**SHORT COMMUNICATION**

**Wideband microstrip antenna for the detection of solutes in water**

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**Abstract**
Effective detection of solutes in water has always been a challenging issue in real-time. This article presents a technique to detect solutes such as table sugar (CHOO$_3$), common salt (NaCl), and combinations thereof in water using a wideband microstrip antenna with an electromagnetic band gap ground structure. An antenna is designed and fabricated to operate at the bandwidth of 3 GHz with a stable gain of 9 dBi maintaining voltage standing wave ratio $\leq 2$. The uniquely designed antenna works as a sensor in its near field to sense solutes in water as a function of the resonant frequency. Apart from sensing solutes, the proposed technique also efficiently detects temperature of soft drinks. As temperature of soft drinks changes, reflection characteristics of an antenna change too. The results of the experiments show that as the concentration of the solute increases, the return loss decreases. The beauty of this technique is its efficient detection without any physical contact with a solution and without disturbing the chemical processes inside the solution. This method can be quite useful for food regulation boards to analyze and detect the contents of beverages, soft drinks and any consumable liquid, whether hot or cold.

**KEYWORDS**
concentration of solute, microstrip antenna, reflection characteristics

**1 | INTRODUCTION**

Beverages such as soft drinks, fast food, canned juices, packed food, ready to eat food are very popular and are comfort foods. They are readily available for consumption and due to excessively preoccupied lifestyles, people prefer them more often. Subsequent consequences of such type of consumption lead to various serious health issues such as diabetes, stroke, kidney failure, and so forth. Most fast food, ready to heat and eat type of foods are complemented by soft drinks, canned juices, and other liquid beverages which are equally unhealthy most of the times.$^{1-6}$

Soft drinks are composed of solutes such as table sugar (CHOO$_3$) and common salt (NaCl) in an excessive amount. It is, therefore, essential to find the percentage of these solutes before their consumption. Moreover, while transporting liquid beverages, it is necessary that a particular temperature be maintained for the item to be safe for consumption. If the temperature, due to some mishandling, varies beyond a certain range, the beverage can become adulterated and hazardous for consumption.
Therefore, it is crucial to maintain requisite temperature which in turn maintains the properties of the composition of the liquid.

There are many methods used currently to determine the composition of solutions. These methods can be broadly listed as (1) drying method, (2) reflection method, (3) coaxial method, and (4) microstrip-based method.

Drying method used in Reference 7 is a technique, as mentioned above, to measure proportion of salt in soil. This method determines the electrical conductance of soil to detect the proportion of salt. The method is time-consuming and requires mixing of chemicals in a testing solution. Furthermore, the microwave measurement technique using an open-ended coaxial cable is used to sense the dielectric concentration of the starch in a salt-starch solution. This technique requires an expensive coaxial probe which determines the changes in dielectric properties based on viscosity of the salt-starch solution. The microstrip-based technology is widely used in different fields such as agriculture, medicine, sensor development, and communication systems. This technology is also used for sensing solutes in a solution. A partial ground surface based on electromagnetic band gap (EBG) structure, defected ground surface (DGS), frequency selective surface, and meta-materials are integrated with a microstrip antenna. This combination is used as a sensor for detecting solutes in liquids. A low-cost radio frequency identification sensor comprising a planar waveguide structure and a radiating antenna is utilized to sense the permittivity of various liquids. A change in the resonant frequency as a function of the liquid substrate is detected. A microfluidic sensor based on split-ring resonators (SRR) is developed in which the resonant frequency depends on the permittivity of the testing liquid. The sensor is developed using a complex photolithography and chemical etching method wherein SRR and ground plane are made from expensive gold-coated copper. Meta-material is fabricated for sensing liquids using printing technology. The experimental setup needs an expensive spectrometer and the results are obtained at higher frequencies of THz range. A compact crescent-shaped patch and slotted partial ground surface are developed as a sensor to detect salt and sugar in water using the reflection coefficient of the reflected wave from liquids. This antenna operates at higher frequencies which detects solutes in water at frequencies in the range of 3–14 GHz frequencies.

A compact U-shaped microstrip antenna is proposed to detect salt and sugar in water. The antenna is impersonated on costly Rogers RT/duroid 5880 material which detects solutes at a higher frequency of 16 GHz. A microstrip technology-based tuning fork-shaped sensor is designed to sense salt and sugar in water. The antenna detects concentration of solutes by inserting it in water which leads to the corrosion and affects the sensitivity of antenna. A reflection-based microwave measurement system consisting of a dielectric slim probe and loop antenna is proposed for measuring salinity of water. The method measures reflection coefficient and is presented in magnitude and phase. A microstrip feed inset patch sensor is designed to measure salinity in seawater. The sensor is fabricated by conductive copper spray coating on the masks made by three-dimensional printer which typically senses salinity of seawater. A high sensitivity rectangular microstrip slot loaded patch antenna is developed using RF-35 substrate for permittivity measurement. The patch antenna is tested using five different dielectric samples with dielectric constants ranging for sensitivity comparison. A compact, low-profile microstrip antenna is presented for the detection of salt and sugar in water. The antenna uses DGS technology DGS technology for improving the antenna parameters and reducing the antenna size.

A variety of techniques are developed to generate a phase change of an EBG structure based on the reconfigurable or tunable capabilities of an antenna. Reconfiguration is achieved by using varactor diodes, PIN diodes, P-I diodes, or radio frequency (RF) micro-electro-mechanical system switches. The operating frequency and polarization can be made reconfigurable through a variation of EBG characteristics. The mechanical movement of elements also offered phase variations across the EBG array. An array of square patches with a series of cuts and grooves in the substrate cause the deposition of liquid. As the variation in the dielectric characteristics of the liquid changes, there is a phase of the surface waves.

The methods in the literature review for the detection of moisture and solutes in the solution are time-consuming, complex, and also incur inaccuracies during the measurement process. Table 1 provides a brief comparison of the significant research in the detection of the solutes in any given solution.

In this study, a coplanar waveguide (CPW) fed slotted wine glass shaped microstrip antenna with a two-dimensional (2D) EBG woodpile structured ground surface is designed. The presented antenna has a wide impedance bandwidth of 3 GHz, maintaining voltage standing wave ratio (VSWR) ≤ 2. The antenna gives a maximum gain of 9 dBi and a stable radiation pattern throughout the operating bandwidth with considerable efficiency. The proposed antenna is kept in the near field of the solution, and its reflection characteristic is observed. The return loss values drop at specific frequencies for different solutes such as table sugar (CHOO₃), common salt (NaCl), sugar and salt, and soft drink. The presented antenna detects solutes and their concentration in water using a noncontact reflection method. The antenna can also be used to observe the effect of the temperature variation on the dielectric properties of the soft drink.
### Table 1 Comparison table of the literature review

| Sr. no. | Author(s)       | Reference | Approximate antenna size | Method Opted                                      | Drawback/shortcoming                          |
|---------|-----------------|-----------|---------------------------|---------------------------------------------------|-----------------------------------------------|
| 1       | Rahman et al.   | 19        | A tuning fork shaped patch of 24 mm × 18 mm × 1.57 mm | Reflection method by inserting the antenna in the testing solution | Higher operating frequency                   |
| 2       | Rahman et al.   | 20        | Psi-shaped patch with the slotted ground plane of 24 × 18 × 1.57 mm size | Reflection method by inserting an antenna in the testing solution | Higher operating frequency                   |
| 3       | Yeo and Lee     | 23        | Inset-fed, slot loaded rectangular microstrip patch antenna 80 mm × 80 mm × 0.76 mm | Reflection method for determining the sensitivities of antennas | Complex structure                             |
| 4       | Lee et al.      | 22        | Microstrip patch of 20 mm × 10 mm × 5 mm size | Reflection method by inserting an antenna in the testing solution | May lead to the deterioration of the antenna due to insertion in solution |
| 5       | Jun et al.      | 28        | Square shaped microstrip antenna with 111 mm × 111 mm × 5 mm size | Reflection method by inserting an antenna in the testing solution | Complex structure and may lead to deterioration of the antenna due to insertion in solution |
| 6       | Islam et al.    | 18        | Crescent-shaped patch of 32 mm × 22 mm × 1.60 mm size | Reflection method | Higher operating frequency                   |
| 7       | Njokweni and Kumar | 24 | Square shaped patch of size 25.65 mm × 25.65 mm × 1.5 mm with DGS | Reflection method by inserting the antenna in the testing solution | May lead to deterioration of the antenna due to insertion in solution |

Significant contributions of this work include:

i Proposal and design of an in-house fabrication of wideband microstrip antenna to sense wide frequency variation in reflection characteristics of solutions.

ii Deployment of the antenna for the detection of the concentration of sugar, salt, and their combination in water at room temperature.

iii Detection of variation in reflection characteristics such as frequency and reflection coefficient of the composition of soft drinks as a function of temperature variation.

A detailed design of the microstrip antenna and 2D woodpile EBG structure as the ground surface and the experimentation setup and the corresponding analysis are explained apart from the list of references.

## 2 | Design of the Antenna and 2D Woodpile EBG Based Ground Surface

The design of an antenna for detecting solutes in water is quite challenging. The antenna should be wideband so that it can detect frequency shift due to a change in the dielectric property of the solution. There may be a change in the return loss characteristic at any frequency in the given wideband. In addition, the reflection characteristic is desirable to be flat so that any change can be detected in the given bandwidth. In this section, the design of a wine glass shaped antenna with a hexagonal shaped slot and CPW feeding is presented. CPW feeding to the antenna enhances the operating bandwidth of the antenna. The height of the substrate is chosen to be high enough to assure more bandwidth. In addition, a partial ground surface is designed based on a 2D EBG woodpile structure which is proposed to enhance the bandwidth with flat reflection characteristics.29,30 A parametric study of the width of the strips of the woodpile structure is also carried out to obtain maximum bandwidth. A detailed design of the antenna is described as follows:

The dimensions of the proposed antenna are shown in Figure 1. The wine glass shaped microstrip antenna has a width \( W = 43.56 \) mm, length \( L = 22.69 \) mm, a ground surface width \( W_g = 40.5 \) mm, a ground surface length \( L_g = 31 \) mm.
The spacing between the ground surface and the wine glass shape $s = 2.56$ mm. The gap between the feeding CPW line and the ground surface $g = 0.7$ mm. The antenna, the ground plane, and the CPW feed line are printed on a substrate of the size of $85 \text{ mm} \times 85 \text{ mm} \times 1.6$ mm. The substrate is a cheap and readily available glass epoxy (FR4) material with thickness $h = 2.4$ mm, relative permittivity $\varepsilon_r = 4.4$, and loss tangent $\tan \delta = 0.02$. The radius of the hexagonal slot $r = 1.2$ mm.

The shape of a wine glass has a smooth curvature along the length, so it becomes a traveling wave type of structure when implemented as an antenna. The variation in the width of the wine glass shape from the bottom toward its open end is responsible for its wide bandwidth.\textsuperscript{22-24,30} In addition, the slot is engraved in the antenna structure to increase the bandwidth of the antenna. The shape of the slot plays an important role. Rigorous simulations with different shapes such as square, circle, and triangle are carried out. From the simulations, it is found that the hexagonal shape shows the highest bandwidth due to the number of corners in it. A comparative study of the performance of the wine glass shaped antenna with and without the slot is performed. Figure 2 shows return loss characteristics for the antenna with and without a slot.

Table 2 shows bandwidths at corresponding resonating frequencies for the microstrip antenna with and without the hexagonal slot.
### TABLE 2  
Impedance bandwidths for antennas with and without a slot

|                     | Antenna without a slot | Antenna with a slot |
|---------------------|------------------------|---------------------|
| 0.87 GHz            | 1.6228 GHz             |

### FIGURE 3  
Return loss characteristics for various strip-widths of the woodpile structure. The microstrip antenna with a 1-mm wide strip for the woodpile structure offers the highest impedance bandwidth of 3 GHz, as observed from Figure 3.

A ground surface with a 2D woodpile structure is proposed for the enhancement of the bandwidth. The woodpile structure is made of horizontal and vertical metallic strips piled on one another, as shown in Figure 1. Here, this woodpile structure is proposed as an EBG based ground surface.

The optimization of the width of the metallic strip is carried out using a parametric study. The strip width is varied from 1, to 2 and 3 mm and the corresponding parameters are studied. The inclusion of the woodpile structure as a modified ground surface enhances the frequency response making it smoother and reducing its return loss. Figure 3 depicts reflection characteristics for various strip-widths of the woodpile structure.

### 3  
**EXPERIMENTATION SETUP AND ANALYSIS**

CPW-fed microstrip antenna is fabricated as per the design described in Section 2. A fabrication process is carried out in-house using an EP-42AUTO PCB Prototype machine. Figure 4 shows the fabricated antenna. The fabricated antenna is tested using a Rogers R & S ZNB vector network analyzer with a range of 300 MHz–8 GHz.

Figure 5 offers a comparison of the simulated and measured results of the return loss for the fabricated antenna. The simulated and measured results agree with each other.

Table 3 shows the simulated and measured impedance bandwidths.
APPLICATION OF THE ANTENNA AS A SENSOR

The purpose of designing the wideband microstrip antenna is for sensing the reflections received from the solution. The shift in the frequency can take any value depending on the dielectric properties of the solute. The proposed work also determines the concentration of table sugar and common salt in water and observes the effect of temperature on the dielectric properties of soft drinks. The antenna acts as a sensor for the detection of water solutes. The antenna is placed near the water solution to observe the near field reflection characteristics. The change in the reflection loss at a particular frequency gives a clue of the specific solute in the water. The concentration of solutes in the water is varied to study its effect on the reflection characteristics.

The near field distance between the antenna and the solution is also varied to observe its effect. This experiment is also useful to determine the exact distance between the antenna and the solution for a proper shift in reflection characteristics.

The antenna is also used to observe variation in the reflection characteristics of a soft drink at various temperatures. Soft drinks are transported from one place to another due to which they can face a drastic temperature variation due to atmospheric conditions at different locations. The temperature changes the material properties of soft drinks along with reflection characteristics.

Figure 6 presents the experimental set up for measuring reflection characteristics of the fabricated antenna for sensing the solutes in water.
In this study, three types of solutions are considered. The first testing solution contains water and salt in which salt concentration is varied from 5% to 20%. The antenna is placed in the near field range of various distances starting from 20, 15, 10, and 5 mm above the water surface. The second solution is of water and sugar, where the concentration of sugar is varied from 20%, 15%, 10%, all the way down to 5%. In this case, readings are taken in the near field area, that is, 20, 15, 10, and 5 mm. The third solution is a water-sugar-salt solution wherein the concentration is of 20%, 15%, 10%, 5%, and the same near field distances are considered, that is, 20, 15, 10, and 5 mm above the solution.

The return loss characteristics of all these solutions are observed and studied. After an investigation of these water solutions, the peak reflection coefficient variation at various resonant frequencies is shown in Table 4.

From Table 4, it is observed that the reflection coefficient increases as the distance between the solution and the antenna reduces. In addition, as the concentration of sugar, salt, and sugar-salt combination in the water increases, there is a decrease in the reflection coefficient. The number of free molecules of water decrease with the increment of sugar and salt concentration in water. When solutes such as sugar or salt are added to water, they change the dielectric property of water. The chemical bond of the dissolved ions and the water molecules is responsible for this change in the dielectric property. The ionic conductivity of water also reduces, which again reduces the polarization of water.

The effective dielectric constant of the solution decreases, which also reduces the dielectric constant of the solution. Consequently, the intrinsic impedance of the solution reduces due to a decrement in the dielectric constant of the solution. When an antenna is kept near the field of the solution, there is a significant change in reflection.

Table 5 displays the reflection coefficient of the solutions placed in various near fielded distances, namely, 20, 15, 10, and 5 mm. It is observed that the minimum reflection coefficient is obtained at the range of 10 mm above the solution for all the three cases. Table 5 explains the corresponding observations considering the near field distance of 10 mm.

Figure 7 depicts the reflection characteristics of all the solutions under observation. As observed from Figure 7, there are significant changes in the frequency characterization due to the presence of salt, sugar, and their combination in water.

The experimentations based on the observation of variation in reflection characteristics of the solutions were performed for the first time and had not been reported anywhere in the current literature. These experimentations offered

| Solution                  | Solute (%) | Distance (mm) | Frequency (GHz) | Return loss (dB) |
|---------------------------|------------|---------------|-----------------|------------------|
| Water + salt              | 20         | 20            | 3.16            | −24.5            |
|                           | 15         | 15            | 3.11            | −25.298          |
|                           | 10         | 10            | 3.17            | −32.44           |
|                           | 5          | 5             | 3.22            | −30.26           |
| Water + sugar             | 20         | 20            | 2.873           | −24.12           |
|                           | 15         | 15            | 2.846           | −26.23           |
|                           | 10         | 10            | 2.746           | −36.047          |
|                           | 5          | 5             | 2.78            | −29.419          |
| Water + salt + sugar      | 20         | 20            | 2.41            | −22.6            |
|                           | 15         | 15            | 2.52            | −27.69           |
|                           | 10         | 10            | 2.55            | −34.384          |
|                           | 5          | 5             | 2.451           | −33.93           |

| Solution                  | Solute (%) | Distance (mm) | Frequency (GHz) | Return loss (dB) |
|---------------------------|------------|---------------|-----------------|------------------|
| Water + salt              | 10         | 10            | 3.17            | −32.44           |
| Water + sugar             | 10         | 10            | 2.746           | −36.047          |
| Water + salt + sugar      | 10         | 10            | 2.55            | −34.384          |
good results which would be useful for the estimation of contamination (dielectric constant variation) of soft drinks before consumption. This estimation can be performed using the proposed low-cost antenna.

In the earlier research,19,20 reflection coefficient was observed considering the concentration of solutes. The novelty of the work lies in the consideration of the near field distance along with the concentration of the solutes. Here, in the presented study, the appropriate distance between the solution and the antenna is calculated using the experimentations. Then, after fixing it, the concentration of the solutes is increased from 10% to 90%.

Typically, an antenna has to be placed in the liquid to sense its dielectric property. This method causes corrosion and deterioration of the antenna.21 The presented antenna senses dielectric properties in the near field of the solution; therefore the antenna is safe from corrosion and deterioration.

From that, it is observed that the return loss decreases as the concentration increases. Table 6 shows the observed return losses of various solutions when the concentration of solutes are varied from 10% to 90%.

Figure 8 shows a comparative graph of return loss versus percentage concentration of the solute.

This antenna is used to study the reflection characterization in the presence of a soft drink. Cold soft drinks are transported from one place to another. During this transportation, they face sudden temperature changes. The variation in the temperature causes the difference in the dielectric properties of soft drinks. Furthermore, the concentration of the sugar in a soft drink is much higher, so it should be tested before consumption.

Table 7 shows the variation of three reflection characteristics of the antenna for different temperature conditions.

The antenna is placed near the field area of a soft drink at a distance of 10 mm, and reading is taken at room temperature initially. It shows the frequency of 2.7736 GHz. Then the soft drink is heated up to 38°C for comparing it to conditions that exist during transportation (as the vehicles transport the drink bottles in the sunlight when the atmospheric temperature can be more than 38°C) and the antenna shows 2.7289 GHz. Furthermore, the soft drink is allowed to cool down to

### Table 6 Return loss for various concentrations of solutes

| Sr. no. | % Concentration of solute | Return loss in dB for salt at 3.17 GHz | Return loss in dB for sugar at 2.746 GHz | Return loss in dB for salt + sugar at 2.55 GHz |
|---------|--------------------------|---------------------------------------|----------------------------------------|---------------------------------------------|
| 1       | 10                       | −32.44                                | −36.047                                | −34.384                                    |
| 2       | 20                       | −33.42                                | −36.917                                | −35.18                                     |
| 3       | 30                       | −34.184                               | −37.6704                               | −35.876                                    |
| 4       | 40                       | −34.813                               | −38.4013                               | −36.777                                    |
| 5       | 50                       | −35.778                               | −39.3873                               | −37.4757                                   |
| 6       | 60                       | −36.5086                               | −40.1273                               | −38.1738                                   |
| 7       | 70                       | −37.3726                               | −40.9973                               | −38.7718                                   |
| 8       | 80                       | −38.1649                               | −41.6673                               | −39.6621                                   |
| 9       | 90                       | −38.7939                               | −42.3771                               | −40.6486                                   |

*aSolute is salt, sugar, and combination of salt and sugar.*
**FIGURE 8** Return loss versus concentration of solute

![Graph showing return loss versus concentration of solute](image)

**TABLE 7** Return loss characterization for a soft drink with temperature variation

| Sr. no. | Condition                  | Frequency (GHz) | Return loss (dB) |
|---------|----------------------------|-----------------|------------------|
| 1       | First room temperature     | 2.7736          | −27.764          |
| 2       | Temperature increased (38°C) | 2.7289          | −33.719          |
| 3       | Second room temperature    | 2.8273          | −28.623          |

**FIGURE 9** Return loss characterization for a soft drink with temperature variation (T1 = time at 27°C, T2 = time at 38°C, T3 = time at 27°C)

![Graph showing return loss characterization for a soft drink with temperature variation](image)

room temperature. After cooling, the frequency is 2.8273 GHz. Figure 9 shows variation in return loss characteristics due to a change in the temperature of the soft drink. This change is huge whenever the drink gets cold, and when temperature goes up, physical properties of the solution change and the quality of the product deteriorates. The frequent ups and downs in the temperature can damage the taste and destroy the quality of the drink. This, in turn, upon consumption, can affect human health as it may lead to vomiting and diarrhea.

### 4 CONCLUSION

This research study successfully proposes a wine glass shaped microstrip antenna-based sensor for detecting sugar and salt concentration in water while placed near a field area. The same structure is also efficiently deployed to detect variation in the temperature of liquid beverages which in turn endorses the consumable characteristics of the same.

An antenna of the size of 85 mm × 85 mm is fabricated on a low-cost FR4 substrate. It also has a robust radiation pattern throughout the operating band. Hence, the antenna can be used for sensor applications and various other applications for wireless communication.
The comparison between the simulated and measured results of the return loss for the fabricated antenna agrees with each other. The measured value of the impedance bandwidth also matches with the simulated bandwidth of 2.991 and 2.9042 GHz values. The error between the two values is only 3%. The results obtained from the comparison of the return loss for various concentrations of the solutions containing salt, sugar and equal combination of both also indicate the deep, sharp glitches at 2.55, 2.746, and 3.17 GHz, respectively. These glitches confirm the detection of salt, sugar and the combination of both in water using the wine glass shaped antenna. In addition, the results for the return loss for various concentrations of the solutes validate that as the concentration increases, the return loss decreases in all the three cases. The results also indicate that the return loss is the function of the temperature. As temperature changes from normal to high and again to normal, it affects the values of return loss and corresponding frequency.

The results for salt/sugar water solution demonstrate that the percentage of salt/sugar concentration is inversely proportional to the reflection coefficient. This is the consequence of decrement in the dielectric constant and a reduction in the number of water molecules in the solution. From this observation, it can be concluded that the sensor is of favorable sensitivity for the detection of sugar and salt contents in water. The sensor can also efficiently detect variations in reflection properties due to changes in the temperature of solutions such as soft drinks and beverages.

This low-cost, real-time sensor system can be used in various applications such as food and beverage industries for quality checks. It can also suffix the maintenance of salt and sugar percentages in food items within safe limits so that human beings who consume these products can be protected from various diseases such as blood pressure, diabetics, kidney failure, and botulism.

PEER REVIEW INFORMATION
Engineering Reports thanks Md. Naimur Rahman and other anonymous reviewers for their contribution to the peer review of this work.

PEER REVIEW
The peer review history for this article is available at https://publons.com/publon/10.1002/eng2.12336.

DATA AVAILABILITY STATEMENT
Data sharing is not applicable to this article.

CONFLICT OF INTEREST
The authors declare no potential conflict of interest.

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**How to cite this article:** Mahajan RC, Vyas V. Wideband microstrip antenna for the detection of solutes in water. *Engineering Reports*. 2021;3:e12336. [https://doi.org/10.1002/eng2.12336](https://doi.org/10.1002/eng2.12336)