Comparative Study of Microstrip Rectangular Patch Antenna on different substrates for Strain Sensing Applications

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Abstract - ***The feasibility of applying patch antennas for strain sensing is investigated. The resonant frequency of microstrip patch antenna is calculated by the dimensions of its patch. In this work, three types of microstrip patch antennas are developed using three different substrates FR4, RT Duroid 5880 and Polyimide. This paper describes the simulation of a slotted rectangular microstrip patch antenna for strain measurement for three different materials. The microstrip antenna is designed and simulated using Computer Simulation Technology (CST) Microwave Studio. The dimensions of slotted patch antenna are changed when the antenna is under strain, resulting in shift of its resonant frequency. Hence, the applied tensile strains can be measured from the shift in resonant frequency. The resonant frequency of the microstrip patch antenna decreases linearly with the increase of applied strain along the length direction of antenna.***

Key Words: *Computer Simulation Technology (CST), Microstrip antenna, Strain sensor, Polyimide.*

1. 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 [1], 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 work 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 slotted rectangular patch antenna is considered due to its simplicity. 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 verified by Daliri [1], using a circular patch antenna in which the resonant frequency of a patch varies uniformly in every direction with applied strain. It is presented that there is a linear relationship between the strain and the percentage of resonant frequency shift regardless of the materials used for antenna manufacturing [2]. On other hand, U Tata [3] using a square patch antenna in which the resonant frequency of a rectangular patch antenna depends on its length and width.

In this paper, three different substrates are used and their sensitivity to applied strain is investigated. The analysis is carried on two flexible substrates namely polyimide and RT Duroid 5880 and a non-flexible substrate FR4.

2. ANTENNA DESIGN AND PRINCIPLE OF OPERATION

2.1 Resonant Frequency

The patch antenna, as shown in figure 1, consists of a layer of dielectric substrate, a rectangular patch printed on one side of the substrate and a ground plane coated on the other side of the substrate. The rectangular patch and the ground plane, both made of conductive metals, form an EM resonant cavity that radiates at a specific resonant frequency. Based on the transmission line model [4], the resonant frequency of a rectangular patch antenna is calculated as

$$f_{res} = \frac{c}{2\sqrt{\varepsilon_{re}}}\frac{1}{L_e+2\Delta L_{oc}} \quad (1)$$

Where c is the velocity of light The electrical length L_e of the antenna is defined as the dimension of the metallic patch along the direction of the radiation mode.

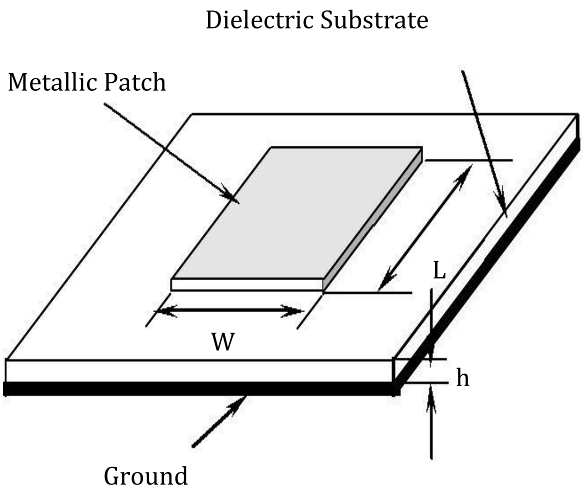

Fig -1: Patch antenna

The effective dielectric constant ε_{re} is related to the dielectric constant of the substrate ε_r, the substrate thickness h and the electrical width of the patch ω_e [5],

$$\varepsilon_{re} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2\sqrt{(1+\frac{10h}{\omega_e})}} \quad (2)$$

The line extension ΔL_{oc} is calculated from the effective dielectric constant ε_{re} , the substrate thickness h and the electric width ω_e,

$$\Delta L_{oc} = 0.412h\,\frac{(\varepsilon_{re}+0.3)(\omega_e/h+0.264)}{(\varepsilon_{re}-0.258)(\omega_e/h+0.813)} \quad (3)$$

Assuming the antenna is subjected to a tensile strain ε_L along its electrical length direction, the patch width and the substrate thickness will change due to Poisson's effect, i.e.,

$$\omega_e = (1-\nu_p\varepsilon_L)\omega_{e0} \text{ and } h = (1-\upsilon_s\varepsilon_L)h_0 \quad (4)$$

Therefore, the resonant frequency in equation (1) can be expressed as

$$f_{res} = \frac{c}{2\sqrt{\varepsilon_{re}}(L_e+2\Delta L_{oc})} = \frac{C_1}{L_e+C_2 h} \quad (5)$$

where $C_1 = \frac{c}{2\sqrt{\varepsilon_{re}}}$

and $C_2 = 0.812\,\frac{(\varepsilon_{re}+0.3)(\omega_e/h+0.264)}{(\varepsilon_{re}-0.258)(\omega_e/h+0.813)}$

The strain-induced elongation, therefore, will shift the antenna resonant frequency. At an unloaded state, the antenna frequency f res0 is calculated from the antenna length Le0 and substrate thickness h_0, i.e.,

$$f_{res0} = \frac{C_1}{L_{e0}+C_2 h_c} \quad (6)$$

Under a strain ε_L , the antenna frequency shifts to

$$f_{res(\varepsilon_L)} = \frac{C_1}{L_{e0}(1+\varepsilon_L)+C_2 h_0(1-\upsilon\varepsilon_L)} \quad (7)$$

By using equation (6) and (7)., the relation between shift in resonant frequency and strain is given as:

$$\frac{\Delta f_{res}}{f_{res}} = \frac{\Delta L_{oc}}{L_e} = -\varepsilon \quad (8)$$

Where ε is the strain, the resonant frequency varies in an opposite direction to that of strain outside, so the strain can be obtained through the variation of the resonant frequency, then the microstrip patch antenna becomes a strain sensor.

2.2 Design and Simulation

In this paper a slotted rectangular microstrip patch antenna has been designed using CST Microwave Studio. There are three different materials used to design the slotted patch antenna. The three substrates are FR4 (lossy), Rogers RT Duroid 5880 and Polyimide with the permittivity 4.3, 2.2 and 3.5 respectively. The simulation results of antenna with same dimensions and different materials are shown in figure

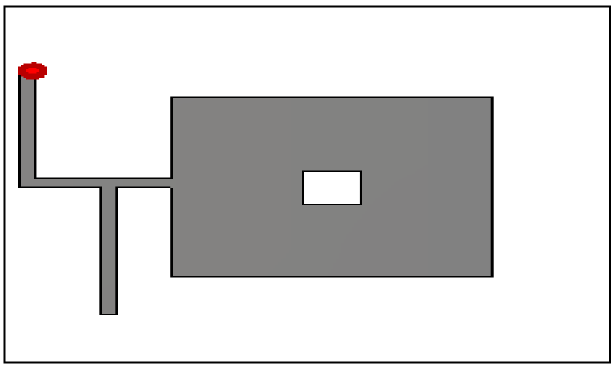

Fig -2: Front view of slotted rectangular patch antenna

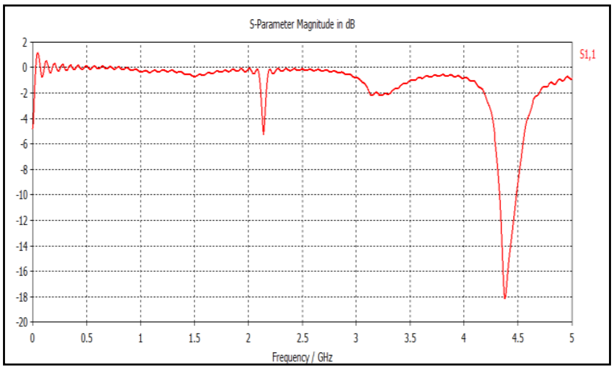

Fig -3: Return loss of the rectangular patch antenna using FR4 substrate without strain

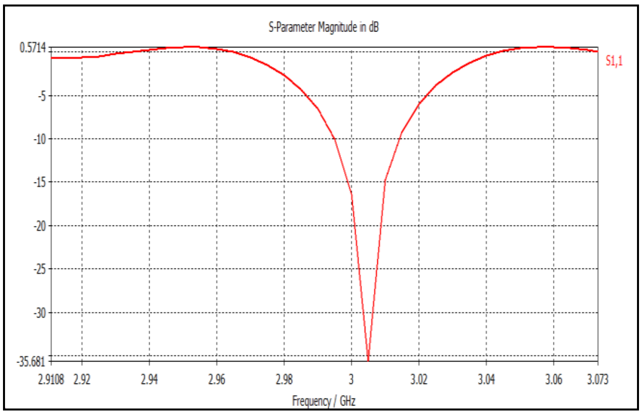

Fig -4: Return loss of the rectangular patch antenna using RT Duroid 5880 without strain

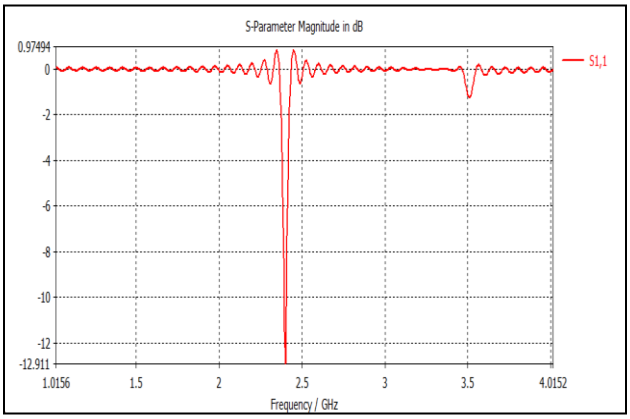

Fig -5: Return loss of the rectangular patch antenna using Polyimide without strain

3. RESULTS AND DISCUSSION

Different amount of strain was subjected to the three designed antennas with unlike materials and the return loss is plotted. It is seen, that when the tensile strain is applied on the slotted patch antenna, the lengths of the rectangular patch antenna change. Figure 6, figure 7 and figure 8 show the simulation results when the patch antenna is strained with different loads. A clear shift in the resonant frequency can be seen in the simulated results. On the comparison of three substrates it is found that the Rogers RT Duroid 5880 is the most sensitive to the applied strain among the three substrates.

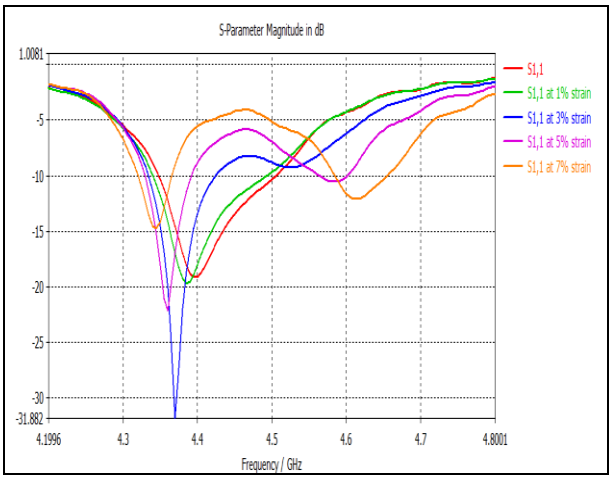

Fig -6: Return loss of the rectangular patch antenna using FR4 substrate with strain

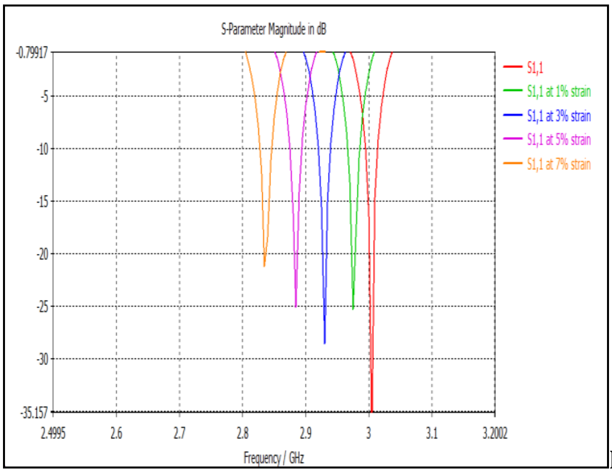

Fig -7: Return loss of the rectangular patch antenna using RT Duroid 5880 substrate with strain

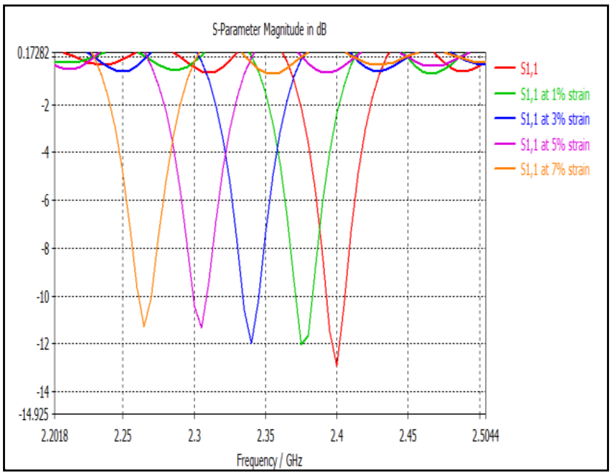

Fig -8: Return loss of the rectangular patch antenna using Polyimide substrate with strain

Figures 9-11 illustrate the linear fitting of the resonant frequency and the applied strain for the slotted patch antenna subjected to length direction deformation. There is an tremendous linearity between the resonant frequency and the strain for flexible material antenna sensors. The slope of curve signifies the resolution of antenna sensor. The antenna sensor has more sensitivity at high initial resonant frequency, along with the larger dimension of the antenna patch as well, and the simulated results are in good concurrence with the theoretical study.

Table 1: Simulation Results for Applied Strain versus Resonant Frequency (GHz)

S. No.	Strain %	Resonant Frequency (GHz) FR4	Resonant Frequency (GHz) RT Duroid 5880	Resonant Frequency (GHz) Polyimide
1.	No Load	4.400	3.0005	2.40
2	1 %	4.386	2.9751	2.376
3.	3 %	4.370	2.9303	2.340
4.	5 %	4.360	2.8847	2.307
5.	7 %	4.343	2.8361	2.264

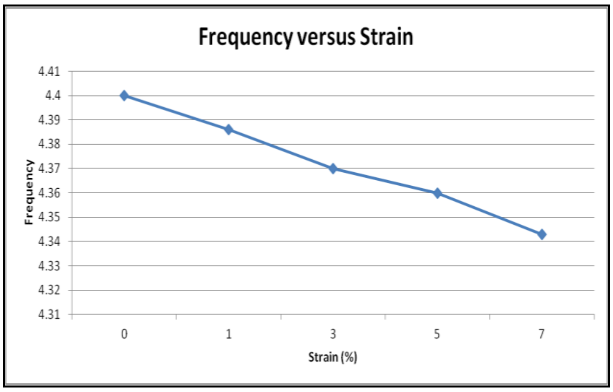

Fig -9: Frequency-Strain curve of sensor with FR4 substrate

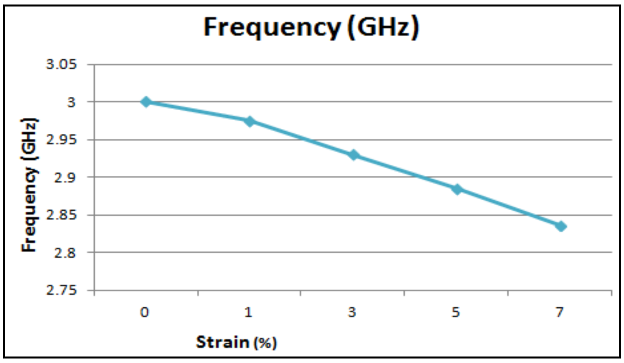

Fig -10: Frequency-Strain curve of sensor with RT Duroid 5880 Substrate

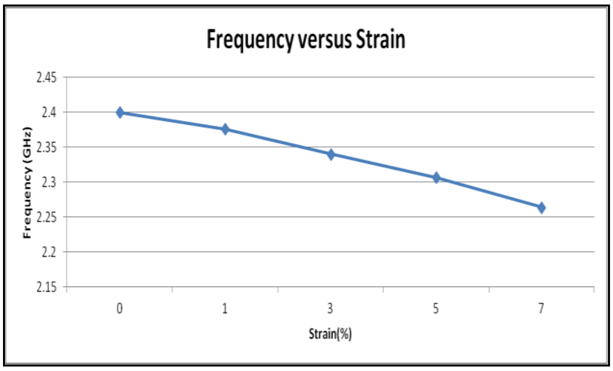

Fig -11: Frequency-Strain curve of sensor with Polyimide Substrate

4. CONCLUSION

The simulation results and theoretical results confirm the linearity between the resonant frequency shifts of slotted rectangular patch antenna and the strain. Therefore, it is possible to use rectangular patch antenna fabricated on a flexible substrate (RT Duroid and Polyimide) to be used as a strain sensor in Structural Health Monitoring and Biomedical application

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BIOGRAPHIES

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Dr. Vandana V. Thakare received the B.Tech. Degree from Rani Durgawati University, India in 1999. She received her M.Eng. Degree and Ph.D. degree from Rajeev Gandhi Prodyogik Vishwavidhyalaya, India, in 2003 and 2011, respectively She has been into technical teaching for 14 years in the field of Electronics and Communication. She has received National ISTE best women Engineer teacher award in 2011. Her research field includes Microwave Engineering.

