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Salt and sugar detection system using a compact microstrip patch antenna

S. N. Njokweni and P. Kumar*

Discipline of Electrical, Electronic and Computer Engineering, University of KwaZulu-Natal, Durban, 4041, South Africa.

*E-mail: pkumar_123@yahoo.com

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Abstract

One of the reasons for many diseases such as diabetes, stroke, high blood pressure, kidney disease, etc., is the excess consumption of salt and sugar in the diet. So, to minimize these health problems, it is important to consume appropriate quantity of salt and sugar in the diet. This paper presents the design and development of a salt and sugar detection system using a low cost compact microstrip patch antenna. The salt and sugar detection system using a compact microstrip antenna is based upon the variation of antenna parameters in the solutions of different concentrations of salt and sugar. The defected ground structure (DGS) is utilized for decreasing the size and improving the performance of the proposed microstrip patch antenna. The antenna is fed by using a microstrip line and it resonates at 2.4 GHz. The designed antenna is simulated and optimized using the computer simulation technology (CST) microwave studio. The antenna with optimized dimensions is fabricated and measured. The measurements of the return loss of the fabricated microstrip patch antenna for various solutions with different concentrations of salt and sugar are performed. The measured results confirm that the proposed compact microstrip patch antenna is suitable to detect the concentration of salt and sugar in the water. From the measured results, it is observed that the return loss of the antenna decreases, when the concentration of salt and sugar is increased. The proposed antenna is also suitable for compact 2.4 GHz wireless local area networks (WLAN) applications.

Keywords

Compact size, Defected ground structure (DGS), Microstrip patch antenna, Reflection coefficient, Salt and sugar detection.

Humans commonly suffer with many diseases because of food having excess quantity of salt and sugar. Limited practices have been taken to overcome the situation. A drying technique is given by Gartley (2011) to compute the salt in the soil by estimating the electrical conductivity of the soil. A coaxial probe has been utilized through microwave measurement method to detect the dielectric properties of pure water and saline water by Gadani et al. (2012). However, these techniques of detecting salt are tedious. The system advancement cost of these methodologies is high.

The dielectric properties of the water change, when the salt and sugar are dissolved in the water (Cheng et al., 2014b). The variation in the dielectric properties of solution with different concentrations of salt and sugar causes the changes in the properties of radio frequency (RF) signals. Antennas are commonly used in wireless communications for transmitting and receiving electromagnetic (EM) signals. Antennas and electromagnetic waves can also be used as sensors. Makwana and Ghodgaonkar (2013) used the dielectric resonator antenna (DRA) as radio frequency identification (RFID) tag for human identification. Kot et al. (2014) presented the feasibility of using EM waves for identifying objects behind the walls. Microstrip patch antennas are suitable in many applications such as agriculture, medicine, sensor, communication, etc., as these antennas show favorable characteristics like low profile, light weight, easy fabrication, etc. In the present days, wireless correspondence frameworks and expanding of different remote applications, more extensive data transfer capacity or wider bandwidth, multi-band and low-profile antennas are in incredible interest for both business and military applications. Low gain and narrow bandwidth are the major limitations of the microstrip antennas (Balanis, 2005; Garg et al., 2001). DGS technology helps to improve the performance of the microstrip patch antennas. In DGS technology, the ground plane of the microstrip antennas is made defected by incorporating slots (Khandelwal et al., 2017; Lalitha Bhavani Konkyana and Alapati Sudhakar, 2019). By using DGS, Ngobese and Kumar (2018) proposed a high gain antenna array. Nhlengethwa and Kumar (2020) used the concept of DGS to enhance the gain of the microstrip antenna. The dual-band microstrip patch antennas using DGS are designed in the studies of Mabaso and Kumar (2018) and Mabusha and Kumar (2020). A triple-band microstrip patch antenna is proposed by Mabaso and Kumar (2019). The size of the microstrip antenna is reduced using DGS in the study of Sanega and Kumar (2020). The bandwidth of the microstrip patch antenna is enhanced using DGS by Mumin et al. (2018). Using DGS, the microstrip antennas are designed for ultra-wideband (UWB) applications (Kumar, 2017, 2019; Dharmarajan et al., 2019, 2020). The microstrip antenna with DGS was designed for dual polarization by Ghosh et al. (2011). Yadav et al. (2019) proposed the microstrip antenna with DGS for circular polarization. The multiple input multiple output (MIMO) antennas with DGS were proposed by Pandit et al. (2018) and Nigam et al. (2020).

Microstrip antennas can also be utilized to detect salt and sugar in the water as the dielectric properties of the solutions are different for different concentrations of salt and sugar in water. Cheng et al. (2014a) proposed the salinity and sugar detection system for detecting salt and sugar in water. The rectangular, square, and circular patch antennas were used to detect salt and sugar concentration in the water. Rahman et al. (2018b) proposed a salinity and sugar detection system using a Psi-shaped microstrip patch antenna. Islam et al. (2018) proposed a salt and sugar detection system for detecting salt and sugar concentration in water using a crescent-shaped microstrip patch antenna. Rahman et al. (2018a) proposed a tuning fork-shaped microstrip patch antenna-based salt and sugar detection system for detecting salt and sugar concentration in water.

A compact microstrip patch antenna to detect salt and sugar concentration in the water is proposed in this paper. The proposed antenna for salt and sugar detection utilizes the concept of DGS for reducing the size of the antenna. Moreover, as the slots in the ground plane also behave like resonating elements, so it enhances the performance of the salt and sugar detection system as the concentration of salt and sugar affects from both sides, i.e. patch and ground plane. The proposed antenna is compared with the existing antennas used for salt and sugar detection. It is observed that the proposed antenna for salt and sugar detection is compact in size and the cost of the antenna is low as antenna is fabricated on FR4 substrate. The experiments for detecting the concentration of salt and sugar in the water are performed. The experiments confirm that the proposed antenna can be used to detect salt and sugar concentration and the antenna is also suitable for 2.4 GHz wireless applications. Rest of the paper is organized as follows. The second section presents the design, geometrical configuration, and dimensions of the proposed antenna. The antenna parameters and the measurements for detecting salt and sugar concentration in water using the proposed antenna are discussed in the third section. The conclusion of the work is given in the fourth section.

Antenna geometry and design

A rectangular patch is widely used patch as it is easy to analyze using the transmission line model and cavity model (Balanis, 2005). The antenna dimensions are calculated using the transmission line method of analysis. The configuration of the proposed compact microstrip patch antenna is shown in Figure 1. The top view, side view, and bottom view of the antenna are depicted in Figure 1A, Figure 1B and Figure 1C, respectively. The rectangular microstrip patch is designed on a FR4 substrate. The width W of the patch for resonant frequency f_{reso}, substrate thickness h and substrate dielectric constant ε_r is calculated by using the following equation (Balanis, 2005):

$$W = \frac{c}{2f_{reso}}\sqrt{\frac{2}{\varepsilon_r + 1}} \tag{1}$$

where c is the speed of light. The fringing effect decreases the dielectric constant of the material and after taking this effect into account, the effective

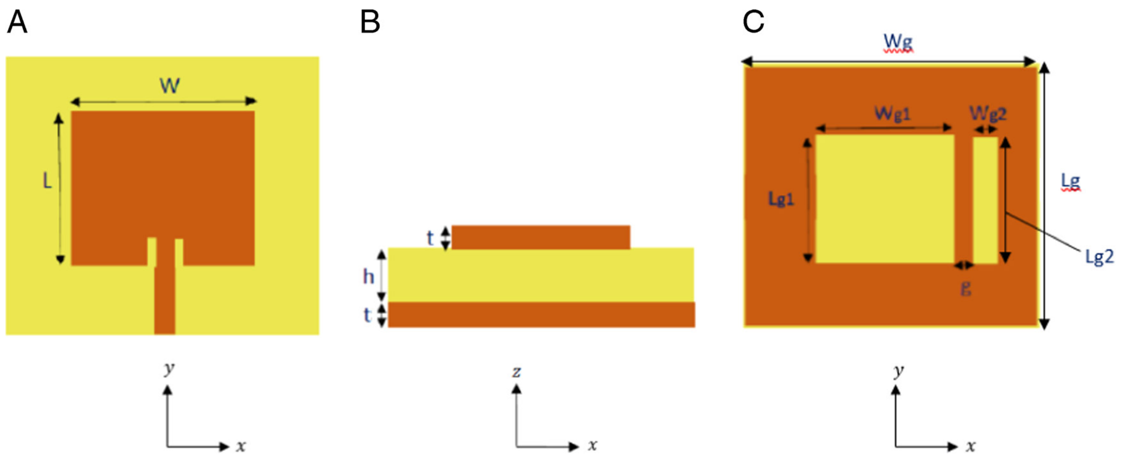

Figure 1: Antenna geometry: (A) top view, (B) side view, and (C) bottom view.

dielectric constant ε_{reff} is calculated by using the following equation (Balanis, 2005):

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2\sqrt{1 + \frac{12h}{W}}} \quad (2)$$

The fringing effect increases the length of the patch by ΔL on each side. So, the actual length of the patch L is computed by using the following equation (Balanis, 2005):

$$L = L_{eff} - 2\Delta L \quad (3)$$

where L_{eff} is the effective length of patch due to fringing field and is given by the following equation:

$$L_{eff} = \frac{c}{2f_{reso}\sqrt{\varepsilon_{reff}}} \quad (4)$$

The increment in the length of patch on each side due to fringing field is given by the following equation (Balanis, 2005):

$$\Delta L = \frac{0.412h\left(\varepsilon_{reff} + 0.3\right)\left(\frac{W}{h} + 0.264\right)}{\left(\varepsilon_{reff} - 0.258\right)\left(\frac{W}{h} + 0.8\right)} \quad (5)$$

To improve the antenna performance and to reduce the size of the antenna, the two slots are cut in the ground plane as shown in Figure 1C. The slots in the ground plane reduce the reflection coefficient of the structure and improve the antenna performance. The proposed structure is simulated and optimized using CST microwave studio. The optimized dimensions are given in Table 1. In this table, *L, W*, *Lg*, and *Wg* are the length of the patch, width of the patch, length of the ground plane and width of the ground plane, respectively. *Lg*1 and *Wg*1 are the length and width of the slot positioned at the center in the ground plane. *Lg*2 and *Wg*2 are the length and width of the slot positioned at a gap distance

Table 1. Optimized dimensions of the compact antenna.

S. No.	Dimensional parameter	Values
1	L	25.65 mm
2	W	25.65 mm
3	Lg	51.3 mm
4	Wg	51.3 mm
5	$Lg1$	25.65 mm
6	$Wg1$	25.65 mm
7	$Lg2$	24.41 mm
8	$Wg2$	5.1525 mm
9	g	2.5875 mm
10	h	1.5 mm
11	t	0.035 mm
12	ε_r	4.3

2.5875 mm from the center slot in the ground plane. The DGS is resonating in nature and by adjusting the dimensions of the slots in the ground, the resonant frequencies are varied and the size of the antenna is reduced. The dimensions of the antenna with DGS and without DGS for the same substrate parameters and same resonant frequency are shown in Table 2. It can be observed that slots in ground plane provide a reduction in the antenna area by 21.5%. The antenna with DGS is fabricated for the measurements. The fabricated compact microstrip patch antenna is shown in Figure 2. The top layer and bottom layer of the fabricated antenna are shown in Figure 2A and Figure 2B, respectively.

Results and discussion

In this section, various antenna parameters and the measured results for the salt and sugar detection system are presented. Figure 3 depicts the simulated reflection coefficient versus frequency and voltage standing wave ratio (VSWR) versus frequency. It can be observed from the reflection coefficient of the antenna that the bandwidth of the antenna is from 2.2866 GHz to 2.5072 GHz (220.6 MHz) and the antenna is resonating at the frequency 2.4 GHz. From the VSWR graph of the antenna, it can be observed that the value of VSWR is less than 2 for the frequency range from 2.2866 GHz to 2.5072 GHz. The variation in length of the slot positioned at the center in ground plane causes the shift in resonant frequency of the antenna as shown in Table 3. The length is chosen for the resonant frequency 2.4 GHz. The VSWR of the antenna for this length is 1.389. The normalized radiation patterns of the antenna in $\phi = 0$ degree plane and $\phi = 90$ degree plane at 2.4 GHz are shown in Figure 4A and Figure 4B, respectively. From the patterns of the antenna, it can be observed that the direction of the major lobe in both planes is at 0 degree and the shape of the patterns is closed to figure of eighth in both planes. It can also be observed that the 3 dB beam width is broad in both planes. The gain, directivity, radiation efficiency, and total efficiency of the antenna are given in Table 4. The antenna provides a maximum gain of 2.12 dB and maximum directivity of 0.095 dBi.

Figure 5 presents the experimental set up for measuring the return loss of the antenna. The antenna is connected at the port of TR5048 network analyzer (NA) and the NA is connected with the computer to observe the return loss of the antenna using TR5048 NA software as shown in Figure 5. The antenna is dipped in various solutions with different concentrations of salt and sugar and the return loss at various frequencies is measured. Salt (NaCl) and sugar or sucrose ($C_{12}H_{22}O_{11}$) are crystalline

Table 2. Dimensions of the antenna with and without DGS.

S. No.	Antenna type	Area of patch	Area of ground plane
1	Antenna without DGS	838.1 mm^2	3,352.4 mm^2
2	Antenna with DGS	657.9 mm^2	2,631.7 mm^2

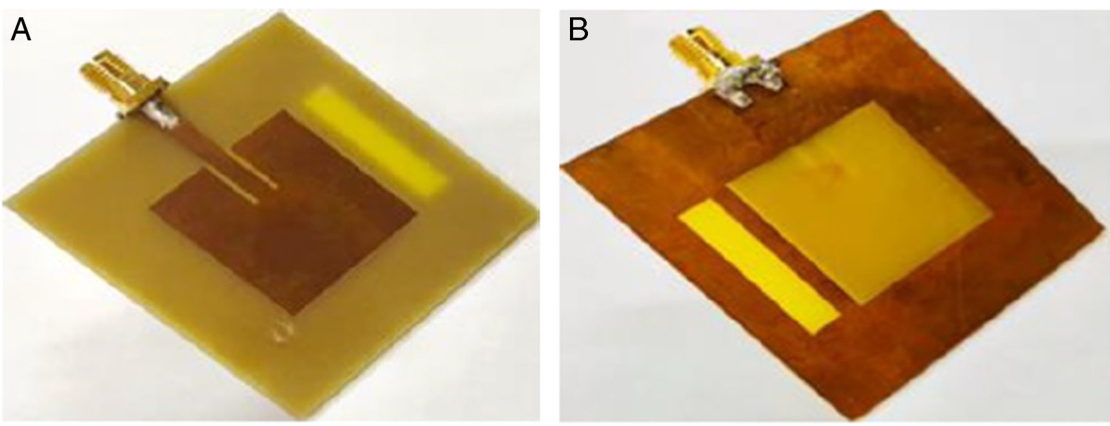

Figure 2: Fabricated antenna: (A) top view and (B) bottom view.

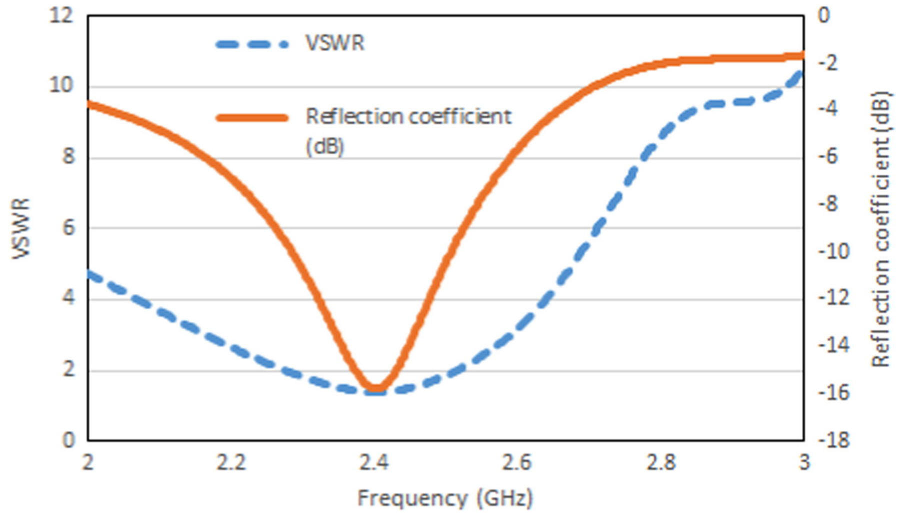

Figure 3: VSWR and reflection coefficient of the antenna.

Table 3. Effect of slot length on various parameters.

S. No.	Slot length	Resonant frequency	VSWR (at 2.4 GHz)	|*S*11| (at 2.4 GHz)
1	24.95 mm	2.466 GHz	1.514	–13.433 dB
2	25.65 mm	2.402 GHz	1.389	–15.768 dB
3	26.45 mm	2.336 GHz	1.68	–11.913 dB
4	28.95 mm	2.082 GHz	4.624	–3.817 dB

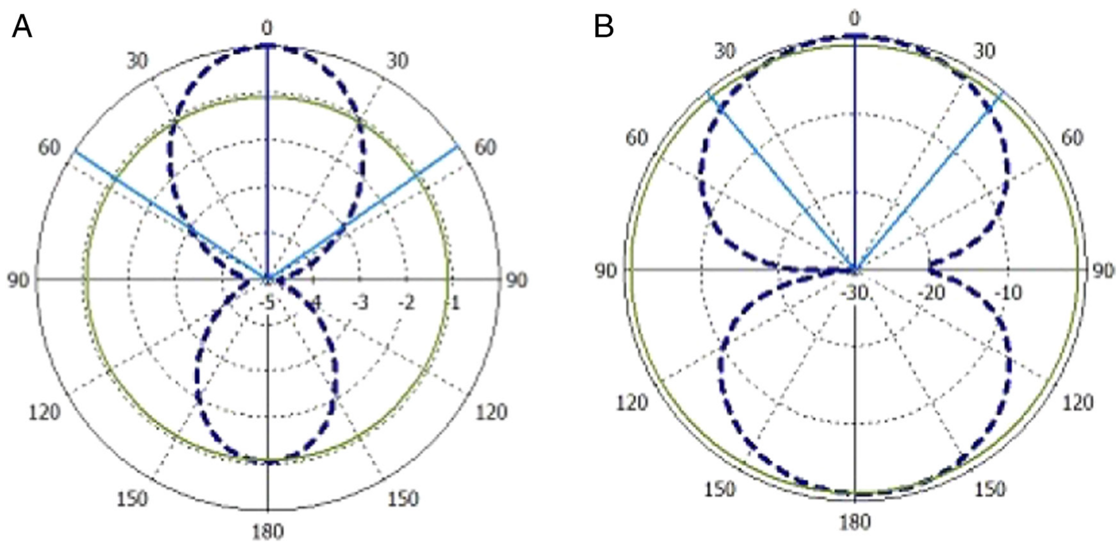

Figure 4: Radiation patterns of the antenna at 2.4 GHz: (A) $\phi = 0$ deg. plane and (B) $\phi = 90$ deg. plane.

Table 4. Gain, directivity, and efficiencies of the antenna at 2.4 GHz.

Radiation efficiency	Total efficiency	Max. gain	Max. directivity
−1.84 dB	−1.97 dB	2.12 dB	3.95 dBi

compounds and easily dissolve in the water to form a solution. These compounds usually in solution appear in an ionic state. Salt–water solution is formed when sodium chloride (NaCl) dissolves completely in water (H_2O) and sugar–water solution is formed when sugar dissolves in water. Different quantities of salt and sugar are taken separately in the water in order to create a low, medium, and high concentrated solutions of salt and sugar in the designed containers that fits the size of the fabricated microstrip antenna for the experimental procedure.

The solutions of different concentrations of salt and sugar are prepared using the molarity. The molarity of salt and sugar solutions for different concentrations for measurement procedure is calculated as the ratio of moles of the solute to the volume of the solution. The solution is prepared in the cylindrical glass container. The molarity of the solution is given by the following equation:

$$Molarity\left(\frac{mol}{L}\right) = \frac{M_0}{V_0} \tag{6}$$

where M_0 is the moles of solute (Mols) and V_0 is the volume of solution (L). The percentage concentration by mass (conc) is calculated by the following equation:

$$conc = \frac{M_{solute}}{M_{solution}} \times 100 \tag{7}$$

where M_{solute} and $M_{solution}$ are the mass of solute (*g*) and mass of solution (*g*), respectively.

The measurement of return loss using the measurement setup is performed for three different salt solutions with different salt concentrations as 20, 50, and 80%, and three different sugar solutions with different sugar concentrations as 20, 50, and 80%. The 20, 50, and 80% of salt concentrated solutions contain the 20 grams of salt in 100 mL of water, 50 grams of salt in 100 mL of water, and 80 grams of salt in 100 mL of water, respectively. Similarly, the 20, 50, and 80% of sugar concentrated solutions contain the 20 grams of sugar in 100 mL of water, 50 grams of sugar in 100 mL of water, and 80 grams of sugar in 100 mL of water, respectively. The return loss of the antenna is measured by dipping the fabricated microstrip antenna in each solution and the return loss is measured using a network analyzer as shown in Figure 5. The return loss of the antenna for salt solutions of different concentrations at various frequencies is given in Table 5. From Table 5, it can be observed that the return loss decreases with the increase in concentration of salt in solution at all frequencies. The change in the return loss of the antenna is due to the change in the dielectric properties of the solution for different concentrations of salt. The return loss of the antenna for sugar solutions of different concentrations at various frequencies is given in Table 6. From Table 6, it can be observed that the return loss decreases with the increase in the concentration of sugar in the solution at all frequencies. The change in the return loss of the antenna is due to the change in the dielectric properties of the solution for different concentrations of sugar. From these measurements,

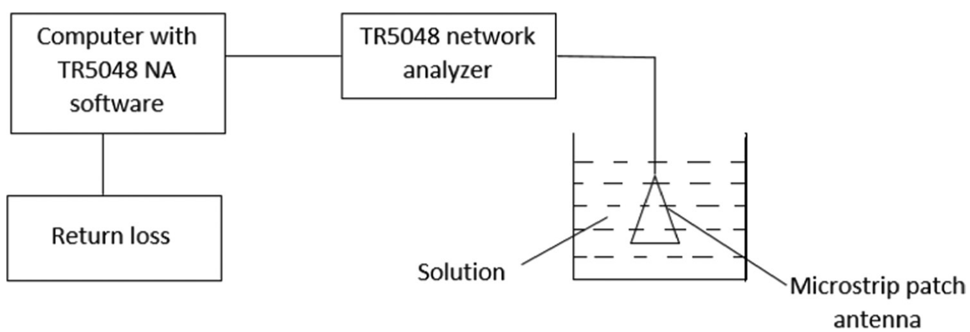

Figure 5: Measurement setup.

Table 5. Return loss of the antenna in different concentrations of salt in water.

S. No.	Frequency	Return loss (concentration: 20%)	Return loss (concentration: 50%)	Return loss (concentration: 80%)
1	2.38 GHz	23.271 dB	21.017 dB	13.334 dB
2	2.56 GHz	23.757 dB	20.54 dB	13.281 dB
3	2.72 GHz	24.582 dB	19.84 dB	13.046 dB
4	2.86 GHz	23.253 dB	17.095 dB	11.691 dB

Table 6. Return loss of the antenna in different concentrations of sugar in water.

S. No.	Frequency	Return loss (concentration: 20%)	Return loss (concentration: 50%)	Return loss (concentration: 80%)
1	2.38 GHz	23.558 dB	19.123 dB	13.022 dB
2	2.56 GHz	24.251 dB	22.012 dB	13.223 dB
3	2.72 GHz	24.097 dB	21.293 dB	13.144 dB
4	2.86 GHz	22.044 dB	17.272 dB	11.962 dB

it can be observed that the return loss of the antenna changes with the variation of salt and sugar concentration in water, hence the proposed salt and sugar detection system based upon compact microstrip patch antenna can easily detect the concentration of the salt and sugar in water. From the antenna parameters, it can be observed that the designed and developed microstrip patch antenna is also suitable for 2.4 GHz wireless applications for the bandwidth from 2.2866 GHz to 2.5072 GHz. The comparison of the proposed antenna for salt and sugar detection system with existing antennas for salt and sugar detection system is shown in Table 7. The dimensions of the antennas are given in terms of free

Table 7. Comparison of proposed antenna with existing antennas for salt and sugar detection.

Reference	Antenna type	Center frequency	Dimensions of the antenna	Substrate parameters
Cheng et al. (2014a)	Rectangular microstrip antenna	2.45 GHz	$0.47\lambda_0 \times 0.388\lambda_0$	$\varepsilon_r = 2.2$, $h = 1.575$ mm
Cheng et al. (2014a)	Circular microstrip antenna	2.45 GHz	$0.465\lambda_0 \times 0.465\lambda_0$	$\varepsilon_r = 2.2$, $h = 1.575$ mm
Cheng et al. (2014a)	Square microstrip antenna	2.45 GHz	$0.529\lambda_0 \times 0.529\lambda_0$	$\varepsilon_r = 2.2$, $h = 1.575$ mm
Rahman et al. (2018b)	Circulated psi-shaped patch	16 GHz	$1.28\lambda_0 \times 0.96\lambda_0$	$\varepsilon_r = 2.2$, $h = 1.57$ mm
Islam et al. (2018)	Crescent-shaped microstrip antenna	10.6 GHz	$1.13\lambda_0 \times 0.777\lambda_0$	$\varepsilon_r = 4.6$, $h = 1.6$ mm
Rahman et al. (2018a)	Fork-shaped patch	9.5 GHz	$0.76\lambda_0 \times 0.57\lambda_0$	$\varepsilon_r = 2.2$, $h = 1.57$ mm
Proposed method	Rectangular microstrip antenna	2.4 GHz	$0.41\lambda_0 \times 0.41\lambda_0$	$\varepsilon_r = 4.3$, $h = 1.5$ mm

space center wavelength (λ_0). From Table 7, it can be observed that the proposed antenna is compact in size and the cost of the proposed antenna is low as it is fabricated on FR4 substrate.

Conclusions

The design of a low-profile microstrip antenna-based detection system for detecting the salt and sugar concentration in the water has been presented. The presented antenna has utilized DGS technology for improving the antenna parameters and reducing the antenna size. The simulated and optimized compact antenna is fabricated. The measurements for the return loss of the antenna for different solutions with various concentrations of salt and sugar have been conducted. From the measurements performed for various solutions with different concentrations of salt and sugar, it is found that the increase in the concentration of salt and sugar in the water decreases the return loss as the dielectric properties of the solution change with change in the concentration of salt and sugar in water. The results show that the presented compact low cost antenna can be used for detecting sugar and salt concentration in the water. The presented compact microstrip patch antenna is also suitable for 2.4 GHz WLAN applications.

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