Moisture Sensor Using Microstrip Patch Antenna

Vibha Patel, Trushita Chaware, Pooja Gundewar, Anjali Askhedkar, Dipalee Pawar, Anurag Nagdeve, and Pranjali Gaikwad

Abstract Analyzing the moisture level of the material is one of the crucial parameters in industries such as the production of sugar, cereal grains, food packaging, etc. Investigation of moisture content in any material is important as it will affect its quality. Moisture measurement is carried out in this work, taking sugar as an example. For this, a rectangular patch antenna is designed at 2.4 GHz frequency. The main reason behind the popularity of Microstrip patch antennas in wireless applications is their low profile structure. Backscatter characteristics of the microstrip antenna are sensitive to medium and therefore they are used to measure moisture content. The percentage of moisture in Sugar and Calcium Chloride is measured for different concentrations. Simulation of the antenna is done using HFSS and return loss is measured using Vector Network Analyzer to analyze moisture contents. Very promising results are obtained for moisture measurement using a microstrip patch antenna.

Keywords Microstrip patch antenna · Moisture sensor · Reflection coefficient · Vector network analyzer

1 Introduction

In many fields like hydrology, geotechnical engineering, the food industry, soil science, and agriculture, estimation of water content is necessary. It is utilized to evaluate the material quality with operating and processing constraints. In real-time, for different materials, sensors operating at microwave frequencies provide effective, non-destructive, and uninterrupted moisture content measurements. The permittivity of a material is mainly affected by the presence of moisture. The main principle of a microwave moisture sensor is to measure the dielectric constant in a material such as

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edibles, soil, and building structures, chemical. As per the studies of measurements of dielectric properties, it has been shown that dielectric loss caused by the water changes the reflection coefficient (S_{11}) parameters [1]. The contact between material under test and the free space of patch antenna was the need in the traditional techniques. Monitoring the moisture in the sugar brix or solution or soil is tedious using these methods in far-field applications.

2 Literature Survey

Small antenna size, but at the same time reduction in the frequency is needed for today's communication. Small antenna size is also required in many applications based on IoT. Microstrip moisture sensor in the range of 1–3 GHz is developed with low insertion loss. The magnitude and phase of transmission coefficient will vary with the change in the moisture percentage. This has been investigated and analyzed in this work [1].

Parallel-plate electrodes, transmission line phase detection, and Time-Domain reflectometry (TDR) are some methods for dielectric measurement. In [2, 3], patch antennas have been designed where the material under test is in contact with probing electrodes in the near field region. Hence, these conventional methods may not be applied to far-field wireless applications. Microstrip antenna can work in the far-field, without the need for a battery. This microstrip antenna is excited by electromagnetic waves generated by the transmitter and the power is supplied to a sensor through the transmitter.

The product quality, processing conditions, and optimum handling are based on its water and moisture content [4]. The permittivity of some composite materials like building structures, soil, foodstuffs, etc. is mainly administered by the presence of water. The dielectric constant of these materials can be measured by a microwave-based moisture sensor. The results presented in [5] show that the paper material can serve the purpose of economical multilayer structures for telecommunication and sensing applications. So, here, we propose a rectangular patch antenna for wireless moisture measurements. This sensor is based on the backscatter characteristics of a rectangular patch antenna. It is designed for 2.4 GHz frequency.

A rectangular patch antenna having an operating frequency of 900 MHz is fabricated for moisture measurements in [6]. The backscatter characteristics are analyzed to measure moisture content and it is a contactless-type of the sensor. The content of moisture in the material under test is increased progressively and return loss is monitored. And it has been observed that the return loss reduces with a rise in moisture content for various materials. In [7] moisture content of lubricating oil is monitored using a microstrip patch antenna. Results of this work show, this sensor monitors the moisture contents of the lubricating oil. This method is based on the evaluation of the parameter S_{11}. Compared to existing techniques, it is easy as it does not contain transmitting and reflecting devices.

A compact frequency reconfigurable microstrip patch antenna with good return loss is discussed as a moisture sensor [8]. The length and width of ground and patch for a slotted rectangular patch antenna for soil moisture measurement in the frequency range of is 30 and 25 mm. This is used for the 2–5 GHz frequency range. Soil moisture, in rhizoboxes, is measured [9] and quantitative results are discussed. Results show that moisture measurement using microstrip patch antennas is non-invasive, reliable, and accurate. It has promising applications for moisture measurement.

In [10], a compact patch sensor is designed with a size of size 20 mm × 20 mm × 1.676 mm. This work focuses on the reduction of mean relative error (MRE) between the predicted moisture content (PMC) and actual moisture content (AMC).

3 Working Principle of Patch Antenna for Sensor Applications

The inherent presence of fringing fields between patch and substrate causes electromagnetic radiations. The performance of the patch antenna is determined by patch size, Patch shape, and permittivity of the substrate. The patch size also determines the resonance frequency of the antenna.

Salt and sugar solutions are made for different concentrations. Sensor i.e. patch antenna is used for measuring the reflection coefficient, which will vary as per the concentration. As the salt and the sugar contents increase in the solution, the dielectric constant decreases.

In [2], when salt is added to the water, the dielectric properties change. Because of this dielectric constant decreases and the polarization of water reduces. similarly, when sugar is added, bond formation occurs between molecules of sugar and water. This also causes a reduction in the polarization of water molecules and decreases the dielectric constant.

The dielectric constant and loss factor is directly proportional to the moisture content under certain conditions depending on temperature. Due to the high dielectric constant of water, change in moisture content results in shortening of wavelength. The presence and absence of moisture can be detected by the received power level from the microstrip patch antenna. The measurement of moisture was taken with the help of Vector Network Analyser to the patch antenna sensor through coaxial cable. As the dielectric constant reduces, the effective dielectric constant also reduces. Therefore, the load impedance decreases, and subsequently, decrement is observed in the reflection coefficient also.

4 Patch Antenna Design

A conducting patch mounted on the ground plane constitutes a microstrip antenna. The ground plane and conducting patch are separated by a dielectric substrate. To get maximum radiation, a lower dielectric constant is preferred. The standard rectangular patch antenna shown in Fig. 1 is considered, which is fed by a microstrip transmission line. The high conductivity metal i.e. copper is used to making the ground plane, microstrip transmission line, and patch antenna. The patch of length L_{rp} and width W_{rp} is designed. It is designed on the top of a substrate of thickness h_{rp}. The substrate is of dielectric constant ϵ_r. The thickness of the ground plane is not critically important but antenna efficiency is depending on thickness h. Typically, thickness or height h_{rp} should not be smaller than 0.025ƛ.

Based on length L_{rp}, the frequency of operation of the patch antenna of Fig. 1 is determined. The center frequency will be approximately given by:

$$f_c \approx \frac{c}{2L_{rp}\sqrt{\varepsilon_r}} = \frac{c}{2L_{rp}\sqrt{\varepsilon_r \varepsilon_0 \mu_0}} \tag{1}$$

The input impedance of the patch antenna is controlled by the width W_{rp}. Increased widths also result in larger bandwidths.

The behavior of the patch is approximately determined by a resonant cavity that is defined as a closed metal structure confining electromagnetic fields. At various resonant frequencies, certain modes exist in a cavity. Therefore, to get maximum radiation, the antenna should be excited at a resonant frequency. When an antenna

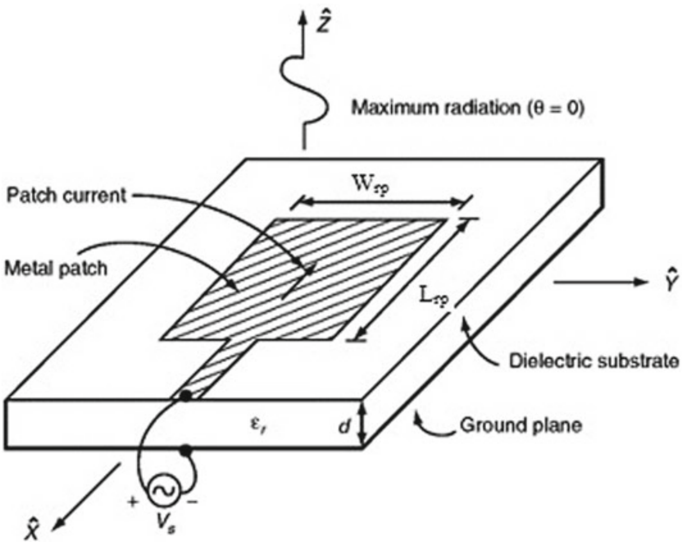

Fig. 1 The geometry of rectangular patch antenna [11]

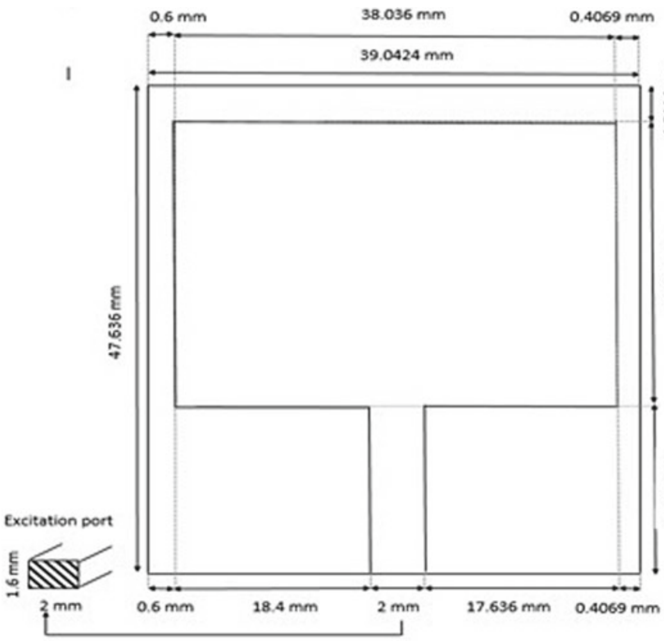

Fig. 2 Design of rectangular patch Antenna with dimensions

is excited at a resonant frequency, a strong EM field is created inside the cavity that results in a high current on the patch surface. So, maximum radiation is produced from an antenna.

Here, a microstrip antenna of the rectangular patch is designed. It is fabricated on silicon rubber as a flexible substrate. This patch antenna is designed to resonate at the desired 2.4 GHz frequency and its dimensions were calculated using standard design equations at the desired operating frequency of 2.4 GHz. These dimensions maximize the gain pattern, as the antenna resonates. Figure 2 illustrates the designed rectangular patch antenna geometry.

Antenna substrate's characteristics i.e. dielectric constant, height, and loss tangent are not constant. Therefore, substrate material should be chosen such that it can maximize radiation. This will increase bandwidth and efficiency. The FR4 Epoxy is used as a dielectric substrate in our Design. In FR4, FR stands for Flame Retardant, and type 4 shows Woven Glass-reinforced Epoxy resin. The glass resin determines the range of the dielectric constant of FR4 Epoxy. This material is less expensive and commonly used as compared to other PCB materials.

The width (W_{rp}) of the microstrip antenna is given by

$$W_{rp} = \frac{C}{2f_o}\sqrt{\frac{2}{\varepsilon_r + 1}} \tag{2}$$

where

c is the light velocity in free space
ε_r is dielectric constant
f_o is the resonant frequency.

The effective dielectric constant of substrate is calculated using Eq. (3)

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + 12\frac{h_{rp}}{W_{rp}}\right)^{-1/2} \tag{3}$$

where h_{rp} is the height of the antenna substrate.

The length of the patch antenna is a critical parameter as it determines the resonance frequency. The actual length and the calculated length are not the same because of fringing fields and the finite height of the substrate. And The actual length of the patch is determined using Eq. (4)

$$L_{rp} = L_{eff} - 2\Delta L \tag{4}$$

where L_{eff} is given by Eq. (5)

$$L_{eff} = \frac{c}{2f_o\sqrt{\varepsilon_{reff}}} \tag{5}$$

ΔL, that is an increment in length can be computed using Eq. (6)

$$\Delta L = 0.412h_{rp}(\varepsilon_{reff} + 0.3)(W_{rp}h_{rp} + 0.264)/(\varepsilon_{reff} - 0.258)(W_{rp}h_{rp} + 0.8) \tag{6}$$

The rectangular patch antenna design parameters are shown in Table 1.

Table 1 Rectangular patch antenna design parameters

Parameters	Value
Substrate's dielectric constant	4.4
Resonance frequency (f_o)	2.4 GHz
Dielectric substrate height (h_{rp})	1.6 mm
Length of patch (L_{rp})	38.036 mm
Width of patch (W_{rp})	29.442 mm
Length of ground plane (L_g)	39.042 mm
Width of ground plane (W_g)	47.636 mm
Length of feed line	15.460 mm

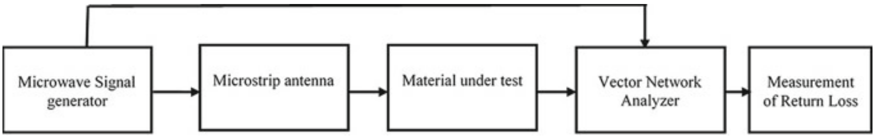

Fig. 3 Block diagram of system

5 Implementation of the System

5.1 Use of Simulation Software

To design a microstrip patch antenna operating at a frequency 2.4 GHz, we used HFSS (High-Frequency Structure Simulator) version 13.0, among various simulation software available like FEKO, IE3D, CST, etc. Being user-friendly, it is popular and also provides good accuracy for complex designs. The frequency range is between 1 and 4 GHz.

5.2 Experimental Set-Up

The block diagram of the system is shown in Fig. 3. The rectangular patch antenna and signal generator of Vector Network Analyzer (VNA), operating at microwave frequencies are connected. The patch antenna is placed at some distance from the Material Under Test (MUT).

At first, Antenna starts radiating at 2.4 GHz. These radiations pass through MUT. The vector network analyzer (VNA) measures the return loss of the reflected signal. Initially, a dry sample with no moisture is kept in the container. Gradually, the moisture content is increased by adding water, and return loss is observed.

Figure 4 shows the experimental setup for the same. The rectangular patch antenna is kept under the container with the material under test (MUT). The electromagnetic signal is passed through the material and return loss is measured on the VNA.

5.3 Steps Involved in the Process

1. Antenna starts radiating at frequency 2.4 GHz.
2. These radiations pass through the material under test.
3. Reflection coefficient S_{11} is obtained through Vector Network Analyzer.

Fig. 4 Experimental set up for moisture measurements

6 Complexities Involved

The proposed work is divided into four main stages i.e. Simulation, fabrication, measurement of conductivity, and antenna parameters. The electrical conductivity of the designed rectangular patch is measured by the four-probe technique. The first stage output depends on the measured value of electrical conductivity of a printed patch antenna. The measurement of antenna parameters such as gain, far-field radiation patterns, resonant frequency, and reflection coefficient S_{11} is the fourth stage.

The trial and error method is used to determine the location of the feeding point. For locating the optimum feed point, a distance of 30% is selected from the edge and is moved in a small step so that S_{11} is minimum.

A vector network analyzer (VNA) is used to measure S_{11}. The antenna and VNA are connected using a coaxial cable of 50 Ω. And To avoid near field interference, the experimental setup is kept on a foam box. The test is performed within the 2–3 GHz frequency range.

7 Results and Discussions

Figure 5 depicts return loss for the designed patch antenna that is observed through VNA. The dip in return loss can be observed at 2.4 GHz frequency. This shows that the antenna resonates at 2.4 GHz. Return loss is measured for different water concentrations in sugar and calcium chloride. In Table 2, observations of return loss for sugar concentrations are given. Figure 6 shows a plot of return loss for different water levels in sugar-based solutions. It can be observed that when the

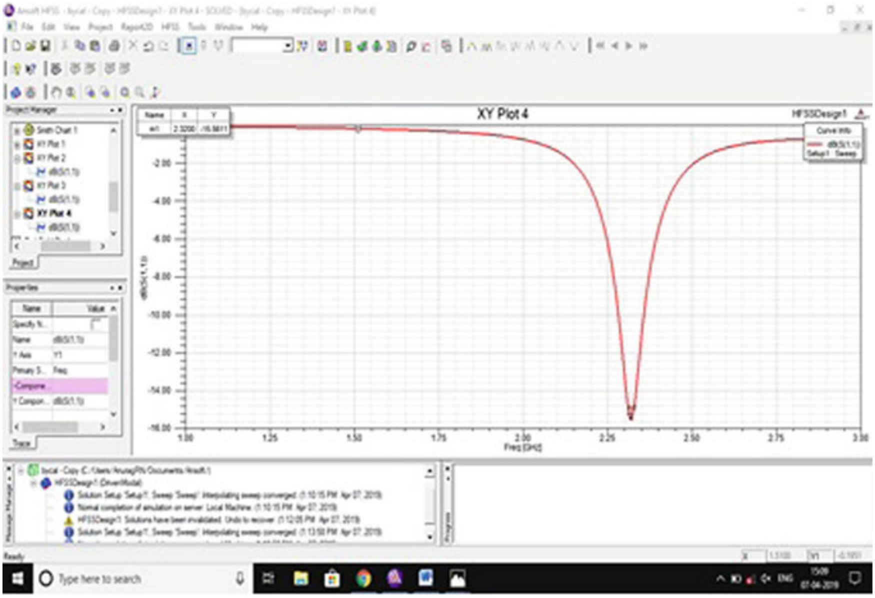

Fig. 5 The return loss of designed patch antenna

Table 2 Measured return loss for sugar solution

Water (in ml)	Moisture (in %)	Return loss (in dB)
0	0	−29.74
50	16.66	−19.92
75	25	−15.04
100	33.33	−12.95
125	41.66	−13.92
150	50	−13.78

water level increases, return loss also decreases [12]. Return loss is also measured for calcium chloride solution and obtained observations are listed in Table 3. A plot of return loss is shown in Fig.7. It can be seen as the water level increases, return loss is increasing at first and then decreasing. Figure 8 shows a plot of return loss for various samples. Here, observations for return loss of various samples i.e. Borax, Potassium Chloride, Lactose, and Sodium carbonate are considered [6]. It can be seen from Fig. 8, for sugar, return loss is increasing and for other samples, it is decreasing. The observations of return loss in percentage for sugar, Sodium carbonate, Borax, Potassium chloride and Lactose are listed in Table 4.

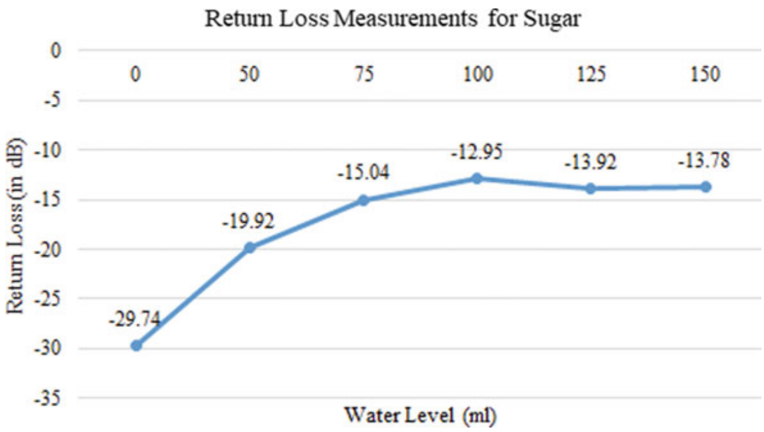

Fig. 6 Graph moisture versus return loss (sugar)

Table 3 Measured return loss for $CaCl_2$ solution

Water (in ml)	Moisture (in %)	Return loss (in dB)
25	10	−13.65
50	20	−11.65
75	30	−19.98
100	40	−20.66
125	50	−22.85
150	60	−18.55

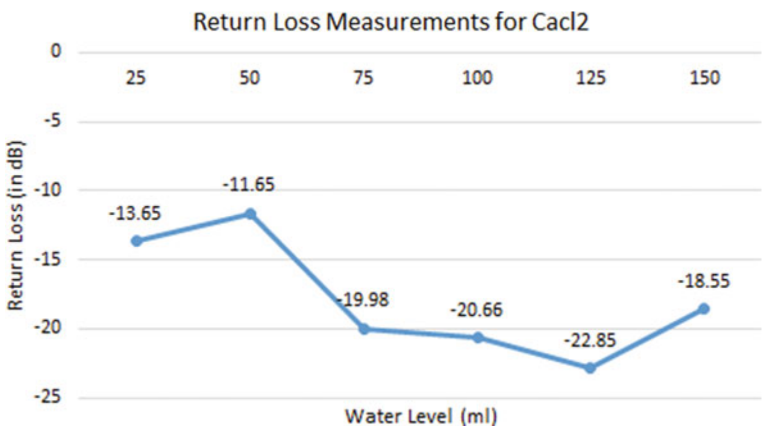

Fig. 7 Graph moisture versus return loss ($CaCl_2$)

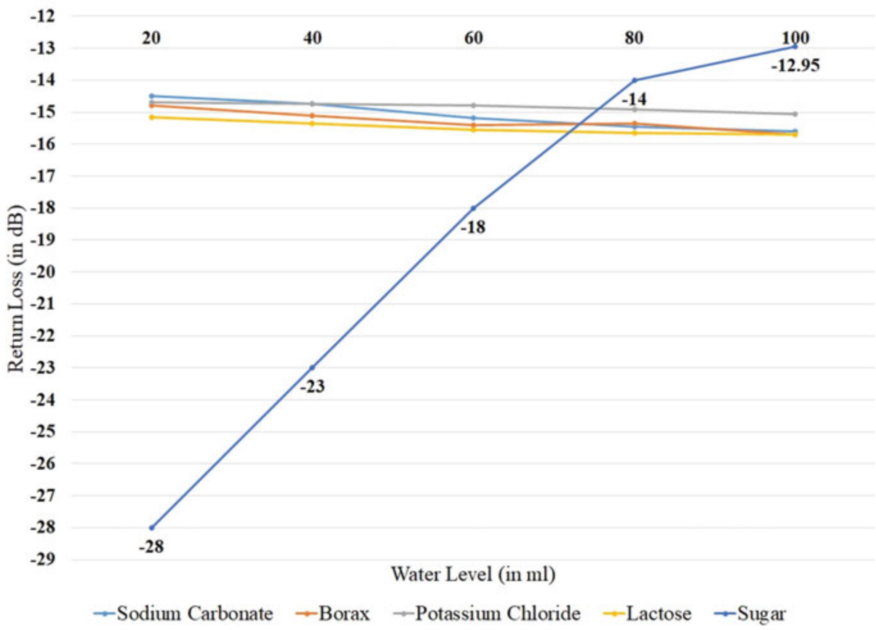

Fig. 8 Return loss comparison for different samples

Table 4 Measured return loss for various samples

Sugar	Water (ml)	20	40	60	80	100
	Return loss (in dB)	−28	−23	−18	−14	−12.95
Sodium carbonate [6]	Water (ml)	20	40	60	80	100
	Return loss (in dB)	−14.5	−14.75	−15.18	−15.46	−15.6
Borax [6]	Water (ml)	20	40	60	80	100
	Return loss (in dB)	−14.8	−15.1	−15.4	−15.35	−15.7
Potassium chloride [6]	Water (ml)	20	40	60	80	100
	Return loss (in dB)	−14.7	−14.75	−14.8	−14.9	−15.05
Lactose [6]	Water (ml)	20	40	60	80	100
	Return loss (in dB)	−15.15	−15.35	−15.55	−15.65	−15.70

8 Conclusion

A low-profile rectangular patch antenna is designed for the measurement of the moisture content of a material. Mounted on an inexpensive FR4 substrate, the antenna has a size of 39 mm by 47.6 mm. The antenna achieves a maximum gain with high efficiency. The proposed design of the microstrip patch antenna is suitable for sensor applications and wireless communication as it has robust radiation patterns. Sugar solution and calcium chloride are considered for testing, and their reflection coefficients are measured. Reflection coefficient changes as per the change in the moisture contents. This microstrip sensor has a favorable sensitivity to detect moisture in a solution.

References

1. Ghretli MM, Khalid K, Grozescu IV, Sahri MH, Abbas Z (2018) Detection of salt and sugar contents in water on the basis of dielectric properties using microstrip antenna-based sensor. IEEE Access 6:4118–4126
2. Gadani DH, Rana VA, Bhatnagar SP, Prajapati AN, Vyas AD (2012) Effect of salinity on the dielectric properties of water. Indian J Pure Appl Phys 50:405–410
3. Jain S, Mishra PK, Thakare VV. A rectangular microstrip moisture sensor based on microwave measurement technique
4. Balanis CA (1971) Antenna theory: analysis and design. Wiley, New York, pp 764–767
5. Yang L, Tentzeris MM (2007) Design and characterization of novel paper-based inkjet-printed RFID and microwave structures for telecommunication and sensing applications. In: Proceedings of the IEEE MTT-S international microwave symposium (IMS'07), pp 1633–1636, June 2007
6. Gundewar PP, Patel VU, Chaware TS, Askhedkar AR, Raje RS, Subhedar MM, Udgire VN (2019)Design of a microstrip patch antenna as a moisture sensor. In: 2019 IEEE Pune section international conference (PuneCon), Pune, India, pp 1–5
7. Zhu L, Li W, Han X, Peng Y (2020) Microfluidic flexible substrate integrated microstrip antenna sensor for sensing of moisture content in lubricating oil. Int J Antennas Propag 2020:9 p, Article ID 9675847
8. Sweety J, Mishra PK, Thakare VV (2016) Design and analysis of microstrip moisture sensor for the determination of moisture content in soil. Indian J Sci Technol [S.l.], Nov 2016
9. de Paula Herrmann PS, Sydoruk V, Marques Porto FN (2020) Microwave transmittance technique using microstrip patch antennas, as a non-invasive tool to determine soil moisture in rhizoboxes. Sensors 20:1166
10. Jain S, Mishra PK, Thakare VV, Mishra J (2019) Design of microstrip moisture sensor for determination of moisture content in rice with improved mean relative error. Microw Opt Technol Lett 2019:1–5
11. (2005) Antenna elements and arrays. In: The electrical engineering handbook, pp 569–583
12. Njokweni SN, Kumar P (2020) Salt and sugar detection system using a compact microstrip patch antenna. Int J Smart Sens Intell Syst 13(1)