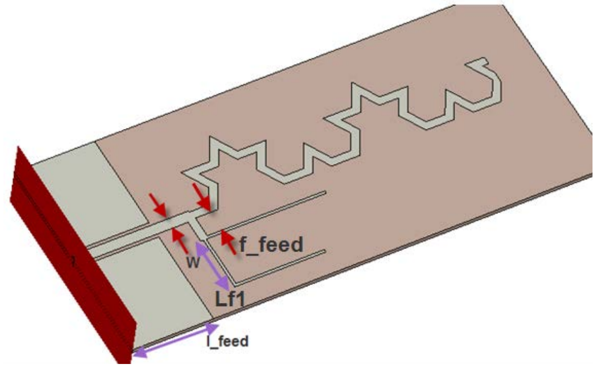

Fig. 22-3 Tri-band monopole antenna with Koch fractal structure

According to figure 23-3, Simulation results for feed line width are swept from 1mm to 2mm, we observe that the more feed line's width is extended, returning losses are improved in all three of the bands.

While increasing the width of the strip improves the antenna results, but if we pay more attention, it causes frequency shift towards higher frequencies, which consequently worsens antenna miniaturization factor. As explained in the context of research it happens due to low electrical length in proportion to its physical length. Thus, the monopole width of 2mm is selected so that the return loss is relatively favorable and that the frequency shift is lower.

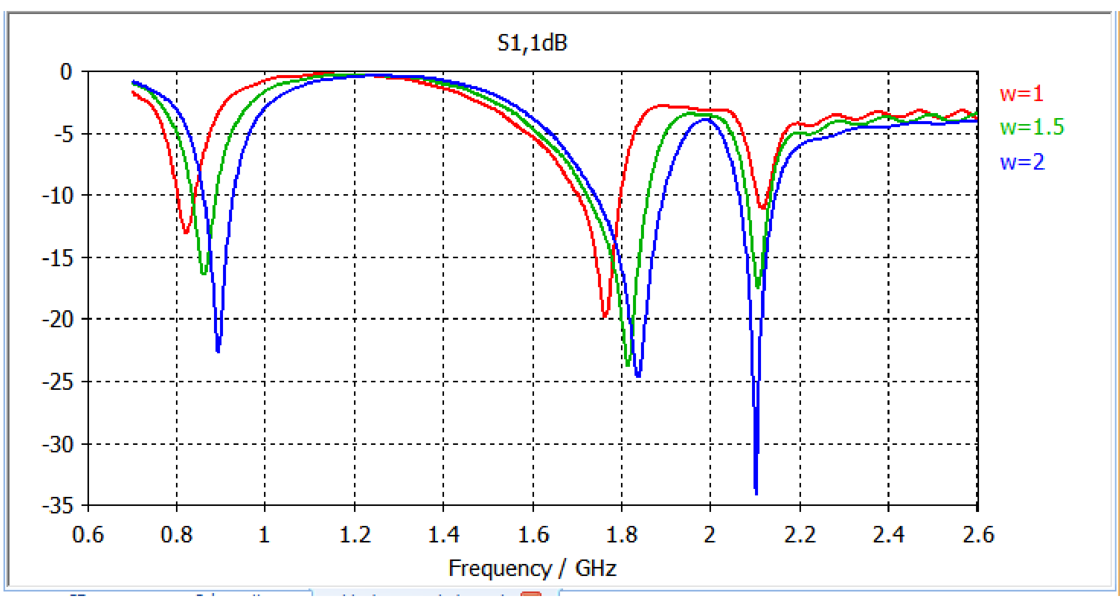

Fig. 23-3 The effect of original monopole width on return loss

The impact of ground plane dimensions on scattering parameters

Surely, in power system of each antenna a particular feed line is used that the antenna's specifications are not independent of the parameters of these lines. In the context of the research the relations relevant to calculations of the input impedance of the CPW line are written. As explained, central strip width is selected equal to 2 mm that in case of construction of these antennas, it will be consistent with standard connectors' dimensions. (Standard connector ferrule diameter 1mm and its Teflon diameter is 4mm). Strip width and the air gap between the ground plane and the main strip, according to the antenna input impedance of 50 ohm it should be equal to 0.6 mm. But this width is easily calculated using Calculator of the software CST itself. Therefore, with these descriptions only two parameters of width and length of ground plane can be swept that the width of the ground plane is in fact dependent on the width of the substrate. According to figure 22-3 that the length of the antenna's ground plane is specified with l_feed parameter, the effects of ground plane length on antenna return loss is shown below. It can be said that this parameter is ineffective on the scattering parameters.

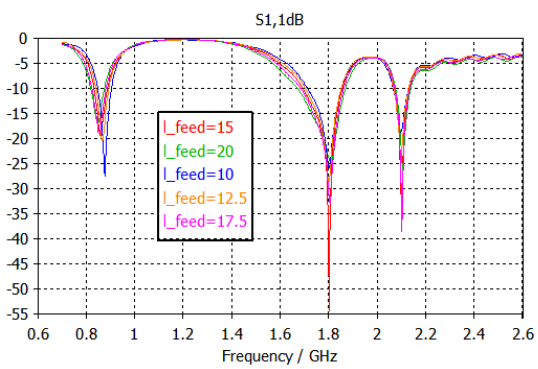

Fig. 24-3 The impact of ground plane length on the return loss

The effect of the horizontal distance between the monopoles on irradiation and scattering parameters

The distance between the lower band and two monopoles LTE 1800/2100 that are named with f_feed parameter (figure 22-3) according to the following figures from 5 to 15 mm are swept and results in two states 10 and 15 are almost close to each other but in F_feed = 5 mm dual-band high frequency response is not favorable and this is because of the exceeded adjacency of the two monopoles and naturally the coupling of the two monopoles are extremely high and the effect of capacitive properties that is created between them, unsettles the antenna's specs. As can be seen from the frequency response of the antenna, extending the distance is almost ineffective but because it increases the antenna's overall width, the 10mm distance suffices.

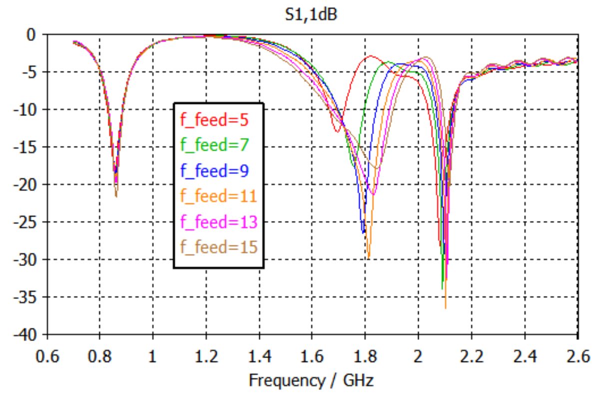

Fig. 25-3 The impact of the distance between the first and second monopole on the return loss

The distance between the second and third monopole that is named with the parameter Lf1, in fact, in addition that this parameter specifies the distance between the two monopoles, but it is also the monopole length of the band LTE 2100. Thus, as it can be seen from Figure 26-3, this parameter is almost ineffective to the other two bands and just displaces the frequency response of the band LTE 2100. As usual, with this increase in distance, leading to a length increase in the third monopole, the frequency response is shifted toward lower frequencies and by reducing it, moves to higher frequencies.

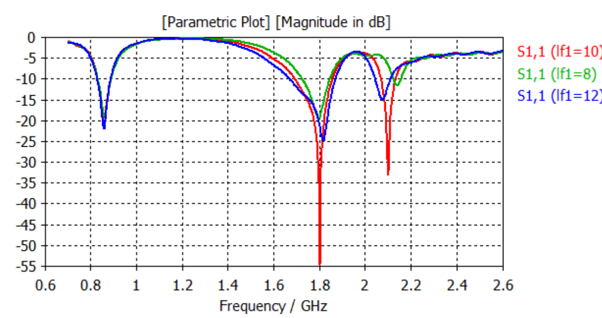

Fig. 26-3 The impact of the distance between the first and second monopole on the return loss

Monopoles Sweep Length

In the third step of tri-band monopole antenna design, we have seen that adding any of the monopoles, creates a new band in the frequency bands. But we did not check the length of the monopoles. Monopoles' resonant frequency and the antenna operating frequency are inversely related and the more the length of the monopole is extended it will be related to lower frequencies. We also saw that monopoles in frequencies which the length of the structure is equal to a quarter wavelength, would begin to have resonance. The relation of wavelength and frequency in ideal wired monopoles are thus explained in the following manner

$$\lambda = \frac{c}{f} \qquad \text{3-7}$$

And C is the speed of light in free space and is equal to 300000000 meters per second. Therefore, if we wish to design the monopole antenna at any frequency, first, by using the above equation, the wavelength is calculated and the length of the monopole is chosen as the size of a quarter of that amount.

As seen in the figure below, lengths L2, L3 and lcc are respectively related to bands LTE2100, LTE 1800 LTE 850

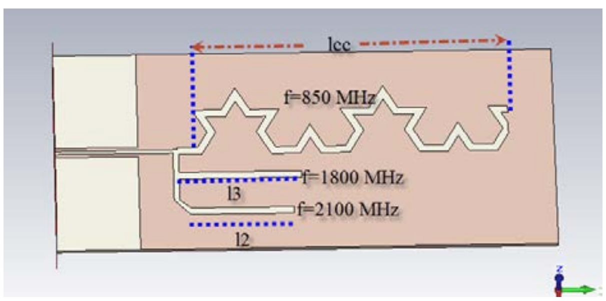

Fig. 27-3 Tri-band monopole antenna with Koch fractal

Firstly we sweep the length of the shortest monopole (L2) (figure 28-3) as the scattering parameters graph suggests, the larger the length of the monopole, the lower is its resonance and it is noteworthy that the change of the length does not affect other resonances. In the latter case, the length of L3 or monopole related to the frequency 1800 varies (Figure 29, 3), again the increase in the length of the monopole causes displacement of the frequency response to lower frequencies. In this case, changes in the frequency response in the frequency MHz 850 is independent of the changes but higher-band frequency response in this case has been affected by these changes. In the third case similar to the two previous cases, length change of the biggest monopole (Fig. 30-3), causes the alteration of the frequency response of the lower band 850 MHz. As a general conclusion it can be said that by changing the length of one monopole, monopoles that are shorter than variable monopole are affected by the changes while the bigger monopoles are independent of the changes. These attributes of the monopoles are utilized in designing the tri-band antenna. It means that firstly the biggest monopole is designed, and then respectively the smaller monopoles are designed and optimized.

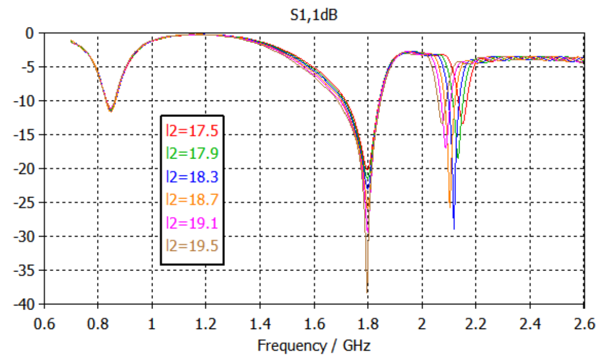

Fig. 28-3 Fractal tri-band monopole antenna's return loss in proportion to (per) monopole sweep length of the band LTE 2100

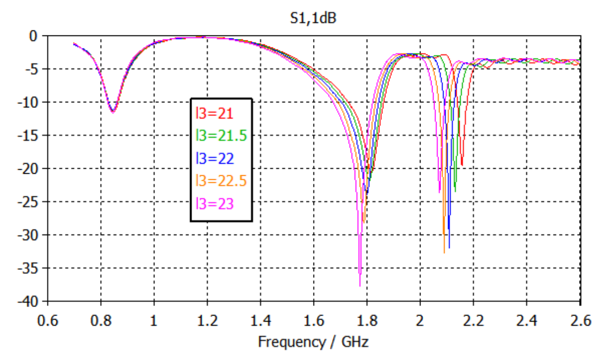

Fig. 29-3 Fractal tri-band monopole antenna's return loss in proportion to (per) monopole sweep length of the band LTE 1800

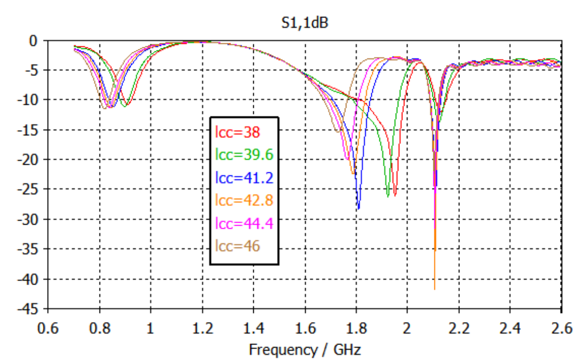

Fig. 30-3 Fractal tri-band monopole antenna's return loss in proportion to (per) monopole sweep length of the band LTE 850

Bending of the monopole of the band LTE850

As mentioned in the previous section, in order to have an optimal and safe design it is necessary to completely check the effect of the simulation parameters on the results, as it was done in the previous section, therefore, by considering the impact of the above parameters, tri-band monopole antenna was optimized and as the final stage in antenna miniaturization, the bottom of monopole was bent 90 degrees along the feed line (figure 31-3).

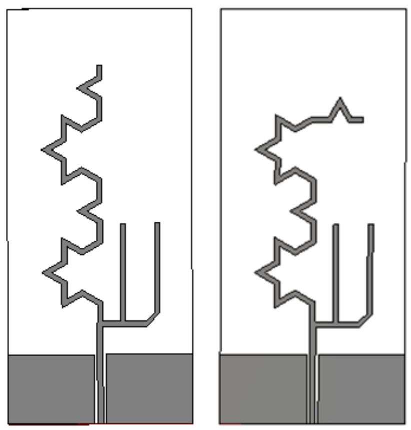

Fig. 31-3 Fractal planar monopole antenna (Right: bent, left: not bent)

According to figure 32-3, it can be said that bending the monopole was almost ineffective on the return loss of antenna. To investigate the effect of bending on antenna radiation pattern, in the figure, antenna radiation patterns in plane H, are compared in three antennas working frequency and again there is not much of an influence on the radiation pattern (Figure 33-3).

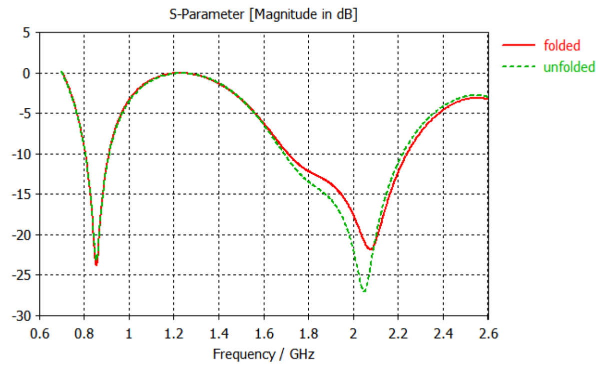

Fig. 32-3 Return Loss of fractal planar monopole antenna (Right: bent, left: not bent)

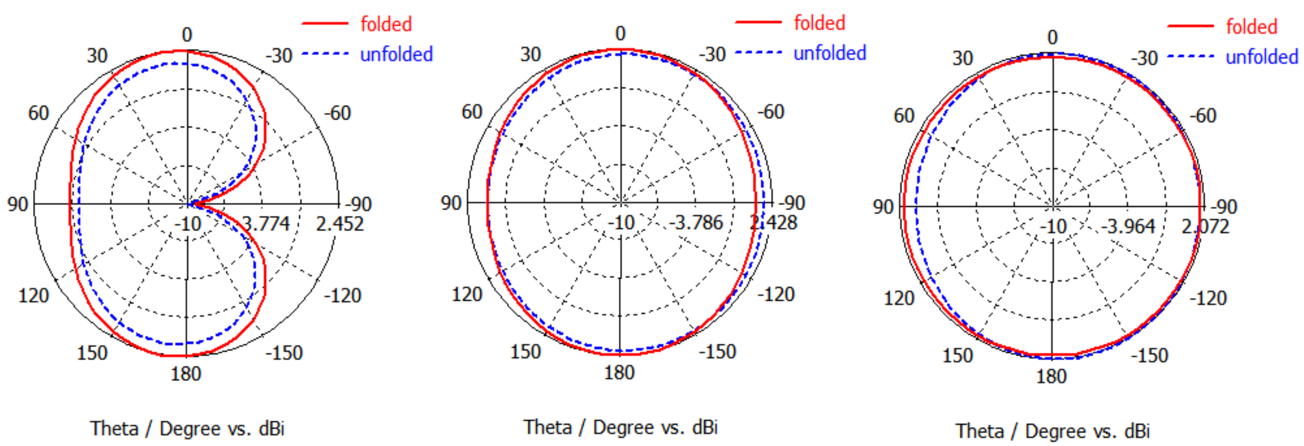

Fig. 33-3 Radiation pattern of the monopole antenna bent or not bent from left to right, respectively at frequencies of 850, 1800 and 2100 MHZ in plane H

Finally, with regard to the influence of each parameter on the simulation results, the finalized antenna dimensions and sizes are shown in Figure 34-3. The final parameters of the designed antenna are listed in table 4-3. The obtained monopole dimensions in millimeters are equal to 55.8 * 23 * 0.8 and with respect to normal monopole in this band in accordance with the results of the first step, the size has become 41% smaller.

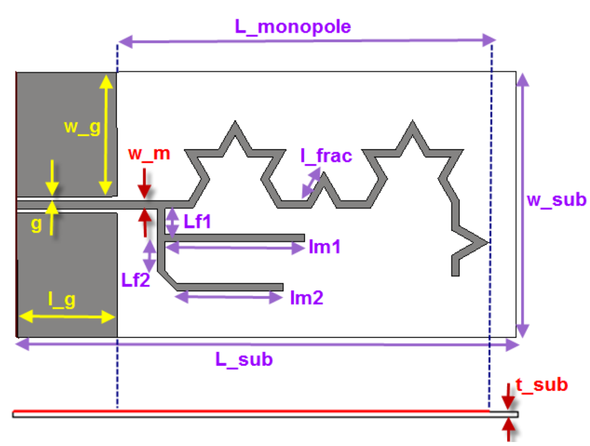

Fig. 34-3 Bent fractal monopole antenna

Table 4-3: Parameters of bent fractal monopole antenna

Parameter	Size)mm(	Parameter	Size)mm(
L_sub	75	Lm2	16
W_sub	40	Lf1	3.87
T_sub	0.8	Lf2	3.87
L_monopole	55.8	L_g	15
W_m	1.3	W_g	18.67
Lm1	22	g	0.6
L_frac	5		

Return loss, radiation pattern and efficiency of bent fractal monopole antenna are respectively shown in the figure 35-3, 36-3 and 37-3. Radiation pattern of the antenna in plane H is quite omnidirectional and also has a good pattern in plane E. By optimizing the dimensions of the antenna, dual-band high frequency antenna (LTE1800 / 2100) which were close to each other, overlap and bandwidth in the upper band is increased (Fig. 35, 3). Also, due to proper adjustments in frequency bands and proper forms of the monopoles, antenna radiation efficiency in LTE bands is better than 76%. The results of the antenna are according to the following table.

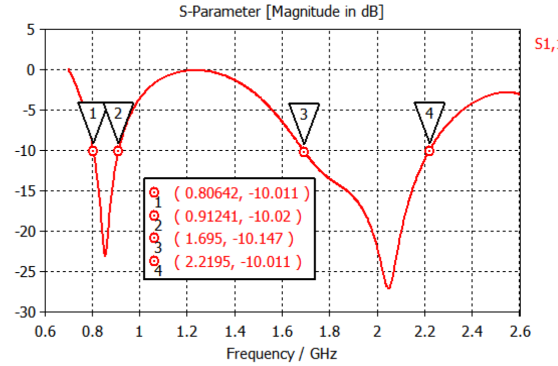

Fig. 35-3 Final return loss of tri-band bent monopole antenna with Koch fractal structure

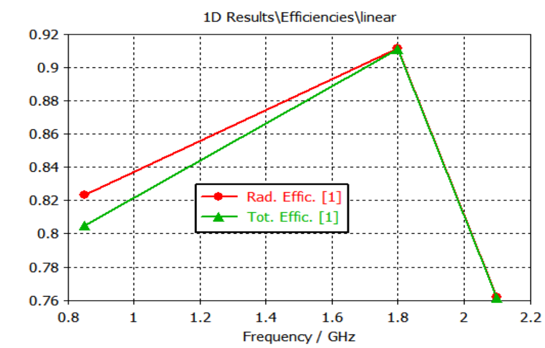

Fig. 37-3 Radiation efficiency and overall efficiency of bent fractal monopole antenna

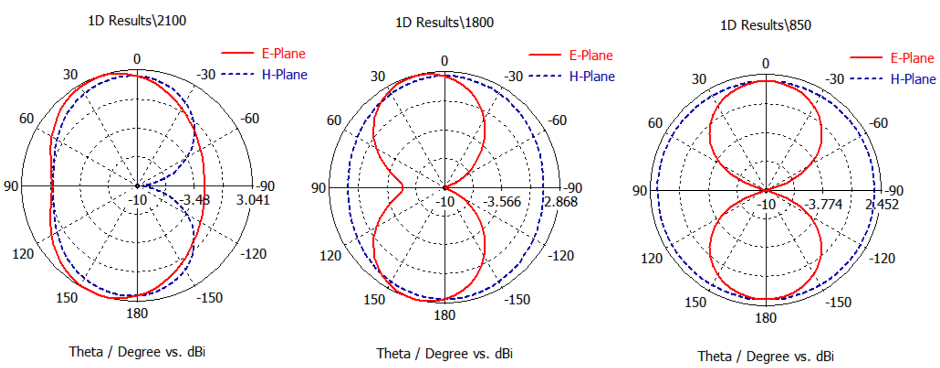

Fig. 36-3 Radiation pattern of bent monopole antenna with Koch fractal structure

Table 5-3: Specifications of planar monopole antenna with bent Koch fractal structure

Board Dimensions(mm)	Monopole dimensions (mm)	Bandwidth)S11<10 dB F0=850 MHz	Bandwidth (S11<10 dB F0=1950 MHz	Antenna Gain (dB)		
				850MHz	1800 MHz	2100 MHz
40*75	25*55.8	12.5%)806-912)	27%(1695-2219)	1.77	3.03	3.07

Results

Comparing the resulting outcome of the present research with the results of previous research works

In this section the work done in this study is compared to a few examples of the work of other researchers (Table 1-4). Total Efficiency of the antenna is more than 76%. In frequency of LTE 1800 because of good implementation the total output of the antenna has reached 90% which is far higher than the efficiency of the other previously done works. Generally, due to size limitations in all mobile antennas, the biggest dimension of the antenna that is low band monopole, is smaller than 60 mm which has been observed in this study. In table 1-4 antenna dimensions by a coefficient of the wavelength in free space are presented.

Table 1-4: Comparing the results of the research with previous works

Article	Dimensions based on a multiple of the wavelength in free space	F1			F2			F3		
		BW(%)	Gain(dB)	Efficiency(%)	BW(%)	Gain(dB)	Efficiency(%)	BW(%)	Gain(dB)	Efficiency(%)
Present study	0.07*0.15	850(S11<-10)			1800(S11<-10)			2100(S11<-10)		
		12.5	1.77	80	27	3.03	91	Common with previous bands	3.07	76
Dual band antenna for mobile broadband [1]	0.05*0.12	900(S11<-6)			1900(S11<-6)			2600(S11<-6)		
		42	1.4	-	53	2.1	-	Common with previous bands	4	-
Planar monopole antenna MIMO[2]	0.11*0.13	770(S11<-7)			1800(S11<-7)			2400(S11<-7)		
		6	0.43	56	20	3.1	66	4	4.23	51
Planar antenna with adjustable capacitor for 3rd and 4th generation mobiles[3]	0.03*0.17	850(S11<-6)			1850(S11<-6)			2200(S11<-6)		
		24.7	1.9	53	18	2.3	58	Common with previous band	2.2	57
Planar antenna with feeding of the band couplingLTE [4]	0.05*0.16	850(S11<-6)			1800(S11<-6)			2400(S11<-6)		
		43	1	55	52	1.7	60	Common with previous band	2	60
Broadband planar monopole antenna with metamaterial band LTE[5]	0.04*0.15	740(S11<-7)			1800(S11<-7)			2100(S11<-7)		
		33	1.57	45	52	4	58	Common with previous band	4	58

Conclusion

According to the purpose of this study which is designing and simulation of the monopole antenna using fractal structures, we designed the monopole antenna by using Koch fractal structure. In the first step we saw that replacing the fractal structure with a simple monopole has little effect on the returning loss, furthermore, there is little variation in radiation specifications of the antenna. In later stages we added monopoles related to other bands to this structure and their effects were also studied. In the final stage, the fractal monopole which the total length of the antenna is dependent on it, was bent to 90 degrees, and with these changes the total length of the antenna in proportion to the simple monopole became 41% smaller in size. The antenna was designed using CST Studio Suite software with two different modes including time domain and frequency domain, and in both cases, the results were finely synchronized with each other.

References

[1] T. Z. R. Li and M. M. Tentzeris, “dual-frequency broadband antenna for mobile device applications,” Antenna and Wireless Propagation Letter. PP. 978-980, 2011.

[2] D. WU, S. W. Cheung and T. I. Yuk and L. Liu, “Design of a printed Multiband MIMO antenna,” 7th European Conference on Antenna and Propagation, PP. 2020-2023, 2013.

[3] C. H. Lin, K. K. Tiong, J. S. Sun, Y. Chen and G. Y. Chen, “A Compact Internal Planar Antenna with a capacitive Tuner for 3G and 4G Mobile Phone Application,” International journal of Communication. ISSUE 2, VOL. 4 , 2010.

[4] Z. Xie, W. Lin and G. Yang, “Coupled-Fed Printed Antenna for LTE Mobile Handset applications,” Microwave and Optical Technology Letters, VOL. 56, NO. 8, August 2014.

[5] J. Luo, S. Gong, P. Duan, C. Mou and M. Long. “Small-Size Wideband Monopole Antenna with CRLH-TL for LTE Mobile Phone,” Progress In Electromagnetics Research. VOL. 50, PP. 171-179, 2014