Microstrip Antenna on Kapton Substrate for Strain Sensing Applications

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***Abstract*— In this paper the feasibility of using a circular microstrip patch antenna fabricated on flexible kapton substrate to measure strain is investigated by performing a preliminary laboratory experiment. When a patch antenna is deformed, the dimensions of the antenna changes and hence the resonant frequency of the antenna changes which is taken to be an indication of change in the strain applied. A circular microstrip patch antenna on a flexible kapton substrate operating at 4.618 GHz has been designed based on the relation between the radius of the circular patch and its resonant frequency. The resonant frequency of the microstrip patch antenna decreases linearly with the increase in the applied strain. The shift in the resonant frequency is nearly 3 MHz when the stain is 0.18%. This microstrip circular patch antenna can be used with other components easily and can be very useful in biomedical applications and in structural health monitoring.**

***Keywords*— Microstrip, dielectric, kapton, antenna, resonant frequency**

I. Introduction

The recent developments in area of structural health monitoring have been tremendous and the need is constantly increasing in the area. Growth in this area has been able to develop structural health monitoring systems using various techniques. But many of the techniques are still not able to monitor conditions in a complex operational aerospace structure. Hence there is always a need to investigate on techniques and methods to develop wireless sensors which are reliable and efficient enough to be used in complex environments and applications.

As previously studied by Daliri Ali [2], the current available wireless sensors are not efficient enough to be used in structural health monitoring for aerospace structures primarily due to high cost and battery power limitations.

The focus of this paper is to make a preliminary study in the laboratory to investigate the feasibility of using a microstrip patch antenna as a sensor for stain sensing applications as it can be a wireless sensing technique. The patch can be rectangular, circular, elliptical or of any other shape. In this paper, a circular patch is considered due to the simplicity of the relationship between a single dimension of the patch and the resonant frequency. The advantages of the microstrip patch antenna lies in the fact that it is light in weight, low fabrication cost and ease of fabrication.

Analytical computation and experiments have been demonstrated by U Tata et al., [1] using a square patch antenna in which the resonant frequency of a rectangular patch antenna depends on its length and width. Instead if a circular patch antenna is used, then only the radius of the patch decides the resonant frequency, thereby making the resonant frequency depend on one variable rather than on two variables as in the case of a square patch.

Kapton is used as a substrate in the flexible circuit industry. Its long flex life and ability to withstand copper etching makes it excellent choice for these applications. It is used heavily in the electronics market as the industry moves to smaller, lighter and faster components. The use kapton substrate instead of FR4 suggested by Ali et.al in [2] for the fabrication of the circular patch antenna is proposed.

II. Design and Simulation

The circular patch antenna as shown in the figure 1 consists of a dielectric substrate and a circular patch printed on one side of the substrate and the ground plane coated on the other side of the substrate. The patch and the ground plane are made of copper and they form an electromagnetic resonant cavity that radiates at a specific frequency called the resonant frequency. Based on the transmission line model, the resonant frequency of a circular patch antenna with radius a, substrate thickness h, and relative permittivity ε_r is given by,

$$f_r = \frac{1.2412c}{2\pi a_{e\sqrt{\varepsilon_r}}} \tag{1}$$

where 'c' is the velocity of light in free space and is given by

$$c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}} \tag{2}$$

a_e is the effective radius of the microstrip patch

ε_r is the relative permittivity of the antenna substrate

μ_0 is the permeability of free space

ε_0 is the permittivity in free space

The effective radius of the patch antenna is given as,

$$a_e = a\sqrt{\left\{1+\frac{2h}{\pi a \varepsilon_r}\left[\ln\frac{\pi a}{2h}+1.7726\right]\right\}} \quad (3)$$

Where 'a' is the radius of the patch and 'h' is the thickness of the substrate. We can write eqn (3) as

$$a_e = c_1 a \quad (4)$$

where,

$$c_1 = \sqrt{\left\{1+\frac{2h}{\pi a \varepsilon_r}\left[\ln\frac{\pi a}{2h}+1.7726\right]\right\}} \quad (5)$$

From eqn (5) the resonant frequency can hence be expressed as,

$$f_r = \frac{c_2}{a_e} \quad (6)$$

where, $$c_2 = \frac{1.2412c}{2\pi\sqrt{\varepsilon_r}} \quad (7)$$

Let the effective radius a_e after applying strain be denoted as a_{es}. Then it is given by,

$$a_{es} = a_e + a_e\varepsilon = a_e(1+\varepsilon) \quad (8)$$

Where, 'ε' is the strain applied. Now, let the resonant frequency after applying strain be denoted as f_{rs}.

$$f_{rs} = \frac{c_2}{a_{es}} = \frac{c_2}{a_e(1+\varepsilon)} \quad (9)$$

The resonant frequency shift can be found now,

$$\nabla f = f_{rs} - f_r = \frac{c_2}{a_e}\left[\left[\frac{1}{1+\varepsilon} - 1\right]\right] \quad (10)$$

and

$$\frac{\nabla f}{f_{rs}} = \frac{\left[\left[\frac{1}{1+\varepsilon}-1\right]\right]}{\left[\left[\frac{1}{1+\varepsilon}\right]\right]} = -\varepsilon \quad (11)$$

Eqn (11) shows that there is a linear relationship between the resonant frequency shift and the strain ε_r. The negative sign indicates that, with the increase in strain the resonant frequency shifts to the left. In the analytical computation of the relationship between the resonant frequency shift and strain, the radius of the patch is considered to be uniform in all directions.

Figure 1 shows the circular patch antenna simulated using CST Studio 2010. The resonant frequency of the designed antenna is 4.392 GHz.

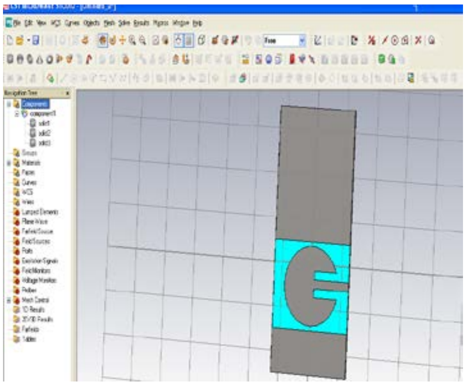

Figure 1 Circular patch antenna simulation

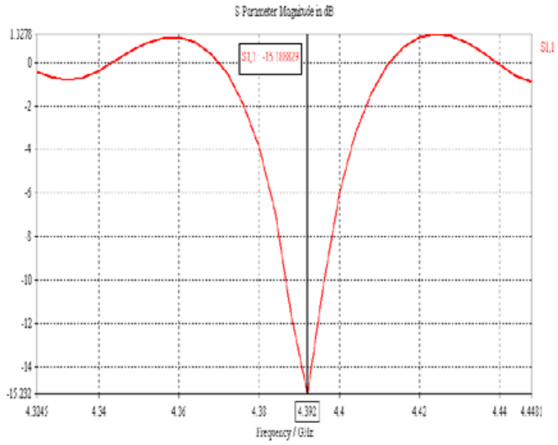

Figure 2 Return loss of the circular patch antenna

III. Experiment

The circular microstrip patch antenna was designed to operate with a resonant frequency of 4 GHz. The antenna as proposed was fabricated on a flexible kapton substrate. The antenna is fed with a microstrip line which acts as a 50 Ω matched load. The fabricated antenna was bonded on an aluminum cantilever beam with its feed line perpendicular to the length of the cantilever beam. This orientation will make the patch stretch along its width when strain is applied. This changes the dimension of the patch which in turn shifts the resonant frequency of the antenna. The cantilever used in the experiment results in a strain of 0.18% on the patch when loaded with 200 gm. For the experimental purpose, the network analyzer was used as the microwave source and also for the measurement of the scattering parameter S_{11}. Strain was increased in steps of 0.18% and the corresponding S_{11} measurements were made and plotted in the graph.

IV. Result and Discussion

The antenna designed was subject to different strain and the return loss is plotted below. Figure 3 shows the simulation results when the patch is strained and Figure 4 shows the experimental result when strained. The results show a clear shift in the resonant frequency.

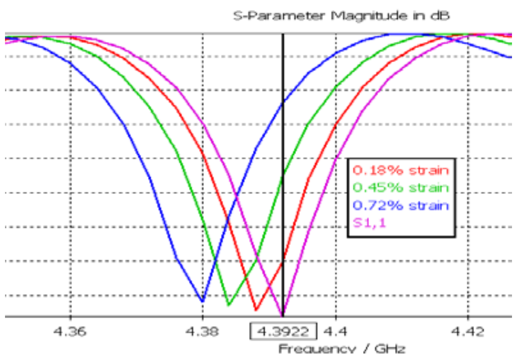

Figure 3 Circular patch antenna simulation when strained

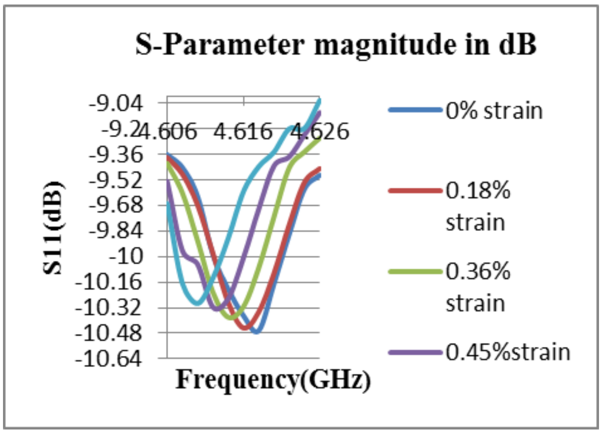

Figure 4 Experimental results of circular patch antenna when strained

TABLE 1. SIMULATION RESULTS FOR APPLIED STRAIN VERSUS RESONANT FREQUENCY

Load kg	Strain % µ strain	Resonant frequency shift of patch GHz
No load	0	4.392
0.2	0.18	4.388
0.4	0.36	4.388
0.6	0.45	4.384
0.8	0.72	4.380

TABLE 2. EXPERIMENTAL RESULTS FOR APPLIED STRAIN VERSUS RESONANT FREQUENCY

Load kg	Strain % µ strain	Resonant frequency shift of patch GHz
No load	0	4.618
0.2	0.18	4.616
0.4	0.36	4.614
0.6	0.45	4.612
0.8	0.72	4.610

This fabricated antenna when used for strain measurement also shows clear shift in the resonant frequency. The resonant frequency decreases by nearly 3 MHz as the strain causing load increased by 0.2 kg. The mathematical model hence derived from the simulation results and the experimental results respectively are as follows:

$$y = 0.61\,x - 0.0027 \qquad (12)$$

$$y = 0.85\,x - 0.0045 \qquad (2) \qquad (13)$$

Where, '*y*' represents the shift in the resonant frequency and '*x*' represents the radius of the patch

V. CONCLUSIONS

The simulation and the experimental results confirm the linear relationship between the strain and the resonant frequency shift of the antenna. It is hence possible to use a circular patch microstip antenna fabricated on a kapton substrate to be used as a strain sensor in structural health monitoring applications and also effectively in biomedical applications.

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