Triple band Modified 90 Degree Koch Fractal H-Slot Microstrip Antenna

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***Abstract*— A tri-band fractal structure for Agriculture, WLAN and GSM band applications is presented. The desired resonances are 0.915, 1.8 and 2.45 GHz. This antenna consists of a modified 90 degree Koch fractal resonator, two layer substrates which are separated by an air gap layer and then fed through the SMA port and finally simulated on RT/Duroid 5880. Fractal shapes have been used to have a multi-band frequencies with a reduction in size. Furthermore, inductive and capacitive loadings have been applied though some stubs, gaps and two shorting posts to reduce the size. Thereafter, the equivalent circuit of the proposed antenna designed based on the literature. The uniqueness of the antenna is the miniaturized size (90 × 90× 10mm^3) compared to the first resonant frequency with high performance. The measured results performed on the performance of the proposed antenna, which has a good agreement with the simulation results.**

Keywords—Koch; triple-band; shrunk size; fractal; performance

I. INTRODUCTION

Pest control without using the pesticides, which have destructive impacts, have become an important problem in agriculture and many branches of science gathered to fix it. Based on the Federal Communications Commission (FCC), 0.047 GHz, 0.915 GHz, 1.8GHz, 2.45GHz can be applied for this purpose; as just the last three frequencies are known as microwave (MW) frequencies [1], [2]. In Microwave frequency bands, the microstrip patch antennas can be used as a solution for these aims. Due to having some characteristics such as light weight, low cost, small size, ease of fabrication and the lack of conduction losses in the resonator these antennas can be useful [3]. Furthermore, some of their specifications such as bandwidth, input impedance, and radiation patterns can be easily varied by adjusting the antenna's dimensions and shape [4].

The multi-band antenna which can operate in many frequency bands is one of the highly applied technologies in the telecommunication area recently. Several techniques have been compounded to augment the performance of the antenna and reduce the antenna size [5], [6]. A Fractal shape which means a broken or irregular segment was presented in 1975 for the first time [7]. The self-similarities of fractals allow the antenna to have a multi-band operation at the small size. The fractal shapes can be named as follows: Minkowski [8], Sierpinski [9], Hilbert [10] and Koch. These fractals have been applied to the microstrip antennas due to their applicable properties such as shrunk dimensions, a single feed and more directive in higher iterations [11].

The square loop microstrip line (Fig 1) is a circularly polarized (CP) traveling wave microstrip line. This square line can be obtained by bending the line into a suitable meander. One of the most important principles, which were applied in this design, is considered as following equation.

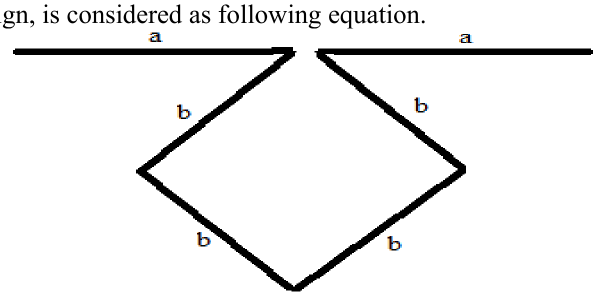

Fig. 1. The square loop microstrip line

$$L=2a + 4b \quad (1)$$

L is the total length of the line

There are many researchers worked on multi- band antenna designs for various wireless applications using H-shaped slot [13, 14], U-shaped slot [15] and C-shaped slot [16]. In addition, some of them worked on the Koch fractal multiband antenna. A Minkowski patch antenna was designed to operate at 2.4, 3.5 and 5.2 GHz and the gain after fabrication was 1.286, 1.410 and 3.945dB respectively [5]. Thereafter, a fractal shape antenna resonating at 0.96 GHz, 1.72 GHz, and 3 GHz presented [17]. A modified Minkowski antenna with resonant frequencies of 2.3GHz, 2.45 GHz, and 5.2 GHz designed for WLAN and WiMAX applications [18]. Then, a triple band H-shaped antenna with three resonances of 1.8 GHz, 2.45 GHz and 5.2GHz indicated the gain of 1.6dB, 1.9dB, and 2.1dB systematically [19].

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This paper is configured as follows: Section 2 illustrates the antenna design procedures. The proposed antenna simulation results such as its equivalent circuit and the measurement results for S-parameter, and far-field characteristics has been presented in Section 3 and then compared with the previous works. At last, Section 4 indicates the paper conclusion.

II. ANTENNA CONFIGURATION

The front, ground and side view of the antenna is represented in Fig 2 and 3 respectively. The proposed antenna is simulated and optimized using the Computer Simulation Technology (CST) with the optimum dimensions presented in Table 1. The proposed antenna comprises a modified 90 degree Koch fractal patch, inductive and capacitive loaded by two shorting posts connect the patch to ground, stubs and two different size of H-slots which has been etched from the ground layer. At first, the antenna designed on an RT/ Duroid 5880 substrate with permittivity of 2.2 and thickness of 1.575mm in order to lower permittivity to increase the BW and radiation efficiency. The design processes are presented as follows: Firstly, the first element is designed for the patch antenna based on first resonant frequency (0.915 GHz) according to transmission line theory which is L_p=163.93 [20]. As the initial calculations to get the actual antenna dimensions, the transmission line technique [21] for the rectangular patch was used.

Calculations of the width patch which is given by:

$$W_p = \frac{\lambda}{2}\left(\varepsilon_r + {}^{1}\!/_{2}\right)^{-1/2} \qquad (2)$$

Calculation of the effective dielectric constant, ε_{eff} which is presented by:

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(1\Big/\sqrt{1+12\left(\frac{h}{w}\right)}\right) \qquad (3)$$

Ground plane dimensions L_s and W_s which are given by [21]:

$$L_s = 6h + L\,, W_s = 6h + L \qquad (4)$$

TABLE I. PROPOSED ANTENNA DIMENSIONS

Parameters	Dimensions (mm)	Parameters	Dimensions (mm)
W_s	90	W_1	3
L_s	90	W_2	1.5
L_1	4	W_4	0.5
L_2	48.5	W_5	2.75
L_3	40.9	W_6	4
L_4	19.4	W_8	5
L_5	13.3	W_9	6
L_6	13.8	E_1	6.83
L_7	17.5	E_2	3.62
L_8	16.5	E_3	10.24
L_9	10.2	E_4	5.33

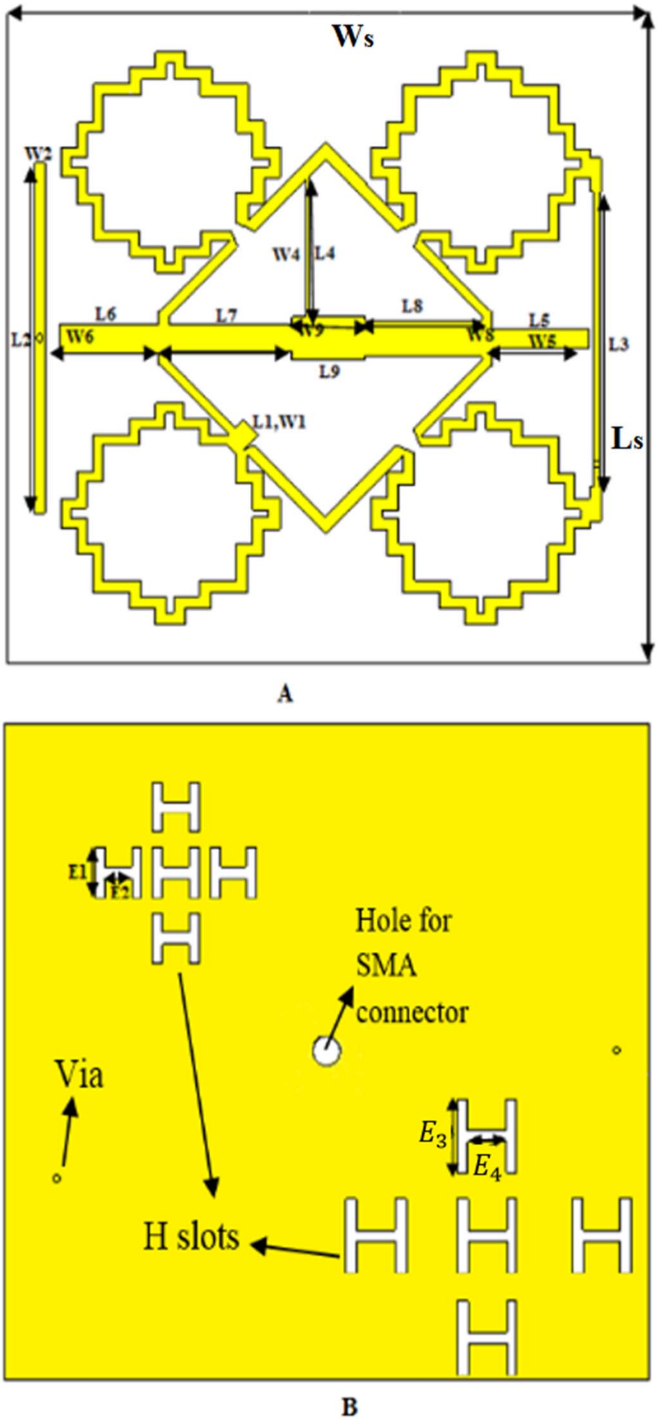

Fig. 2. Front-view (A) and ground view (B) of the proposed antenna

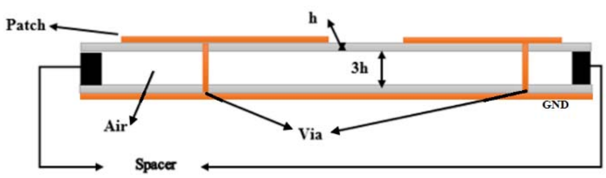

Fig. 3. Side-view of the proposed antenna

The Koch fractal complexity is increasing with enhancement in iterations and its high gain benefit will reduce if the first iteration starts getting higher. Thus, the 3th Koch fractal has been replaced with the proposed array with a half wave dipole length [22]. Afterwards, the first element of the antenna is located on the square loop transmission line to minimize the patch and antenna dimensions compare to the conventional one according to the first harmonic.

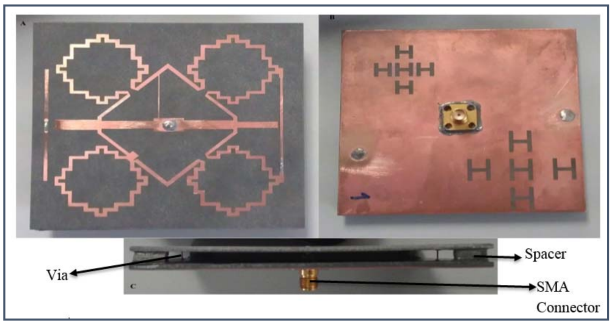

Fig. 4. Fabricated antenna prototype (A: front, B: ground and C: side-view)

In matching circuits case, the Square-loop microstrip line similarity affects the matching well, besides the square-loop can be considered as a patch array [23]. The transmission line with suitable length and width was applied to feed the patch by an SMA connector connected to the coaxial cable. The dimensions of line and stubs were achieved by optimizing the width to match the input impedance (50 Ω) to the patch impedance using CST software (Table 1). The direct impacts of these dimensions on the performance of the return loss S_{11} levels response are tangible. A very interesting applicable results have been recently demonstrated for H-slot coupled microstrip antenna which is removing the back radiation [24]. Thus, the proposed antenna has been loaded by some H-shaped slots which were etched from the ground layer. The advantages of this compound loading (inductive and capacitive) are the suppression of surface wave propagation, which helps to improve antenna's performance such as increasing antenna gain and reducing back radiation [35]. However, one of the resonant harmonics has been faded by changing the substrate material to RT/Duroid, the stub with dimensions of L_1, W_l was used to make the antenna operate again in three bands. Then, it has been loaded by two stubs (L_2, L_3) with capacitive distances from the patch exploited to shift the lower and upper bands. By checking the current distribution around the patch, it can be recognized that loading by stub L_4 has a mostly effect on the second band to shift it to either the right side or left side.

For raising the impedance bandwidth of the antenna the second layer thickness might be increased. But, by an enhancement in substrate thickness, the surface waves, fringing fields and radiated power will increase as well which reduce radiation efficiency [25]. Hence, the proposed antenna has been loaded by two via holes to decrease the surface waves and radiation power and provide better radiation characteristics. Another way to shift the frequency band to higher or lower band is applying the air gap between two layers. This resonant frequency shifting might be due to the indirect relation between the air gap (Δ) and effective dielectric constant (ε_{re}); if the air gap increased, the effective dielectric constant would decrease [26].

Figure 6 demonstrates the Lump Element Equivalent Circuit (EC) of the proposed antenna. As can be seen from Figure 6, at first two shunt capacitances applied to compensate the fringing electric fields at the edge and then the series inductors for the patch. For each of via holes, the related equivalent circuit was used (Fig 5). After designing the equivalent circuit for the patch and via hole, a parallel correlation of a resistance (rg), a capacitance (cg) and an inductance (lg) used for the ground. There is a capacitance (ca) for the air gap between two substrates. Furthermore, between each of two via holes Equivalent Circuits (EC) one capacitance because of coupling (c1-c4) was put. Furthermore, the values for the parameters have been consider based on the references [27,28]. The value of these variables can be got by using the circuit rules. We can see from the right side of the circuit and make it simple and then CST design studio to the values and get the exact resonance.

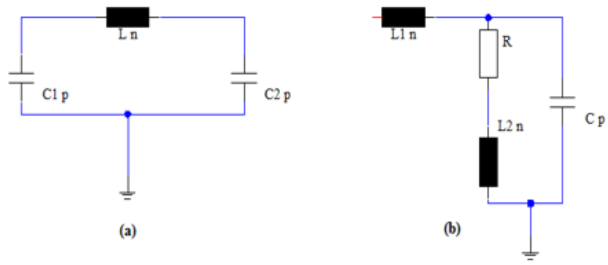

Fig. 5. The via hole in a ground plane (a) and via hole itself (b)

III. RESULT AND DISCUSSION

The performance of the proposed antenna, in terms of return losses, radiation patterns, efficiency and gain have been studied using computer simulation. In comparison with the previous works which applied the same operating frequency and recently reported in [28-32], the proposed antenna dimensions are smaller about 60%, 55%, 10%, and 64%, respectively. The simulated, analytical (equivalent circuit) and measurement S-parameter result of the proposed antenna are shown in Fig 8. These outcomes indicate the ability of the proposed antenna in operating at three resonances. The BW and VSWR for each of these resonances can be seen in Table 2. As seen in Table 2, there is a good matching between the antenna and the feed line since VSWR< 2.

As can be seen from Figure 8, the antenna simulation and its equivalent circuit results are in good agreement plus the antenna resonates at 0.915, 1.8 and 2.45 GHz. The difference between the simulated and the measured results can be attributed to the fabrication tolerance and measurement errors[33]. In addition, changing in the air gap space between the layers after fabrication can affect the results and shift the frequency. Based on what were presented in Table2, the proposed antennas are applicable for ISM band applications [34]. The simulated radiation pattern, gain and radiation efficiency for the three resonance frequencies are shown in Figure 7 and Table 3 respectively.

The proposed antenna has more gain and efficiency compared to previous works presented in literature at the same resonant frequencies (0.915, 1.8, and 2.45 GHz) with compact size. The radiation pattern of the antenna is unidirectional and broadside and it is similar to the microstrip dipole antenna radiation pattern.

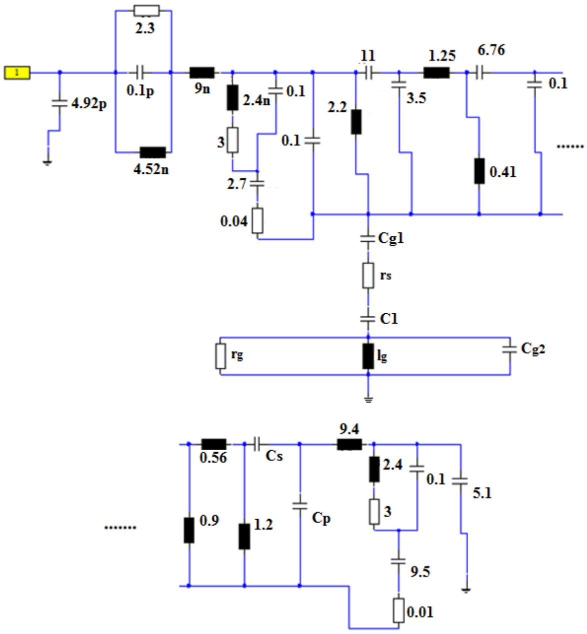

Fig. 6. Equivalent circuit of the proposed antenna (inductors in nH, capacitors in pf, and resistors in ohm)

TABLE II. THE SIMULATED (Sim), EQUIVALENT CIRCUIT (EC) AND MEASURED RESULTS OF THE PROPOSED ANTENNA

EC	**0.915(GHz)**	**1.8**	**2.45**	**Sim**	**0.915**	**1.8**	**2.45**
S_{11}(dB)	-23.3	-19	-22	**S_{11}(dB)**	-20.7	-11.8	-32.8
VSWR	1.6	1.2	1.3	**VSWR**	1.3	1.7	0.6
Measured (GHz)	**0.915**			**1.8**			**2.45**
S_{11}(dB)	-12.45(at0.896)			-10.21(1.78)			-11.94(2.38)

Table III. GAIN AND RADIATION EFFICIENCY OF THE PROPOSED ANTENNA

f(GHz)	0.915	1.8	2.45
Gain(dB)	2.1	3.42	6.68
Efficiency (%)	68	92.22	83

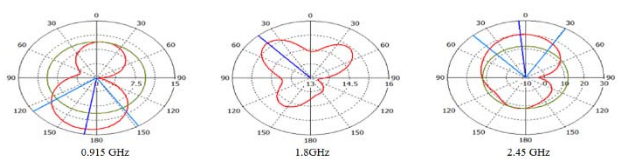

Fig. 7. Electric field radiation pattern of proposed antenna

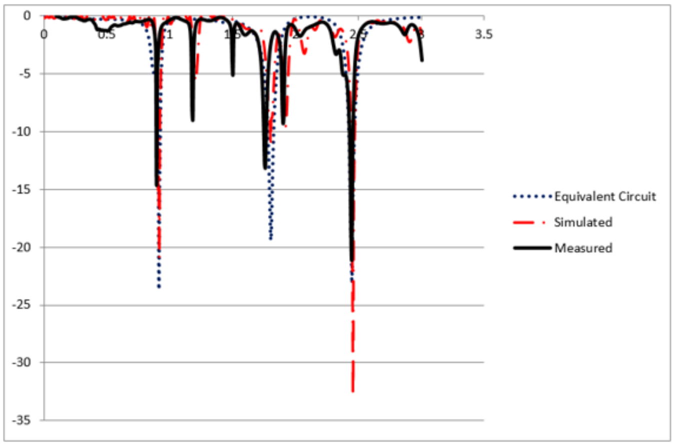

Fig. 8. Return loss result of the proposed antenna

IV. CONCLUSION

A novel modified 90-degree Koch fractal H-slot microstrip antenna resonating at 0.915 GHz, 1.8GHz and 2.45 GHz for ISM band and agricultural applications is presented in this paper. Simulation and measured studies on the return loss, antenna pattern and gain have been performed to study the antenna behavior which has good agreements. Results show that by loading the proposed antenna through shorting posts which connect the patch to ground layer and stubs, the back radiation and surface waves can be suppressed. Furthermore, the proposed antenna has miniaturized size by almost 50 % and higher gain and efficiency at each harmonic compared to the similar previous experiments.

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