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A Digitally Tuned Flexible Reconfigurable Antenna for IoT Devices

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***Abstract*— In this paper, a digitally tuned flexible antenna is proposed for integration onto devices within the Internet of Things (IoT) paradigm. The antenna design caters for the various IoT communication standards by reconfiguring its operating frequency. Accordingly, the antenna reconfiguration allows operation at 868 MHz, 915 MHz, 1.8 GHz and 2.1 GHz. The reconfiguration is achieved digitally by resorting to a digitally tunable capacitor (DTC). The DTC changes its capacitance, and hence its frequency operation, by relying on 5-bit sequence commands through a microcontroller. The proposed antenna is coplanar waveguide fed with its ground plane surrounding the radiating structure. The gain of the antenna varies between 4 dB and 6 dB for different frequencies of operation. Its radiation efficiency varies between 78% and 92%. The antenna is fabricated and tested on a flexible substrate, where the resulting reconfigurable prototype maintains its performance characteristics for different bent states.**

Keywords— ***internet of things, IoT, flexible antenna, planar antenna, reconfigurable antenna, digital tunable capacitor***

I. INTRODUCTION

The increased device connectivity as well as the rise in demand for conformal components that can be integrated in multi-platform IoT devices, necessitate the design of flexible, lightweight antenna components. Such antennas can perform efficiently and accurately, regardless of their physical topology or bent status. Flexible antennas have been extensively proposed in literature for multiple applications that extend from wearable sensors to health monitoring devices and others [1]. The ability of an antenna to be flexible must always be complemented with its efficient operation regardless of the physical status of its deformed configuration.

The catering for this extended need of connectivity is always supplemented by a reconfigurable antenna operation. Such operation enables the antenna to serve a multitude of applications while maintaining a single structure. Reconfigurable antennas also addressed extensively in literature [2-3], are able to change their operation on demand. Many techniques are used for antenna reconfiguration such as electrical switches [2], optical switches, or mechanical reconfiguration [2]. Digital tuning has appeared recently as a new reconfiguration technique that enables an easier reconfigurable antenna control and integration into an IoT terminal [3].

The merging between a flexible antenna component and digital tuning is the focus of this paper. The presented digitally reconfigurable flexible antenna design is proposed for IoT device integration operating at Low Power Wide Area Network (LoRa Europe and US bands), GSM and other ISM bands. The presented reconfigurable antenna relies on digital tuning, is flexible for more conformity and is able to cater for a variety of applications without the need for additional antenna elements. This is to our knowledge the first of a kind digitally tuned flexible antenna component proposed for IoT integration.

Section II of this paper presents the design process of the reconfigurable flexible antenna. The radiation results of the antenna are presented in section III. Section IV concludes the paper.

II. FLEXIBLE RECONFIGURABLE IOT ANTENNA DESIGN

The important aspect of the flexible antenna design presented in this paper, is based on its added reconfiguration ability. The design presented is not only flexible; however, it is further enabled with a digital reconfiguration potential. The presented antenna, shown in Fig. 1(a), is composed of a flexible semi-bowtie antenna design based on coplanar waveguide feeding mechanism (CPW). The antenna structure is inspired from the design presented in [4], however it has been redesigned and tailored to be integrated on a flexible substrate for a more conformal IoT integration. The antenna is of 70x50 mm^2 dimensions mounted on a flexible Ultralow 3850 substrate with a dielectric constant of 2.9 and a thickness of 51 μm. The antenna design includes a variety of slots with a fully planar configuration.

Furthermore, the proposed antenna resorts to the capacitance and resistance variation of the DTC to tune and reconfigure its operating frequencies. The DTC is placed in a shunt position on the feeding CPW line, as shown in Fig. 1(a), in order to dynamically tune the input impedance of the antenna. The antenna, whose prototype is presented in Fig. 1(b), is printed on copper-clad Ultralam substrate (ε_r = 2.9 and h = 50 μm) using an inkjet-printed masking technique followed by etching. Frequency tuning is achieved by varying the DTC digital 5-bit binary input to tune its capacitance.

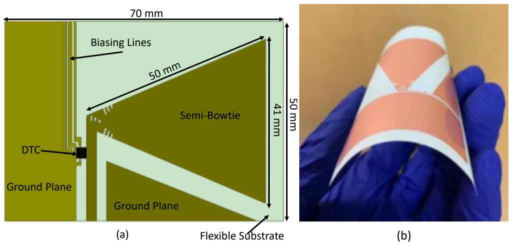

Fig. 1: Flexible Antenna design (a) the detailed antenna design and (b) the fabricated prototype before the integration of the digital tunable capacitor.

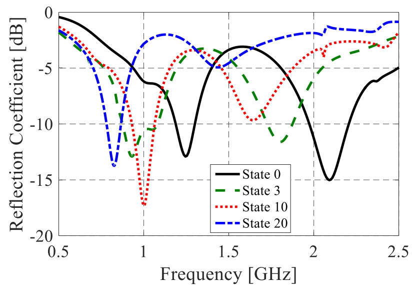

Fig. 2: Reflection coefficient of the flexible antenna for different states.

"Pe64907" Peregrine Semiconductor [5] DTC is used in this work. It achieves 32 different capacitance values (or states), which can be tuned by resorting to a digital 5-bit binary value (2^5=32) input. The modeling of the DTC component accounts for its constant inductive effect of 0.7 nH and its variable capacitance and resistance [5]. The different capacitance and resistance values can be calculated as described in Eq. 1 and Eq. 2 [5]:

$$C_s = 0.056 \times state + 0.85 \quad (pF) \tag{1}$$

$$R_s = \frac{20}{state + \frac{20}{state+0.7}} + 0.7 \quad (\Omega) \tag{2}$$

where "state" corresponds to the decimal value of the corresponding 5 bits' sequence. In state 0, the DTC has a capacitance of 0.85 pF, a resistance of 0.7 Ω and an inductance of 0.7 nH, while in state 20, the DTC achieves a capacitance of 1.97 pF, a resistance of 1.65 Ω and an inductance of 0.7 nH [5]. When the DTC is in state 0, the antenna operates at 1.2 GHz and 2.1 GHz. Then, the antenna shifts its frequency down to 868 MHz as the DTC states increase to reach 20 as shown in the reflection coefficient of Fig. 2.

III. Antenna Radiation Results

The radiation performance of the antenna at different states are shown in Fig. 3 and Table 1. The radiation patterns for the proposed design are presented in Fig. 3 at different frequencies for state 0 and state 3. The antenna is able to achieve different radiation patterns for different applications as desired for IoT integration. For example, the antenna has an omnidirectional radiation pattern at 915 MHz as shown in Fig.3 (a). Whereas, at 1.8 GHz and 2.1 GHz, the antenna produces an almost end fire radiation pattern as shown in Fig.3 (b).

The antenna's radiation efficiency and gain are shown in Table 1 for different states and operational frequencies. For example, the antenna achieves 92% radiation efficiency with a gain of 6 dB at 2.1 GHz. This is achieved when the DTC is in state 0 and is due to the fact that the semi-bowtie diameter is equivalent to half-wavelength at this frequency. The decrease in the antenna's size and the high capacitance and resistance values of the DTC in states ranging between 15 and 32 impact the radiation efficiency and gain of the antenna. Nevertheless, such efficiency and gain are acceptable for IoT applications.

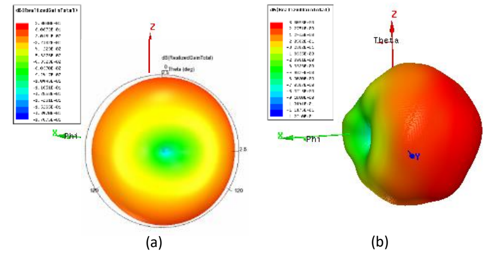

Fig. 3: The radiation pattern of the antenna in the X-Z plane at (a) 915 MHz and (b) 2.1 GHz.

Table 1: The antenna radiation efficiency, gain and size reduction for different operational frequencies and states.

State	Frequency [GHz]	Radiation Efficiency [%]	Gain [dB]
0	2.1	92	6
3	1.8	87	5.6
10	1	84	4.9
3	0.915	86	4.5
20	0.868	78	4.1

I. Conclusion

A frequency reconfigurable flexible antenna design for application in IoT devices is presented in this paper. The presented reconfigurable antenna relies on digital tuning in order to cater for a variety of applications (LORA, GSM and ISM) without the need for additional antenna elements. In addition, the antenna is designed on a flexible substrate for more conformability where its performance remains the same for different bent states.

Acknowledgment

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