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Metamaterial-Based Microstrip Soil Moisture Sensors

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Abstract

In this paper a study of new low cost metamaterial-based soil moistures sensor is proposed. The designed sensors are based on resonant-type metamaterials. This metamaterial sensor consists of two asymmetric circular split ring resonators (aCSRRs) which exhibit high sensitivity quality factor and a thin microstrip line with 50 ohm characteristic impedance. The low cost FR4 dielectric board with relative permittivity 4.30 is used as substrate. The resonance frequencies of proposed sensor versus the soil moisture and its permittivity have been studied. The simulation results have been observed that higher effective permittivity is found when increase soil moister, this result will has an effect on a decreasing of the resonance frequency of the sensor. The sensors which using metamaterials may hope to fuel the revolution of sensing technology.

Keywords: Metamaterials; moisture sensor; microstrip line

1. Introduction

The soil moisture content is one of the important factors that used to determine the optimal plant growth. It is well known that different kind of plants need difference soil moisture level, some kind of plants die due to low soil moisture. Hence it is important that to know the actually value of soil moisture. Several methods to determine the soil moisture are proposed; the gravimetric method (GM) which soil moisture depends on the weight of original sample and oven dried sample, the neutron moderation (NM) which calculate the amount collision between fast neutrons and Hydrogen atoms present in moisture and time domain reflection method (TDR) which soil moisture depends on the propagation time required by electromagnetic wave to transmit and reflect back from sensor transmission waveguide. The main drawback of these techniques are the required of relatively expensive equipment with high power consumption. It is well known that electrical characteristics of the soil are strongly depended on its moisture, therefore the dielectric method to obtain soil moisture content by observing response at different frequencies is proposed. The different of sprit-ring resonator (SRR) structures have been used for soil moisture sensor application [1]. In this work the operating of sensor is based on the principle of the resonant frequency shift. However, the limitation of this work is occurred due to a small magnitude of the resonant frequency shift.

Metamaterials are artificial materials which have the electromagnetic properties that may not be found in nature. The unusual properties of a metamaterial have led to the development of metamaterial antennas [2], cloaking [3], filter [4] as well as metamaterial sensors [5 – 7].

Metamaterial sensor provides many advantages over traditional sensor such as it can exhibit high sensor's selectivity and sensibility [7] that due to a high quality factor (Q-factor is the frequency to bandwidth of resonator ratio) when compared to the conventional resonators. A split-ring resonator (SRR) is one of the metamaterial particles that exhibit negative permeability [8] which is most commonly used in sensor applications [1, 5, 7]. The way to archive high Q-factor by using asymmetric SRR is presented; it has been found that asymmetric SRR can offer very high Q-factor when compared to symmetric SRR structure [9, 10] which means it is suitable to use in sensor applications.

The aim of this paper is to design a low cost and high sensitivity moisture sensor based on metamaterial operating in microwave regimes. The proposed sensor consists of a combination of microstrip line and two asymmetric circular split ring resonators (aCSRRs). The sensor work based on changing the soil moisture, the dielectric properties of soil will change and this will affect effective dielectric constant of the sensor and then the resonant frequency will be shifted.

2. Materials and methods

The proposed metamaterial sensor for soil moisture detector is shown in Fig. 1. This metamaterial sensor consists of two asymmetric circular split ring resonators (aCSRRs) which exhibit high sensitivity quality factor and a thin microstrip line with 50 ohm characteristic impedance. The low cost FR4 dielectric board with relative permittivity 4.30 is used as substrate as presented in Fig. 1(a). The schematic diagram of an asymmetric single CRSS is shown in Fig. 1(a). It consists of metallic pattern on dielectric substrate with bearing gap. A low cost double copper-clad thickness 0.8 mm FR4 board is used as the substrate with length of $l = 14$ mm. The dielectric constant of the substrate board ε_r is 4.30 with dielectric loss tangent 0.025. The dimensions of aCSRRs are: a width of w = 1 mm, radius r = 12 mm and a gap of g = 0.80 mm. In order to have 50 ohm characteristic impedance, the microstrip line is designed with a width of 1.5215 mm.

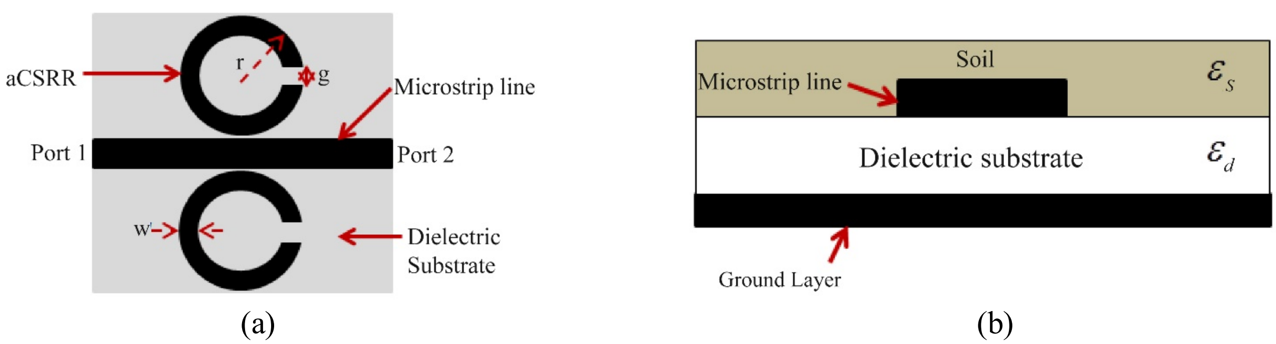

Fig. 1 (a) Layout of the metamaterials sensor based on microstrip line with two aCSRRs and (b) simulation setup for soil moisture microstrip sensors.

3. Results and Discussion

In this work, the geometry of sensor, dielectric substrate thickness (h) and dielectric constant (ε_d) are fixed. Therefore the resonance frequency of the sensor is strongly influenced by the effective dielectric constant (ε_{eff}) which is given by equation (1). Due to the soil moisture strongly influences to the soil permittivity and therefore it's effective permittivity, so it can easily be obtained the resonance frequency of the sensor.

$$\varepsilon_{eff} = \frac{\varepsilon_d + \varepsilon_s}{2} + \left(\frac{\varepsilon_d - \varepsilon_s}{2}\right)\left(\frac{1}{\sqrt{1+12\frac{h}{w}}}\right) \quad (1)$$

where ε_s is the unknown permittivity of the soil sample, w is the width of microstrip line.

The operation of this sensor is based on the frequency shift. The performance of designed sensor is determined for soil moisture varying from 2 to 20%, the variation of soil moisture versus the change of dielectric constant of the soil sample is shown in Fig 2. It has been seen that as the soil moisture increase from 2 to 20% the soil dielectric constants also linearly increase from 2 to 20.

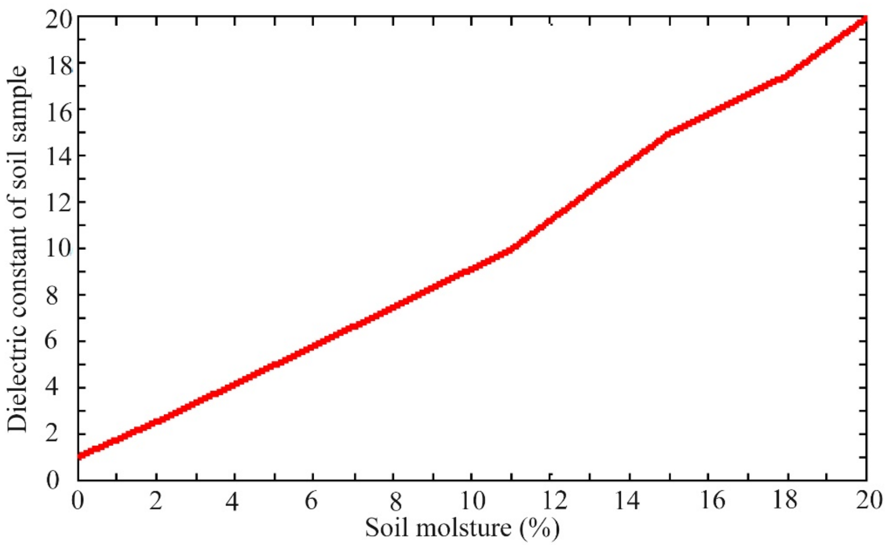

Fig. 2 Variation of the dielectric constant of soil sample versus the moisture

The resonance frequency of proposed sensor with different values of soil permittivity is presented in Fig. 3. An aCSRR sensor is used as stop band filter. It can be seen that when the value of soil permittivity is increased the resonance frequency of sensor is shift to lower frequency. The resonance frequency of the sensor is related to the total capacitance and inductance of the sensor $f_{res} = 1/2\pi\sqrt{L_T C_T}$. It is well known that the capacitance is proportional to the dielectric constant $C = \varepsilon(l/S)$, where S is area of a dielectric material, l is the thickness of a dielectric material, and ε is dielectric material's permittivity. When ε_s increase, higher capacitance is found, the capacitor also increase, which leads to a lower resonance frequency.

Furthermore, the summary of resonance frequency, bandwidth and sensitivity of an aCSRR sensor with varous of soil permitivity are shown in Table 1. These results show that by increasing soil moisture from 2.50 to 20 the resonance frequencies of sensor decrease from 3.42 GHz to 2.34 GHz. Furthermore, we observe that bandwidth increases when the soil permittivity is increased as summarized in 3rd column of Table 1. However, the sensitivity of sensor tends to decrease when the soil permittivity is increased as presented in 4th column of Table 1.

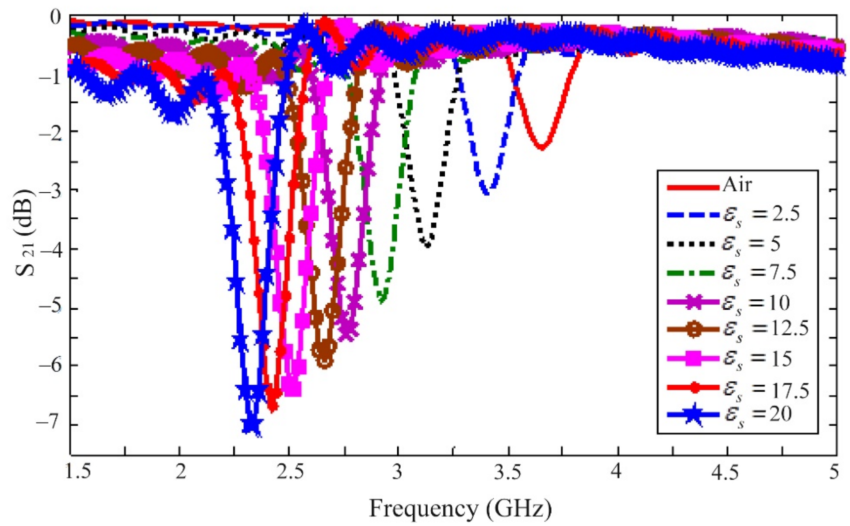

Fig. 3 Resonance frequency of the aCSRRs sensor with different soil permittivity

Table 1 Summary of resonance frequency, bandwidth and sensitivity of an aCSRRs sensor with varous of soil permitivity.

ε_s	**Resonance frequency (GHz)**	Δf **(MHz)**	**Sensitivity**
2.50	3.42	260	13.08
5	2.12	122	25.74
7.50	2.92	159	18.36
10	2.76	174	15.86
12.50	2.66	183	14.53
15	2.52	194	13
17.50	2.42	197	12.26
20	2.34	205	11.33

4. Conclusion

This paper introduced a new low cost and sensitivity soil moisture sensor using metamaterials resonator. We have studied the variation of the resonance frequency according to the soil permittivity which depends on its moisture. The resonance frequency of proposed sensor is shifted to lower frequency when soil moisture increases. Based on the promising of this sensor, we believe that the use of the designed sensor will efficiently be used in various sensing applications.

5. Acknowledgement

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