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Analysis of a Microstrip Rectangular Patch Antenna as a Strain Sensor

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Abstract
Microstrip patch antenna is a flat shape, light weight and low cost antenna that used to receive and transmit electromagnetic wave. This paper describes the simulation of a rectangular microstrip patch antenna for strain measurement. The microstrip antenna designed and simulated using Computer Simulation Technology (CST) Microwave Studio. When the antenna is under strain/crack, its resonance frequency varies accordingly. The resonant frequency of the microstrip patch antenna decreases linearly with the increase of applied strain along the length direction of antenna. The microstrip patch antenna strain sensor can be integrated with other components easily and have a great potential applications in structural health monitoring.

Keywords
Computer Simulation Technology (CST), Microstrip antenna, Strain sensor

I. Introduction

Structural health monitoring technology plays a substantial role in the current civil engineering, spaceflight and aviation. In structural health monitoring systems, sensors are key devices that can sense physical information such as strain and temperature of the system. Optical fiber-based strain sensors have been applied in the structural health monitoring, however, this kind of sensors should be built in the structure beforehand. It usually needs digging holes and slots, which will impact on the mechanical property of the structure. Therefore, more investigations have been focused on new sensors that can conform to structures well without any damage [1-3]. As previously studied by Daliri Ali [4], 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. Many of the sensors available for SHM are wired and therefore have practical limitations in order to be embedded into the structures, like strain gauges, piezoelectric transducers, fiber optic sensors, and micro-fiber composite actuators. On the other hand, wireless sensors currently available in the market use batteries as an energy source which has a limited lifetime and increases the sensor size and weight; therefore, could not be used widely in the structure. In some cases where the sensor receives its energy through an antenna the sensory unit is too complicated. U. Tata [5] demonstrates that rectangular microstrip patch antennas could be used not only for communication between sensor and receiver, but also as a strain sensor. The designed antenna needs to work in two different frequencies and detect strain in two directions. Daliri Ali [4] uses circular microstrip antenna to detect strain in composite materials. This antenna sensor showed that there is a linear relationship between strain and percentage of shift in antennas resonant frequency regardless of the materials used for antenna fabrication. In this paper, it is demonstrated that a patch antenna itself can serve as the sensing unit for strain measurement. The relationship between the applied strain and resonant frequency of the patch antenna is first derived. The design and simulation of rectangular patch antenna for strain measurement are then discussed.

II. Antenna Design and Principle of Operation

A. Side Length and 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 (Bhartia et al 1991), the resonant frequency of a rectangular patch antenna is calculated as

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

where c is the velocity of light. The electrical length L_e of the antenna is defined as the dimension of the metallic patch

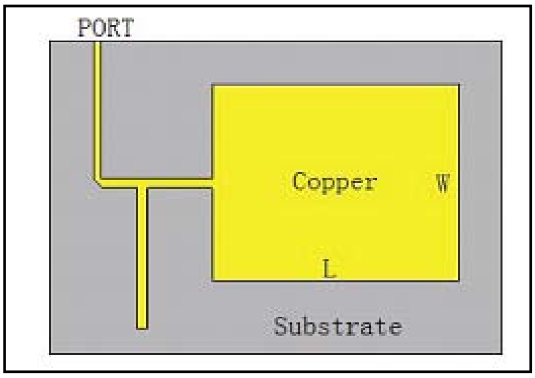

Fig. 1: Geometry of Rectangular patch antenna

along the direction of the radiation mode. 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 $_e$,

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

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

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

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.,

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

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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.,

$$f_{res0} = \frac{C_1}{L_{e0}+C_2 h_0} \quad (6)$$

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.

B. Design and Simulation

In this paper a rectangular microstrip patch antenna operating at 3 GHz has been designed using CST Microwave Studio. The substrate of antenna is Rogers RT Duroid 5880 having permittivity 2.2 and thickness 0.254 mm. The simulation results of antenna is shown in figure

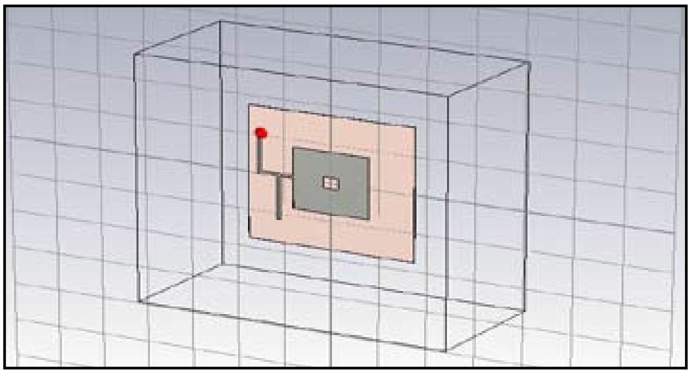

Fig 2 : Front view of microstrip rectangular patch antenna

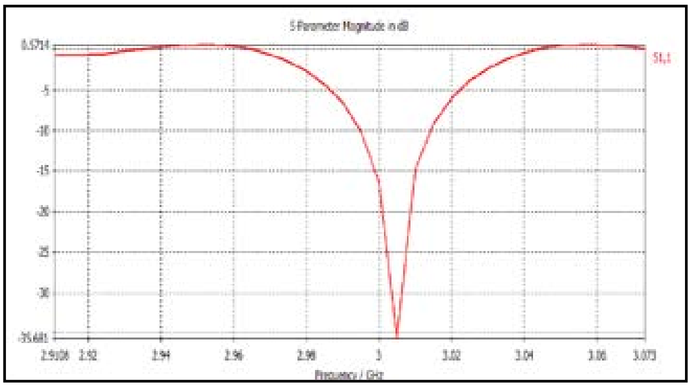

Fig 3: Return loss of the rectangular patch antenna without strain

III. Results And Discussion

Different amount of strain was applied to the designed antenna and the return loss is plotted in figure 5. It is seen that when the tensile strain is applied on the patch antenna, the length of the rectangular patch antenna changes. Figure 5 shows the simulation results when the patch antenna is strained. A clear shift in the resonant frequency can be seen in the simulated results.

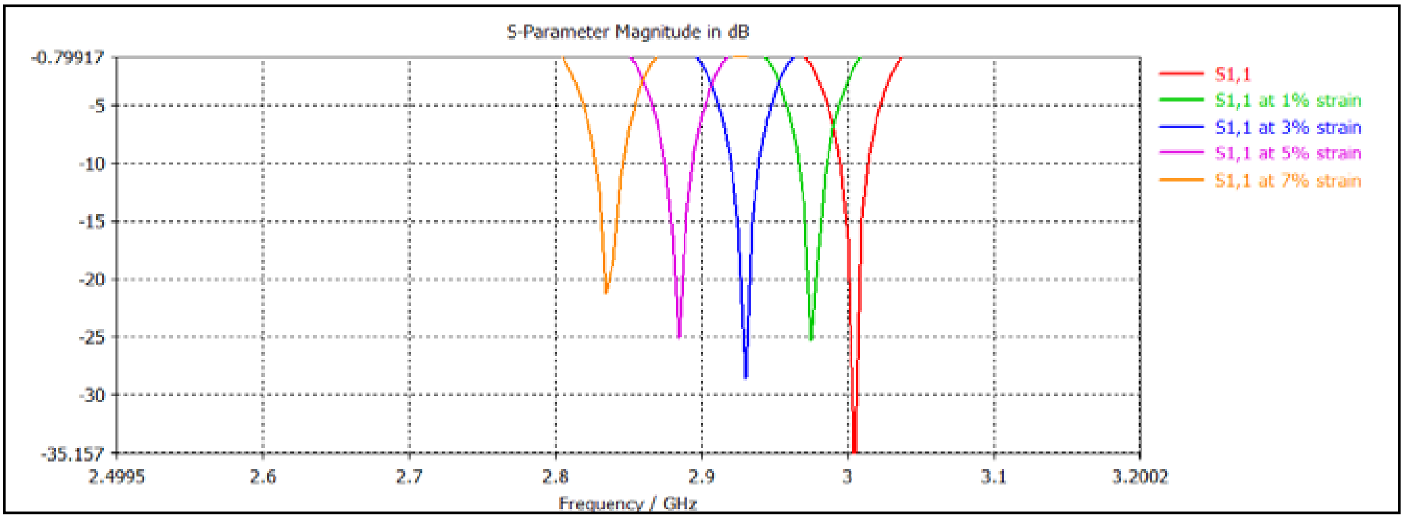

Fig. 4: Rectangular patch antenna simulation curve when strained

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

Load ()	Strain (%)	Resonant Frequency (GHz)
No load	0	3.0005
100000	1	2.9751
300000	3	2.9303
500000	5	2.8847
700000	7	2.8361

The resonant frequency of the patch antenna is 3 GHz. The simulated results of the designed antenna shows clear shift in resonant frequency and thus it can be used for strain measurement. The resonant frequency decreases with increase in strain. A decrement of about 25.40 MHz in resonant frequency is observed when the tensile strain is increased by 1%. An overall decrement in resonant frequency of the antenna is 164.4 MHz as the strain increases from 0% to 7%.

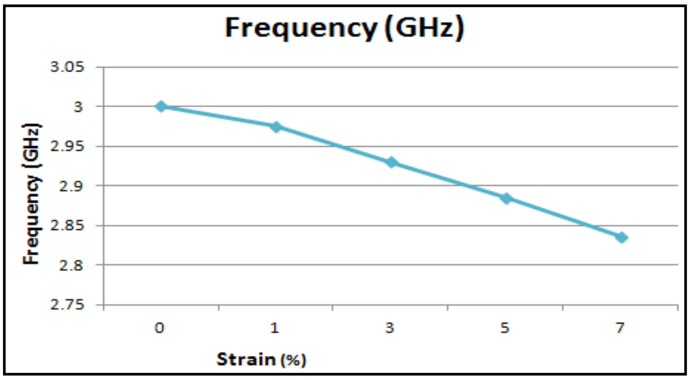

Fig 5: Linear relationship between strain and resonant frequency

The relationship between applied strain and the resonant frequency of the rectangular microstrip patch antenna is shown in figure (5). The resonant frequency decreases linearly with the increase in applied strain.

IV. Conclusion

The simulated results of designed antenna confirm the linear relationship between the resonant frequency shift and the applied strain. So it is possible to use a rectangular microstrip patch antenna fabricated on a Rogers RT Duroid 5880 substrate to be used as strain sensor in biomedical applications and also effectively in structural health monitoring.

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