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Design of Micromachining Based Patch Antenna to Enhance Performances for RFID Tag Application

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Abstract

Antenna is a significant component of wireless communication system. Radio Frequency Identification (RFID) is one of the activities of Automatic Identification (AUID) system which comes under wireless system. To track any object wirelessly in RFID system, antenna acts as the primary and critical component. Radio Frequency (RF) micromachining technology provides an innovative approach in the development of effective antenna. In this paper, initially we present rectangular patch antenna resonant at 40GHz on silicon substrate. In the consecutive step, in order to improve performance of the antenna silicon micromachining has done by etching the substrate between the ground and the patch. Ansoft High Frequency Structure Simulator (HFSS) provides the simulation result and the different performance parameters like gain, return loss, bandwidths etc. are analyzed.

Keywords: *RFID, Micromachining, Bandwidth*

1. Introduction

RFID is an emerging technology and it uses radio waves to automatically read and write data to or from any tag. RFID technology has been applied in many areas such as asset identification, retail chain management, access and vehicle security, animal tracking, voice recognition *etc.* [1-2]. First RFID technology was used in 1940 for "friend and foe" by British for airplane identification. A typical RFID system consists of the transponder (or tag) which is tied with the identified object and the reader (or transceiver) may be able to read and read/write data to the tag. RFID tag contains an integrated circuit (IC) to store and process data, it also handles modulation and demodulation of RF signal; and an antenna for transmitting and receiving the signals. The reader consists of a control unit and an antenna to interact with the tag. Reader may also have USB port to communicate data with another system such as PC in which software are installed to process the data in some sequence manner [3-5]. Depending on whether tag has internal power source or not, the RFID tag can be passive or active [6]. RFID tag that has internal battery is referred to as active tag and tag does not have any internal power source are classified as passive tag. In case of passive tag, the reader transmits radio waves to the tag and the tag antenna creates an AC voltage. This AC voltage is then converted to DC voltage to activate the microchip and the modulator modulates the received signal, afterwards the tag backscattered data to the requested reader. The lifetime of passive tags are more and less expensive compared to active tag [7-8]. Depending on application, RFID technology operates on Low Frequency (LF) (0-300) kHz, High Frequency (HF) (3-30) MHz, Ultra High Frequency (UHF) (300MHz-3GHz) and microwave frequency (> 3 GHz) band. In case of near field, RFID systems are inductively coupled and they normally operate at LF and HF frequency band. The far field RFID system operates at UHF and microwave frequency band and propagates electromagnetic waves towards the reader [9]. In this paper, we proposed rectangular patch antenna in which a cavity has been created by

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silicon micromachining, in order to increase the bandwidth, gain, of normal silicon platform patch antenna and to achieve circular polarization.

2. Reading Range of RFID System

In RFID system, the most important performance parameter is the read range- the maximum distance at which RFID reader can track and powered the chip on the tag. The maximum reading distance of the reader can be calculated by using Friss-free space equation (1) [10-11]

$$r_{\max} = \frac{\lambda}{4\pi}\sqrt{\frac{P_t G_t G_r \tau}{P_{th}}} \tag{1}$$

Where λ is the wavelength, P_t is the power transmitted by the reader, G_t is the gain of reader antenna, G_r is the gain of tag antenna, P_{th} is the minimum power required to activate the chip, τ is the power transmission coefficient ($0 \leq \tau \leq 1$) and it can be expressed according to equation (2).

$$\tau = \frac{4 R_c R_a}{|Z_c + Z_a|^2} \tag{2}$$

Where $Z_c = R_c + jX_c$, is the impedance of the chip, $Z_a = R_a + jX_a$ is the antenna impedance. According to maximum power transfer theorem, the impedance of the tag antenna must be conjugated of the impedance of the chip. If the input impedance of the tag antenna matches with impedance of the chip i.e., τ =1 and gain of tag antenna is 1, then equation (1) becomes result in equation (3).

$$r_{\max} = \frac{\lambda}{4\pi}\sqrt{\frac{P_t G_t}{P_{th}}} \tag{3}$$

Hence the maximum reading range depends on the EIRP (Effective Isotropic Radiated Power = $P_t G_t$) and the threshold power P_{th}. The most important component in the RFID system is the tag antenna, as it determines the size of the tag and reading range of the reader. The performance of tag antenna depends on its parameter like gain, directivity, operating band, beamwidth, axial ratio etc. The tag antenna must be compact in size, low cost, good matching with the chip, have high gain and circular in polarization [12].

3. Introduction to Micromachining

The most compact antenna can be achieved by employing high dielectric constant substrate and this substrate excited the surface wave; as a result the gain and radiation efficiency of the patch antenna decreases. This problem can be overcome by producing small air gap between the patch and ground by a technique called bulk micromachining or silicon micromachining. Micromachining of silicon is a process where semiconductor substrate is mechanically altered, by selectively removing 50-80% from the substrate by etching process. By using bulk micromachining lower effective dielectric constant, increase in radiation efficiency, high quality factor (Q) can be achieved and surface wave can also be removed [13-14]. The effective dielectric constant of the air-substrate mixture in the cavity can be calculated from equation (4) [15]. The accommodation of fringing field produced by the patch in the cavity increases in proportion with the depth of the cavity.

$$\varepsilon_{cavity} = \frac{\varepsilon_{air}\,\varepsilon_{Si}}{\varepsilon_{air} + (\varepsilon_{Si} - \varepsilon_{air})x_{air}} \qquad (4)$$

Where ε_{cavity} , ε_{air} and ε_{Si} are the effective dielectric constant of the mixtures, air and silicon respectively, x_{air} is the air to full substrate thickness.

4. Antenna Structure and Simulation

In this paper, initially a rectangular patch antenna at resonant frequency 40GHz on the silicon substrate having dielectric constant (ε_r) = 11.9 and height (h) = 0.525mm was designed. The width (W) and length (L) of the patch are 1.48mm and 0.87mm respectively. The dimension of the feed line is 0.26mm × 0.27mm. The simulation result shows that parameters like bandwidth, gain, directivity etc. of this silicon platform patch antenna are not so good. In order to improve these parameters micromachining (of area 6mm×6mm) has done by etching the substrate between the patch and ground. The effective value of permittivity is calculated from the equation (4) and the resonant frequency of this antenna also 40GHz. The calculated patch width and length of the micromachining based antenna is 3.54mm and 2.79mm respectively. The height of the substrate is (H_{sub}) = 525µm and the height of cavity is (H_{cavity}) = 500µm. The simulation of both the structures has been carried out on HFSS and view of the micromachining antenna is shown in Figure 1.The model of the normal silicon platform patch antenna and silicon micromachining patch antenna is shown in Figure 2 and Figure 3 respectively.

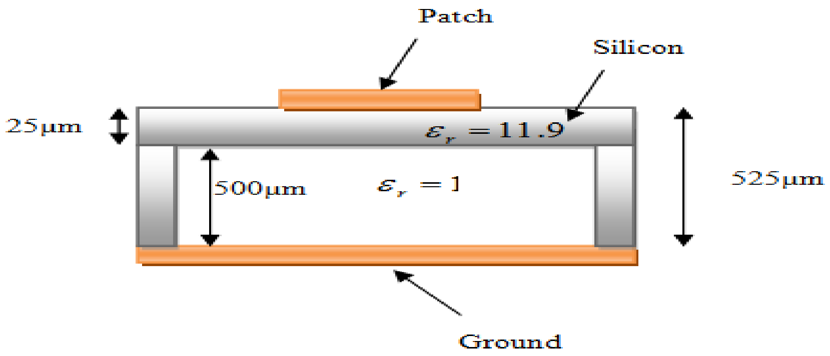

Figure 1. View of the Micromachining Part of Antenna

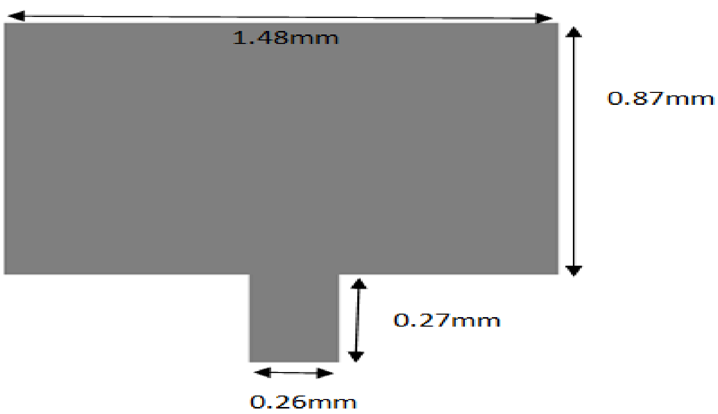

Figure 2. Model of the Normal Silicon Platform Patch Antenna

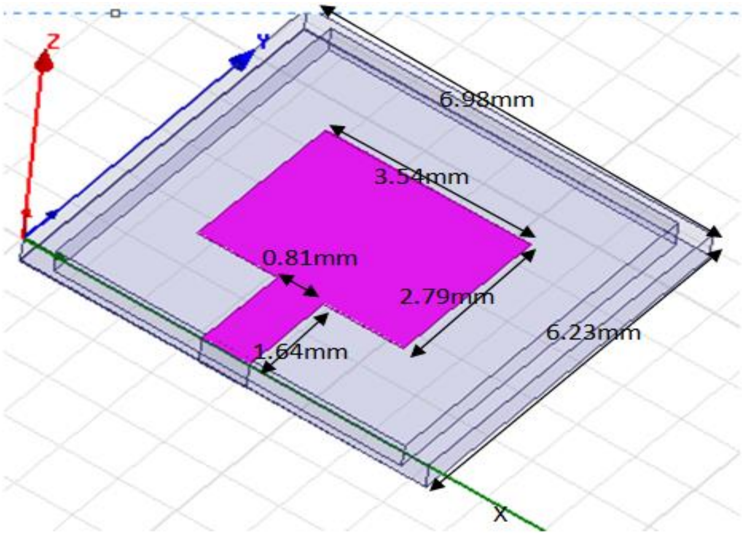

Figure 3. Model of Silicon Micromachining Patch Antenna

5. Results and Discussion

Figure 4 depicts S11 (dB) parameter versus frequency (GHz) for both normal silicon platform patch antenna and silicon micromachining patch antenna. For the normal silicon platform patch antenna we get two radiating bands: one at resonant frequency (f_{r1}) 37.1683GHz gives the S11 value -21.5785dB and another one at different resonant frequency (f_{r2}) 46.0641GHz for which the value of S11 is -14.0335dB. There is no radiating band between these two resonant frequencies. But for the silicon micromachining patch antenna one radiating band has been created between these two frequencies and the value of S11 is -23.0265dB at resonant frequency (f_{r3}) 39.4729GHz, the bandwidth also increases. The percentage bandwidth obtained from micromachining is 7.76% and for normal silicon platform antenna is 4.88%, which has been calculated from Figure 4.

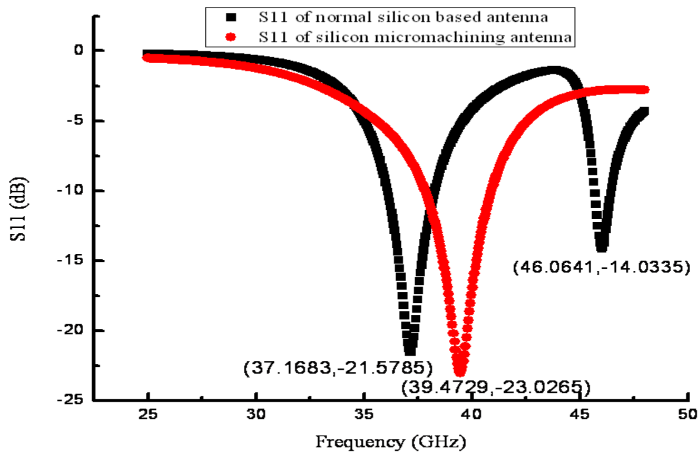

Figure 4. S11 Parameter of both Normal Silicon Platform and Silicon Micromachining Patch Antenna

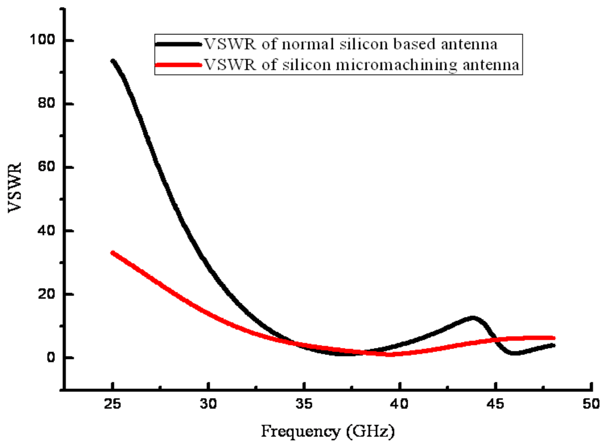

Figure 5. VSWR of both Normal Silicon Platform and Silicon Micromachining Patch Antenna

The value of voltage standing wave ratio (VSWR) for the normal silicon platform patch antenna and that of micromachining patch antenna are 1.1819 and 1.1596 respectively at their corresponding resonant frequency is portrayed in Figure 5. VSWR defines the matching of the antenna with the free space radio waves. As the value of VSWR for the micromachining patch antenna is more close to 1 than that of normal silicon based patch antenna, the matching of the silicon micromachining patch antenna with free space is more compared to that of normal silicon platform antenna.

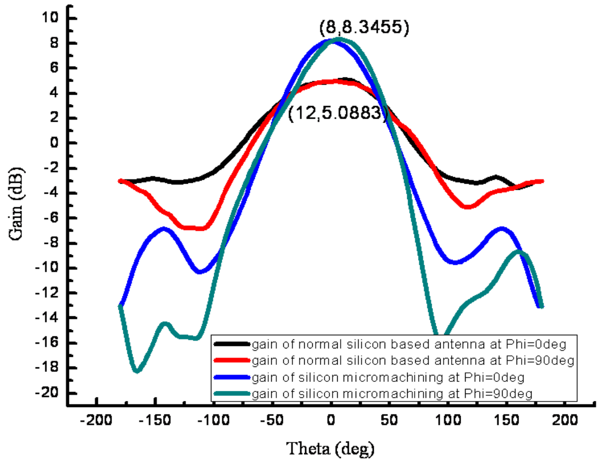

Figure 6. Gain of Normal Silicon Platform and Silicon Micromachining Patch Antenna both at Phi=0deg and at Phi=90deg

Figure 6 describe that the value of maximum gain for the silicon micromachining antenna is 8.3455dB at $\theta = 8^{\circ}$ and for the normal silicon platform patch antenna is 5.0883dB at $\theta = 12^{\circ}$. The gain of an antenna defines the intensity in a given direction to the intensity produced by an ideal antenna.

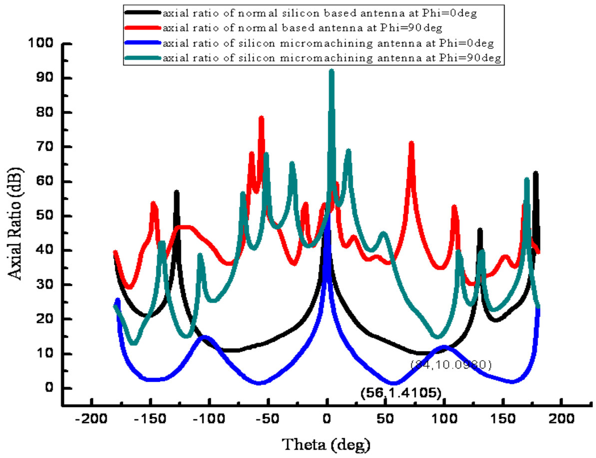

Figure 7. Axial Ratio of Normal Silicon Platform and Silicon Micromachining Patch Antenna both at Phi=0deg and at Phi=90deg

The plot of axial ratio (AR) versus theta (θ) for both the normal silicon platform patch antenna and silicon micromachining patch antenna has depicted in Figure 7. The minimum value of AR for micromachining antenna is less than 3dB and for the silicon platform normal patch antenna is greater than 3dB. Since for the silicon micromachining antenna AR is less than 3dB and hence we get circular polarization.

6. Conclusion

In this paper, we discussed about introduction of RFID system and Micromachining technology. Micromachining based antenna provides effective performance compared to normal silicon platform patch antenna. The bandwidth, gain, S11 parameter of the micromachining based patch antenna has increased compare to normal silicon platform antenna and the circular polarization also obtained for this antenna. Therefore, micromachining based technology provides attractive features which are not possible through traditional technology. Hence, micromachining based antenna can be used for RFID tag application.

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