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A Miniaturized Reconfigurable Antenna using Quantum Genetic Algorithm Optimization

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***Abstract*— This paper presents a volumetrically folded antenna design that is further miniaturized and reconfigured by employing Quantum Genetic Algorithm (QGA). The employed QGA determines the pixelated topology of the antenna structure, its feeding point, and the position of the single switch reconfiguring the antenna's frequency operation. As a result, the antenna operates at 868 MHz and 1.865 GHz when the switch is ON and regains operation at 2.4 GHz when the switch is OFF. In addition, the antenna size is reduced by 87% at 868 MHz, in comparison with planar antennas operating at the same frequency. The presented reconfigurable antenna can be proposed for Wi-Fi enabled Internet of Things (IoT) devices' integration.**

Keywords—Folded antenna; IoT; Miniaturization; Quantum Genetic Algorithm; Small antenna; Reconfiguration; Automated Design.

I. Introduction

Small, miniaturized and agile antennas are in demand especially with the rise of the Internet of Things (IoT). In an IoT environment, a multitude of devices connected together, require the necessary compact communication hardware in order to satisfy all the constraints imposed by the paradigm of millions of interconnected devices.

Multiple techniques are employed for miniaturization and size reduction of antennas. These techniques include folding [1] and incorporating slots and slits into the antenna structure [2]. On the other hand, miniaturizing an antenna while following IoT requirements entails the application of optimization algorithms. In the literature, genetic algorithm (GA) [3], quantum genetic algorithms (QGA) [4] and particle swarm optimization (PSO) [5] are some of the optimization techniques employed in antenna designs. In fact, the design of antennas for IoT devices requires the merging of different techniques in order to satisfy the IoT standard limitations.

In this paper, an antenna design is optimized by relying on QGA for IoT devices' integration. The QGA is also leveraged to reconfigure the antenna structure by relying on a single RF MEMS switch [6]. The final antenna structure is folded with a pixilated topology that enables the antenna to resonate at 868 MHz and 1.865 GHz when the switch is ON and adds to its operation, 2.4 GHz when the switch is OFF. The resulting structure exhibits an 87% size reduction at 868 MHz in comparison to planar antennas operating at the same frequency. The total resulting dimensions of the antenna are 40 x 52 mm^2. The implementation of QGA not only automates the design, but results in an optimal structure that is suitable for wirelessly enabled IoT devices integration. Section II of the paper discusses the antenna design based on QGA. Section III presents the antenna results and performance analysis, while section IV concludes the paper.

II. QGA based Miniaturized antenna Design

QGA is employed at first, in order to reduce the size of the antenna's basic structure. The resulting antenna structure exhibits a 3D folded patch antenna resonating at 2.4 GHz. The substrate used is Rogers Duroid 5880 with a dielectric constant of 2.2 and a thickness of 0.79 mm. The antenna is folded into 8 different layers as shown in Fig. 2(a). The folding is executed at the locations where the current distribution is the strongest. The total dimensions of the antenna are 40 mm x 52 mm x 5.16 mm. The QGA employment is manifested through a pixilation of the antenna topology that shifts the antenna operation to 868 MHz. Such frequency operation is fundamental for IoT communication operation. In reality, the pixilation of the antenna surface results in a topology that reduces the size of the antenna while ensuring appropriate impedance matching at the desired frequency bands. These pixelated slots are incorporated in layers 4, 5 and 6 of the antennas' structure.

QGA is an algorithm that associates quantum computation (QC) [7] and GA [3]. In comparison with GA, QGA is more efficient. Since the cost function plays a very important role in QGA optimization. In fact, this paper presents a novel cost function as shown in Equation (1).

$$cost = \frac{1}{50*fitness} = \frac{(10*(abs(Frequency-0.868))+1)}{\left(\left(\exp\left(\frac{Gain}{4}\right)\right)*abs(SParameter)\right)} \tag{1}$$

In addition, the overall size of each chromosome in the QGA code is 1612 bits and these bits are distributed in different layers. The QGA algorithm locates the best possible positions of the pixilation, and the optimal position of the feed. Hence, QGA fully defines the antenna structure and shapes its design. The code is executed for 100 iterations. After every iteration, and for every chromosome of the population, the fitness value is calculated. For each iteration, an assessment of the 20 fitness functions of the population is done and as a result the chromosome having the best fitness is kept. A rotation gate followed by the quantum mutation are applied on the parents' chromosomes and as a result, children are generated. The best fitness of each iteration is saved, normalized and evaluated. As

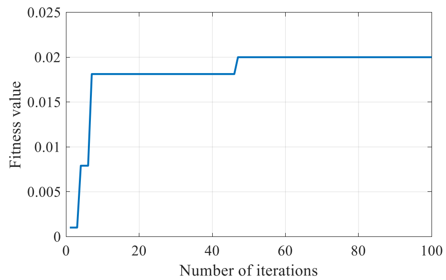

Fig. 1. Normalized fitness in function of the number of iterations

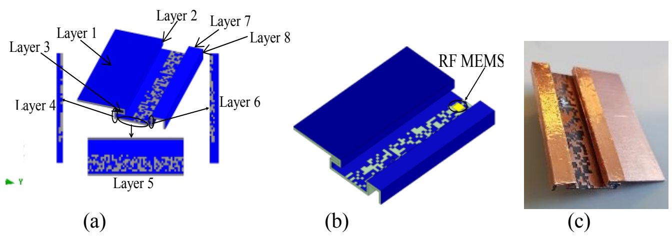

Fig. 2. (a) Antenna structure with different layers, (b) Reconfigurable antenna structure and (c) the fabricated prototype.

can be seen in Fig. 1, the fitness converges to a value of 0.02 after executing 100 iterations of the QGA code.

III. Reconfiguring The Antenna using QGA

After the antenna size is reduced, QGA is leveraged in order to reconfigure the antenna frequency to enable its integration within wirelessly capable IoT devices. Hence, a single RF MEMS is integrated at an optimal position determined by the QGA algorithm by relying on a modified cost function and a similar process to the one described in Section II. The integration of the RF MEMS enables the antenna to switch its frequency operation between 868 MHz and 1.865 GHz when the switch is ON and 868 MHz, 1.8 GHz and 2.4 GHz when the switch is OFF. Hence, the antenna not only regained its selective Wi-Fi operation, but also maintained its IoT operational mechanism. Furthermore, the integration of the RF MEMS forces a rearrangement of the antenna topology due to the impact of the RF MEMS on the input impedance. Hence, the pixilation is rearranged in order to accommodate the addition of the RF MEMS and in order to maintain impedance matching at the desired frequencies.

Finally, after hundreds of iterations of the code, the antenna design exhibiting its different layers is shown in Fig. 2(a) for its static configuration and in Fig. 2(b) for its reconfigurable topology where the optimal position of the switch is indicated. The frequency operation of the antenna is shown in Fig. 3 for the different states of the RF MEMS. The radiation patterns of the antenna at 868 MHz and 2.4 GHz in the X-Z plane and Y-Z plane are shown in Fig. 4. As a result, this antenna presents a suitable compact candidate for integration into small devices that constitute the backbone of IoT.

IV. Conclusion

This paper presents a QGA based antenna design resulting in a miniaturized reconfigurable antenna for IoT applications. This design is optimized by relying on a QGA code. The resulting antenna structure resonates at 868 MHz, 1.865 GHz, 1.8 GHz and 2.4 GHz using a customized QGA fitness function. The antenna achieves an 87 % miniaturization aspect at 868 MHz. The employment of QGA transformed the design into an optimal miniaturized reconfigurable topology with a high miniaturization ratio, suitable for integration into wirelessly capable compact devices.

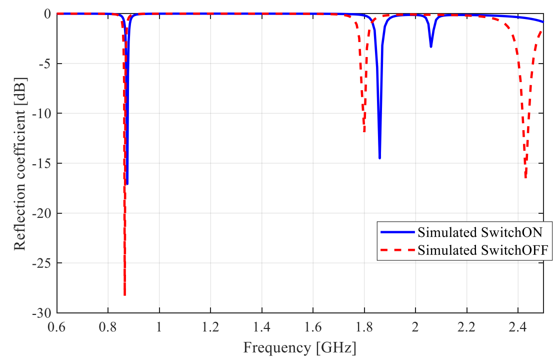

Fig. 3. Reflection coefficient when the RF MEMS is in its ON and OFF states.

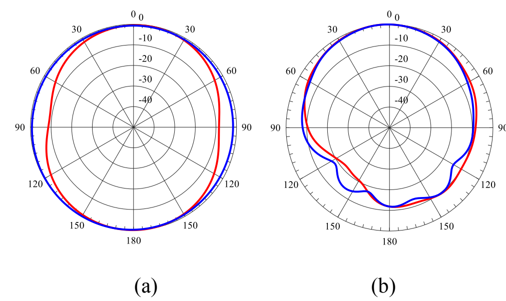

Fig. 4. Radiation pattern of the antenna at (a) 868 MHz in the X-Z plane and Y-Z plane and at (b) 2.4 GHz in the X-Z plane and Y-Z plane.

Acknowledgment

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