Design and Analysis of Compact Fractal Patch antenna with Enhanced Bandwidth and Harmonic Suppression for WiMAX Applications

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Abstract

A single-layer a compact fractal patch antenna with capabilities of both bandwidth enhancement and harmonic suppression is proposed. For this purpose, a pair of λ/4 microstripline resonators is introduced and coupled in proximity to a rectangular patch. First, the miniaturization is investigated by Koch slot to radiating edge of the reference antenna through its symmetry plan. The wideband property can be obtained by making partial ground and coupled radiating λ/4 resonators. Different from other reported dual-resonance patch antennas, the proposed antenna does not require the electrically thick substrate, so it has attractive low-profile property. Thanks to the good features of λ/4 resonators and capacitive feeding scheme, harmonic radiating modes of the patch antenna can be significantly suppressed as highly demanded in modern highly integrated communication systems. The antenna has been designed on FR4 substrate with an overall dimension of 46mm *46mm *1.6mm.The substrate has dielectric constant of 4.4 and thickness of 1.6 mm. The simulated results show that the proposed antenna achieves good impedance matching an operating bandwidth of 2.52–4.27 GHz (52.91%). Thus it covers Wi-MAX 3.30-3.70GHz band, and LTE 2.50-2.69 GHz band. The working principle, and design procedure are extensively described. Finally, a prototype antenna operating at 3.5 GHz is designed and fabricated. The Simulated results show that its bandwidth 1750MHz is 17 times wider than that of the traditional insert-fed patch counterpart, and the harmful spurious radiation from other higher order radiating modes has been effectively suppressed.

INTRODUCTION

In Modern communication and radar systems, the antenna and the front-end are placed closely or even integrated together [1]. In these systems, the microstrip patch antenna is much popular since it can be easily integrated with many other active and passive circuits such as filters, amplifiers, oscillators, and mixers. Despite these attractive features, the microstrip antenna usually suffers from several inherent drawbacks. One is the narrow bandwidth because of its resonant property with a high Q; the other is the high level of harmonic radiation, which will decrease the efficiency of the system and even cause harmful interferences with other systems. To enhance the bandwidth of patch antennas, many efforts have been made by using the aperture coupling feed [2], proximity coupling feed [3], or stacked patch configurations [4] - [6].

When compared with the probe-fed method, the microstrip fed approach is much useful in the implementation of an array antenna with a number of radiating elements. In this context, the microstrip feeding network and patch radiating elements can be fully integrated on a single-layer substrate and the entire array can be fabricated simultaneously by using the printing technology. However, the thickness of the dielectric substrate must be electrically small, so that it brings a challenging task in the design of a wideband microstrip fed patch antenna on a single-layer substrate. So far, a few techniques have been reported to solve this problem. In [6], additional non-radiating resonators are employed to construction impedance-matching network. In [7] and [8], a half wavelength (λ/2) resonator and a composite right/left-handed resonator is employed, respectively, to achieve the wideband performance. Since the sizes of the feeding networks are significantly enlarged, these approaches can hardly be applied in the design of an array. A size-miniaturization method is reported in [9], but the patch configuration is destroyed by an extra T-shaped resonator. Moreover, the harmonic radiation cannot be suppressed because this T-shaped resonator operates as a λ/2 resonator.

In this paper, a microstrip-fed fractal patch antenna with enhanced bandwidth and good harmonic suppression performance is presented. As reported in [10], a patch could be capacitively fed by a coupling gap. In our method, a pair of λ/4 resonators is employed and placed in proximity to the radiating patch for wideband radiation under dual resonances. The advantages of this method are as follows.

1) Operating bandwidth of a single-layer patch antenna is enhanced even for an electrically thin substrate, and it can be further controlled to some extent by adjusting the gap width between the patch and the λ/4 resonators.

2) Harmonic radiation at high frequency is effectively suppressed thanks to the characteristics of capacitive feeding structure and λ/4 resonators.

3) The feeding-line section is small in size so as not to increase the overall size of the patch antenna in array applications.

GEOMETRY AND WORKING PRINCIPLE

The dielectric chosen is FR4-epoxy substrate having relative permittivity of 4.4 and the thickness of 1.6mm. The resonant frequency of the rectangular patch antenna, of length L and width W can be calculated using the following formula.

Geometry

Calculation of Lambda (λ0)-

$$\lambda_0 = \frac{c}{f} \quad (1)$$

Where c : speed of light = $3 \times 10^8 m/s$
f : frequency = 3.5 GHz

$\lambda_0 = 86mm$ at 3.5 GHz

The center frequency will be approximately given by:

$$f_c = \frac{c}{2L\sqrt{\epsilon_r}} \quad (2)$$

Therefore, length of the patch is given by:

$$L = \frac{c}{2f_c\sqrt{\epsilon_r}} \quad (3)$$

Where fc is Centre frequency =3.5GHz
ϵ_r=4.4 and c=3x10^8
L=19.35mm

Width of the patch:

$$w = \frac{c}{2f_r}\sqrt{\frac{2}{\epsilon_r + 1}} \quad (4)$$

For c=3*10^8 m/s, *fr*=3.5GHz, ε *r*=4.4we get
W=26.08mm.

Feed width can be calculated by using:

$$Z_0 = \frac{60}{\sqrt{\epsilon_r}} \ln\left(8\left(\frac{H}{W_f}\right) + 0.25\left(\frac{W_f}{H}\right)\right) \quad (5)$$

We get W_f**=2.8mm**
Where W_f is width of feed

Calculation of Feed length (F_l):

$$F_l = \frac{\lambda}{4 \times \sqrt{4.4}} \quad (6)$$

F_l**=10.75mm**
Calculation of Resonator length (Lr):
Resonator length (Lr)=λ/4
Lr=21.5mm

Calculation of Substrate dimension:

$$L_s = L + 2 \times 6h \quad (7)$$

Length of substrate:L_s=20+2$\times 6 \times 1.6 = 38mm$

$$W_s = W + 2 \times 6h \quad (8)$$

Width of substrate:$W_s = 26 + 2 \times 6 \times 1.6 = 46mm$

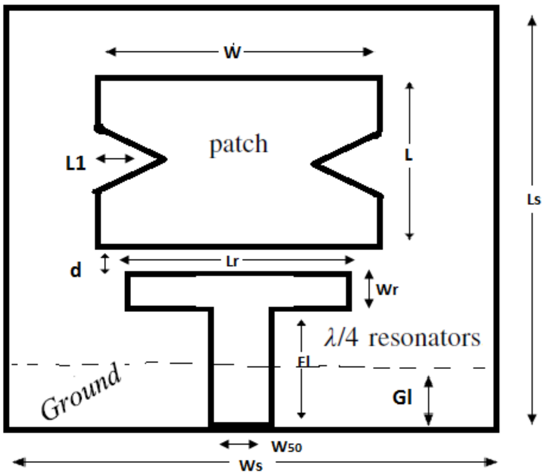


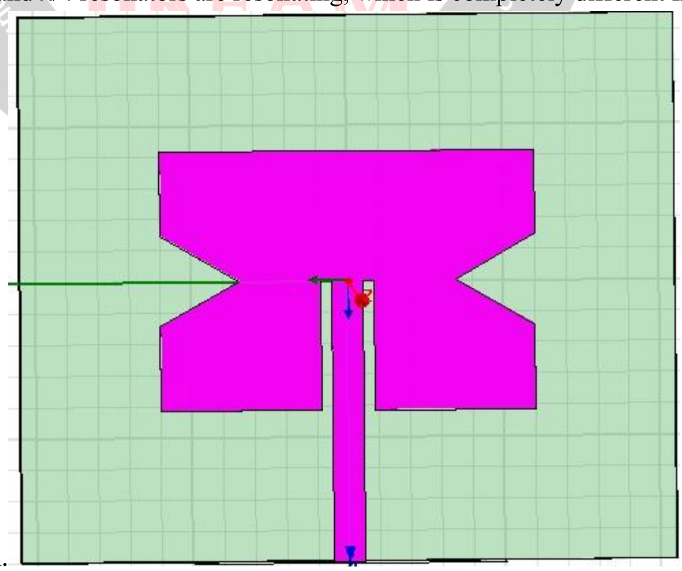
Fig.1 Geometry of the proposed wideband Koch fractal patch antenna

The proposed antenna is optimized by using the HFSS simulation code and the optimized parameters are:
L = 19.6mm, W = 26mm, L1 = 6.5mm, d=1.7mm, Wr = 1mm, Fl = 10.5mm, Lr = 21.5mm, Ls = 46mm, Gl=8mm and Ws = 46mm Figure.1 shows the design of both proposed Koch fractal patch antennas and its dimension. As shown in the Figure, the patches are fed by microstrip line resonator.

Working Principle

A resonator-type patch antenna usually requires an electricallythin substrate, thus suffering from a narrow bandwidth. An effective method for bandwidth enhancement is to construct a dual-resonance structure. For this purpose, an extra non radiating resonator is usually introduced in proximity to the radiating patch. Instead of the above lumped resonator in a thick substrate, a pair of λ/4 resonators is employed herein to form a coplanar distributed resonator, which is placed in proximity to the main patch as depicted in Fig. 1. The coupling gap plays a key role in achieving a wideband performance. Its width affects the dual resonant frequencies significantly. Therefore, the gap width can be optimized to make the two resonant frequencies close to each other, thus combining two narrower bands into a single wide band.

In addition to bandwidth enhancement, the proposed feeding method can effectively suppress the spurious radiation caused by harmonic resonant modes of the patch radiator. It can be intuitively explained in the following two aspects. On the one hand, the patch antenna is capacitively fed through a pair of λ/4 resonators. In this case, the energy can only be transmitted to the patch in discrete frequencies where both the patch and λ/4 resonators are resonating, which is completely different from the traditionalinsert-



fed patch antenna.

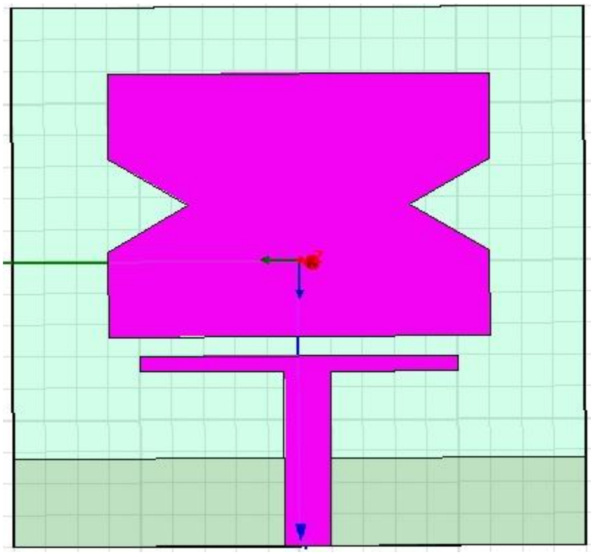
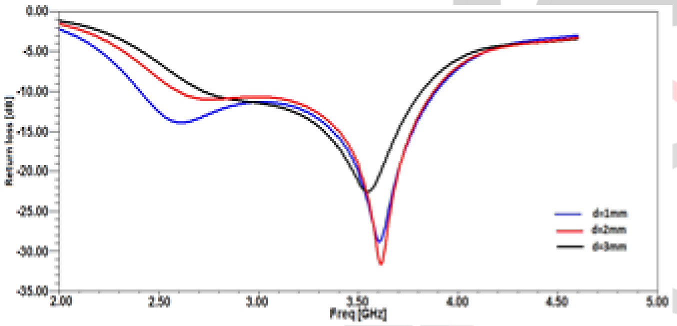


Fig.2 Traditional Koch fractal patch antennaFig 3. Proposed Koch Fractal Patch antenna

RESULTS AND DISCUSSION

Simulation of this proposed Koch fractal antenna has been carried out in HFSS. The simulation results are given in the following section:



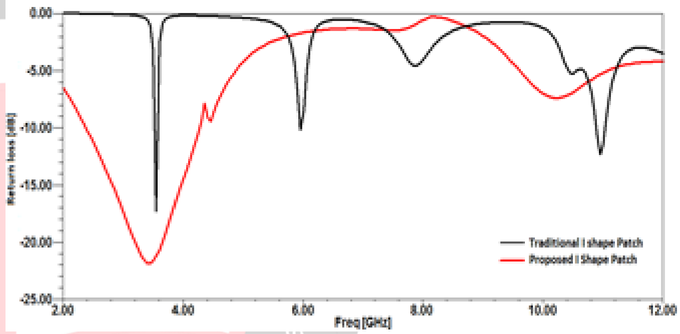


Fig.4 Influence of coupling gap d on the reflection coefficient

Fig 5: Simulated reflection coefficients of the proposed and traditional patch antennas in a wide frequency range

As shown in figure: 5 the value of Return loss is -21.21dB at 3.5GHz. The proposed antenna exhibits a wide impedance bandwidth about 1750MHz and there is harmonic reduction through entire band from 1 to 12GHz.

In addition to bandwidth enhancement as described above, the undesired harmonic radiation at high frequencies can be effectively suppressed by the proposed technique. Fig. 5 displays the simulated reflection coefficients in a wide frequency range under three different d values. For comparison, the result of a traditional fractal patch operating at 3.5GHz is also plotted in the same figure. There are many higher order radiating modes beyond the dominant TM10 mode for the traditional fractal patch antenna. However, most of them will disappear in the proposed fractal patch antennas, thereby validating the effective suppression of harmonic radiations. Comparing the results of d = 1.0 and 3.0 mm, we can further figure out that the effectiveness of the harmonic suppression is hardly influenced by the gap width and operation bandwidth. Comparing the results of d = 2.0mm, we can further figure out that the effectiveness operation bandwidth will increased.

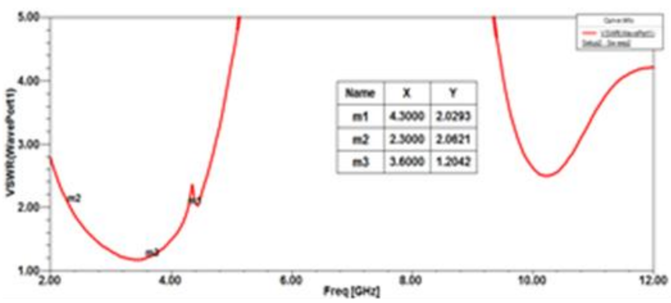


Fig.6 VSWR of proposed antenna

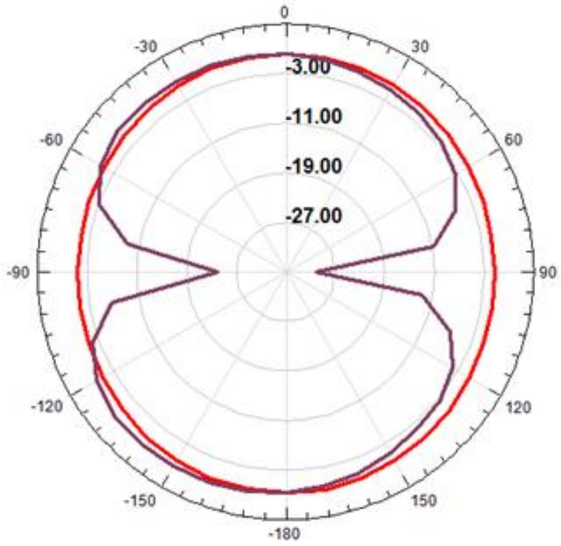
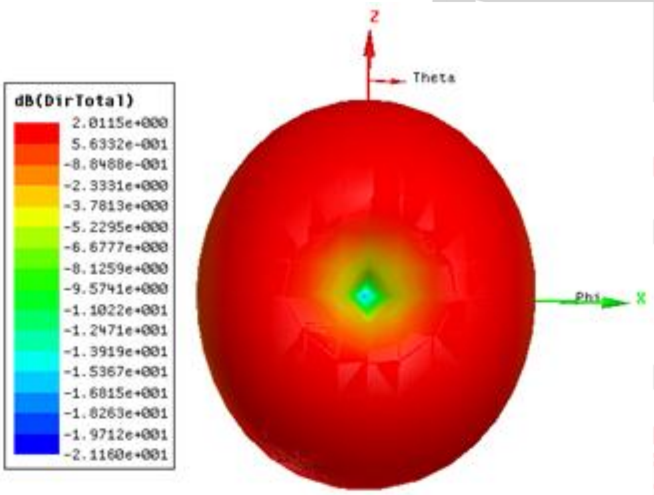


Fig.7 Radiation pattern

From Fig.7 it is observed that the radiation patterns of antenna are Omnidirectional in both E-plane & H plane at frequency 2.4GHZ.



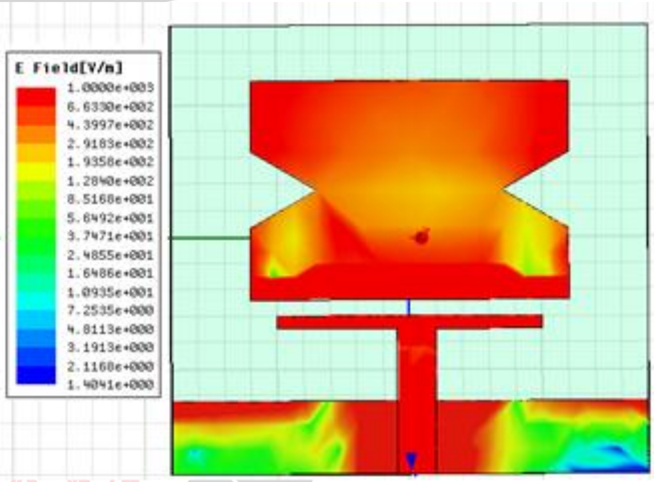


Fig 8. 3D Gain **Fig.9 Surface current distributions**

The simulated gain of the antenna at 3.5 GHz is presented in Figure 8.The maximum gain is 2.0 dBi at 3.5 GHz.The current distribution of the antenna at 3.5 GHz is presented in Figure 9. red color indicates maximum current along the edge of radiating patch.

COMPARISON TABLE

To improve the performance of this antenna, a pair of λ/4 microstripline resonators is introduced. As seen from the table, Traditional patch antenna, and proposed Koch fractal patch antenna are described. It concludes that proposed patch antenna technique improved both bandwidth & harmonics of antenna.

TABLE 1 COMPARISON TABLE

Sr. No.	Results	Freq (GHz)	Return loss (dB)	VSWR	BW (MHz)	Gain (dB)
1.	Traditional-shape Patch Antenna	3.53	-17.51	1.30	50	4.7
2.	**Proposed Koch fractal Patch Antenna**	**3.55**	**-21.21**	**1.29**	**1750**	**2.0**

CONCLUSION

This paper presents a new compact coupled-fed patch antenna in a single-layer substrate. By using a pair of λ/4 resonators, the bandwidth of the Koch fractal patch antenna is significantly enlarged and the harmonic radiations are effectively suppressed, while other advantages of the patch antenna, such as low cost, low profile, and easy integration, still remain.

In the analysis, a traditional vs proposed to analysis has been done. Our investigation shows that the bandwidth of this patch can be widened by adjusting the gap between the patch and the λ/4 resonator. To validate the design method, a proposed Koch fractal antenna operating at band Wi-MAX 3.5 GHz is designed. Its good performance is demonstrated by comparison with a traditional insert-fed patch antenna. The simulated results show that the bandwidth has been enlarged by 17 times and the higher mode radiations have been successfully suppressed. In addition, more symmetric radiation patterns and gains have been obtained. These properties of proposed antenna show that it could be successfully used for Wi-MAX and LTE applications.

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