A Dual-band Strain Sensor Based On Pop-up Half Wavelength Dipole Antenna

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***Abstract*— Here we present a pop-up half wavelength dipole antenna with dual band operation for strain sensing applications. The proposed antenna is lightweight, low cost and easy to fabricate with a simple design based on a compressive buckling technique. This flexible strain sensor can measure 0 to 30% uniaxial strain with the frequency shift in the range of 2.45 GHz to 2.9 GHz in the first band and 5.5 GHz to 6.3 GHz in the second band. A prototype of the proposed structure was fabricated and tested. Measured results show a good correlation with the Finite Element Analysis (FEA) simulation.**

Keywords*— *strain; pop-up; sensing; buckling; antenna.

I. INTRODUCTION

Stretchable strain sensors have been the subject of considerable research during the last decade and they are expected to significantly contribute to new technologies and be applied in various applications including health monitoring systems, human motion detection, smart cloths, environmental monitoring and so forth [1]. To date different types of antenna have been integrated in strain sensor designs [2-5]. For example a strain sensor based on a dual band rectangular microstrip patch antenna is reported in [2]. This sensor can measure 0 degree to 55 degree bending in the antenna by resonant frequency shift in the range of 1.8 GHz to 2.108 GHz for the first operational band and 2.4 GHz to 2.78 GHz for the second band. Other study has reported a circular microstrip patch antenna for strain sensing applications. The sensor can detect 0 to 10% strain by 10% resonant frequency down shift [3]. In [4] a microstrip patch antenna strain sensor has been designed based on the relation between the resonant frequency and the length of the microstrip patch antenna. The suggested sensor measures 0 to 5% strain by 3.6 MHz frequency down shift. Similarly, the strain sensor design reported in [5] is based on a planar dipole antenna and can detect 0 to 5% tensile strain with 28 MHz frequency down shift.

This paper introduces a new stretchable strain sensor design based on pop-up half wavelength dipole antenna by using a compressive buckling technique. This technique is a simple and cost effective fabrication process for transforming 2 dimensional (2D) layouts to 3D [6].

Finite Element Analysis (FEA) method using COMSOL multiphysics® software was applied to perform a two-step simulation [7]. At first a nonlinear buckling analysis was performed for the antenna under different strain levels from 0 to 30% and then the results from the first step were coupled to another RF simulation in order to evaluate the antenna performance. A good consistency was observed between numerical results and experimental measurements.

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II. ANTENNA DESIGN AND RESULTS

The proposed half wavelength dipole antenna is made of double layer 30 μm thick copper ribbons that are bonded with each other at selective sites on a T=0.4 mm thick Silicone rubber substrate (Dragon Skin) with Young's modulus of 166 kPa and Poisson ratio of 0.49. The schematic of the antenna is depicted in Fig. 1 and all geometrical dimensions are presented in Table I. The antena has been designed to work in a single band at 2.45 GHz when flat and the metallic ribbons are electrically connected in each dipole arm. The electrical properties of the elastomeric substrate were measured as 1.6 and 0.04 S/m for permittivity and conductivity, respectively. The input impedance of the antenna is 50 Ω.

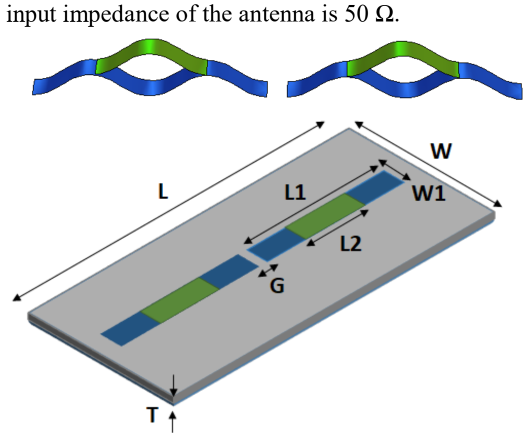

Fig. 1. Schematic of the designed dual band half wavelength dipole antenna.

TABLE I
DIMENSION PARAMETERS OF THE ANTENNA DESIGN

Parameters	L	L1	L2	W	W1	G
Dimensions (mm)	60	25	12.5	20	3	2

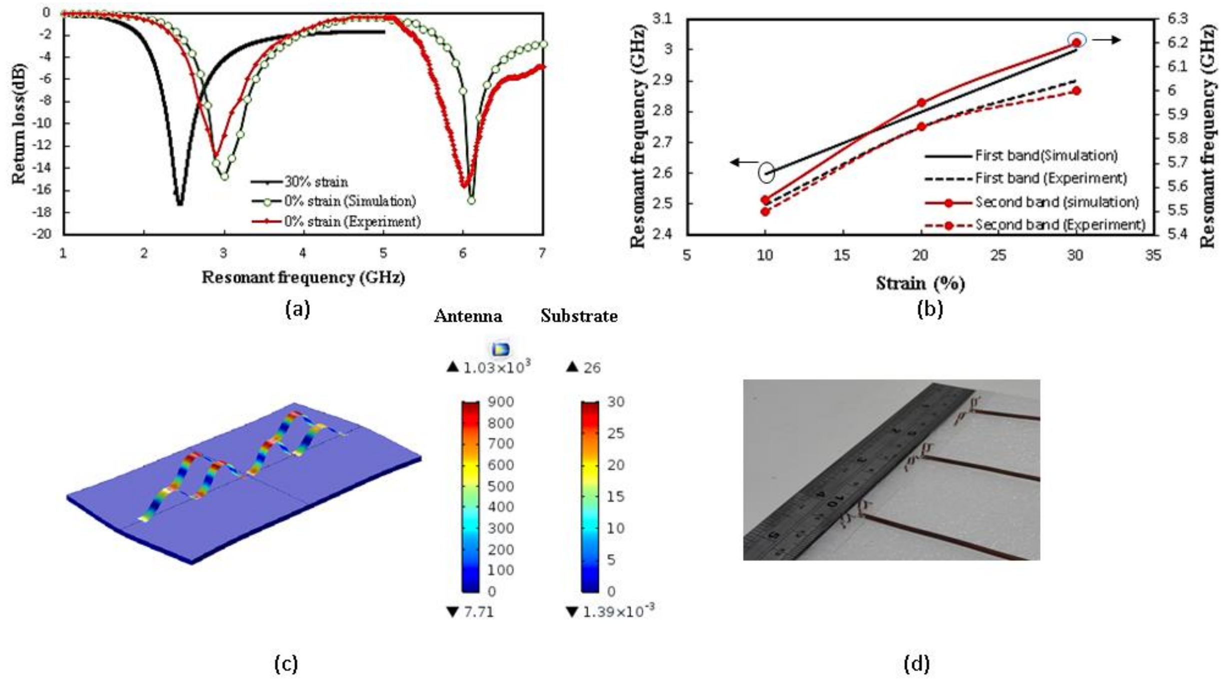

Fig. 2. (a) Numerical and experimental reflection coefficients (dB) of the pop-up half wave dipole antenna versus frequency (GHz) for 0% and 30 % strain in the substrate, (b) Frequency shift versus strain (c) Von Mises stress (MPa) on the antenna and substrate, (d) Antenna prototype for 10%, 20% and 30% prestrain in the substrate.

The nearly incompressible hyperelastic substrate used in this sensor design was simulated with Mooney Rivlin model (two parameters) [6].

Uniaxial tensile strain in the elastomeric substrate and its return to the original dimension induce a compressive stress into the dipole antenna which is selectively bonded to the substrate and initiates buckling in the third dimension. This out of plane displacement leads to a decrease in the overall capacitance and consequently an up-shift in the resonant frequency. Moreover, the two metallic ribbons in each dipole arm are insulated from each other so, after buckling a capacitive interaction between the two metallic ribbons will lead to another resonant frequency (second band).

Fig. 2 represents the Von Mises stress (MPa) for both the substrate and dipole after returning the substrate to its main size (30% strain). It can be seen that the amount of stress close to the bonding zones as well as the bend peaks are much higher than other parts so the structure should be designed to withstand failure at those points.

III. CONCLUSION

In this paper we report a novel highly flexible strain sensor based on the resonant frequency up-shift of a pop-up half wavelength dipole antenna. The proposed antenna exhibits a dual band operation due to the existence of two insulated metallic layers in each dipole arm. The proposed sensor is able to measure a wide range of strain from 0 to 30% in the substrate by frequency shift in the range of 2.45 to 2.9 GHz for the first band and 5.5 to 6.3 GHz for the second band. Numerical data and experimental outcomes are in good agreement with each other.

IV. REFERENCES

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