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Chiral metamaterial-based microwave sensors

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Abstract

A significant resonance shift is found in both reflection and transmission coefficients from both parallel and perpendicular excitations in a helical structure. The responses from the perpendicular excitation show better sensitivity than those from the parallel excitation at 480 MHz-560 MHz for 0.2 circumference difference. Additional electromagnetic properties of a helical structure, such as chirality, optical rotatory dispersion and circular dichroism can also further combine to enhance the sensing performance.

Keywords: Chiral, Metamaterials, Helical, Sensors, Microwave

1. Introduction

The microwave sensors presented in Figure 1 comprise of a microwave generator and detecting circuit located before and after the sample [1]. The interface circuits and computer are used to evaluate the sensing responses. By using electromagnetic waves to categorize the sensing responses, only the sensing element or sample is required to be placed at the observed location. Wires, tubes or electronic circuits will no longer need to be connected to the sensor element. This is one of the main advantages of electromagnetic wave sensors.

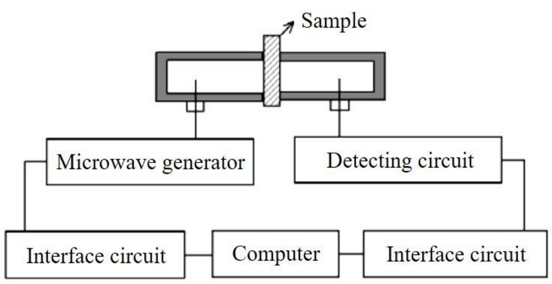

Figure 1 Schematic diagram of microwave sensors [1].

Metamaterials exhibit a strong localization and enhancement of fields, and can significantly enhance the sensitivity, selectivity and resolution of sensors, and open new degrees of freedom in sensing design aspect. Sensitivity and resolution in sensors can be greatly enhanced by metamaterials. Metamaterial structures, mainly spilt ring resonators or SRRs, have been introduced as the sensor element in biosensors instead of metal parts in surface plasmon resonance sensors to detect biomolecular binding or biomolecules [2-3], to name a few. The transduction mechanism of these metamaterial-based sensors is based on resonance frequency shift, which is normally found in any resonance structure. In this paper, helical structures, one of the well-known chiral metamaterials, are investigated in order to be implemented into the sensor element. The extra electromagnetic properties, e.g. chirality, optical rotatory dispersion, circular dichroism, etc., of chiral metamaterials can enhance the sensing performance.

2. Microwave sensors

Kraszewski [4] has introduced the eight generic types of microwave sensors illustrated in Figure 2 to monitor the properties of industrial materials. It is shown that the generator, detector and sample can be set up according to the required system and environment. In the present paper, we investigate the scattering parameters from the designed sensor element for both transmission and reflection types.

3. Numerical studies of sensor elements

The helical structures shown in Figure 3 are investigated for the transmission and reflection responses in the X-band regimes. Reflection (S_{11}) and transmission (S_{21}) coefficients of a one pitch 6.8 mm radius helix with different height "h", varying from 3.0 mm to 5.1 mm, are presented in Figure 4.

The resonances of both S_{11} and S_{21} shift when the height is varied froma high frequency (8.283 GHz for both S_{11} and S_{21}) at 3.0 mm height to a lower frequency (8.206 GHz for S_{11} and 8.227 GHz for S_{21}) at 5.1 mm height. The sensitivity is approximately 5-7 MHz for 0.3 mm height difference.

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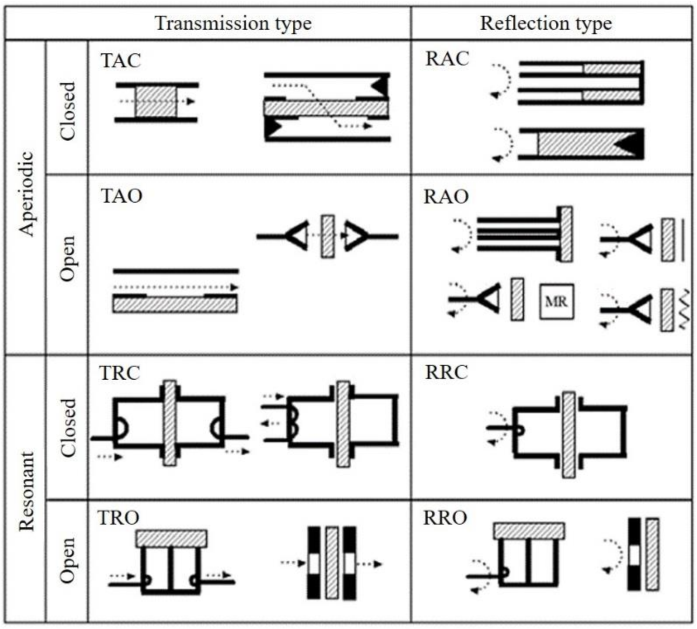
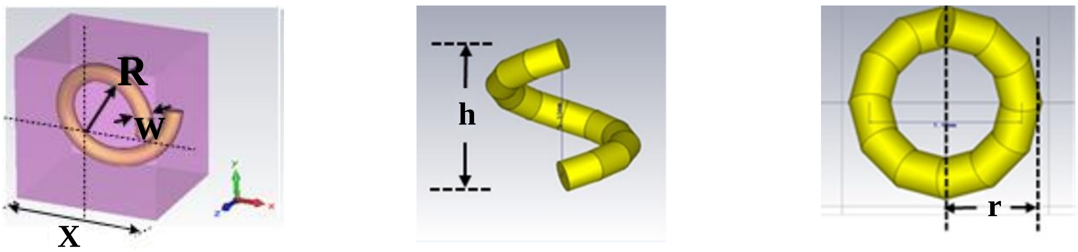
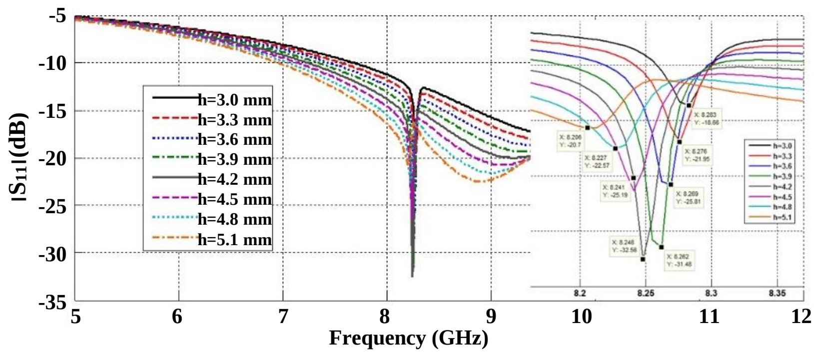


Figure 2 Classification of eight generic types of microwave sensors [4].

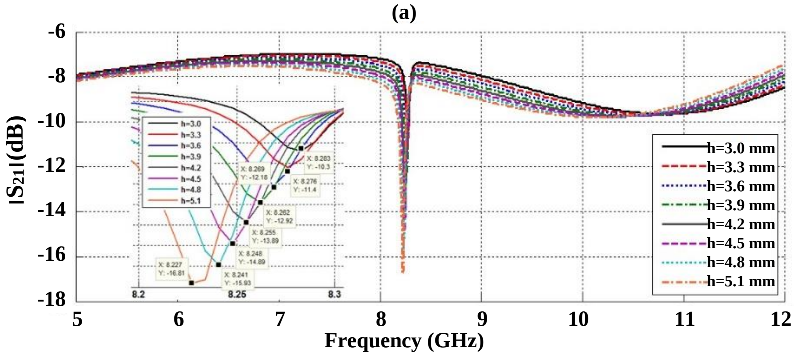


(a) (b) (c)

Figure 3 One pitch helical structure: (a) 3D, (b) side view with height “h” and (c) top view with radius “r”.



(a)



(b)

Figure 4 Reflection and transmission coefficients: (a) S_{11} and (b) $S_{21}$of one pitch helix with different height “h”, varying from 3.0 mm to 5.1 mm. The radius is fixed at 6.8 mm.

Figure 5 shows the S11 and S21 values of the one pitch 5.1 mm height helix with different radius "r", varying from 5.4 mm to 6.8 mm. The resonance shift is observed with the sensitivity of 250 MHz - 380 MHz and 250 MHz - 400 MHz for S11 and S21, respectively, at 0.2mm radius difference.

The broad frequency shift in S11 and S21 indicates good sensitivity in the helical structure due to the height and radius change. Next, a single helix made of a 5.0 mm gold wire is investigated. The helix circumference varies from 4.0 mm-5.0 mm; hence the helix height also varies. This setup mimics the real scenario when the helical structure captures a pipe-like sample, which can expand and shrink due to the pressure difference. Six different helices are shown in Figure 6. S11 and S21 of the six cases from parallel and perpendicular excitations are presented in Figure 7.

The resonance shift is found in both S11 and S21 from both excitations. Both S11 and S21 from the perpendicular excitation show better sensitivity than those from the parallel excitation at 480 MHz-560 MHz for a 0.2 circumference difference.

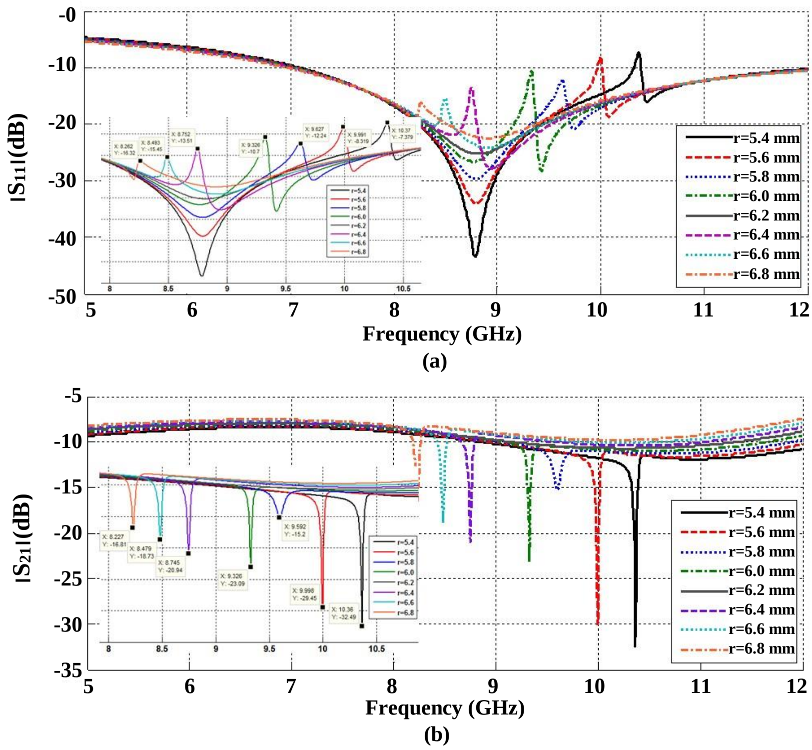


Figure 5 Reflection and transmission coefficients: (a) S_{11} and (b) S_{21} of one pitch helix with different radius "r", varying from 5.4 mm to 6.8 mm. The height is fixed at 5.1 mm.

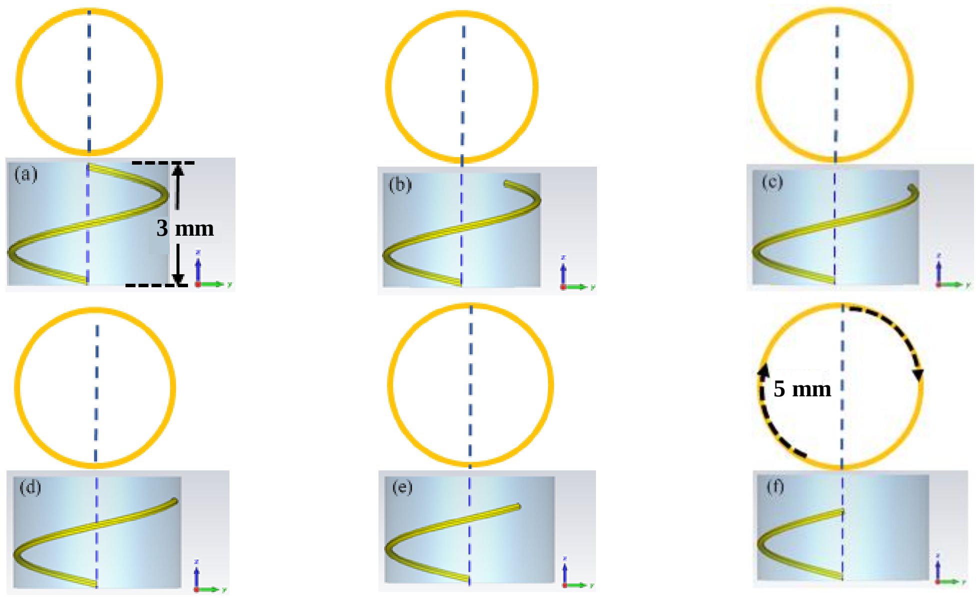


Figure 6 Single helix made of a 5.0 mm gold wire. Helix circumference varies from 4.0 mm - 5.0 mm: (a) 4.0 mm, (b) 4.2 mm, (c) 4.4 mm, (d) 4.6 mm, (e) 4.8 mm, and (f) 5.0 mm.

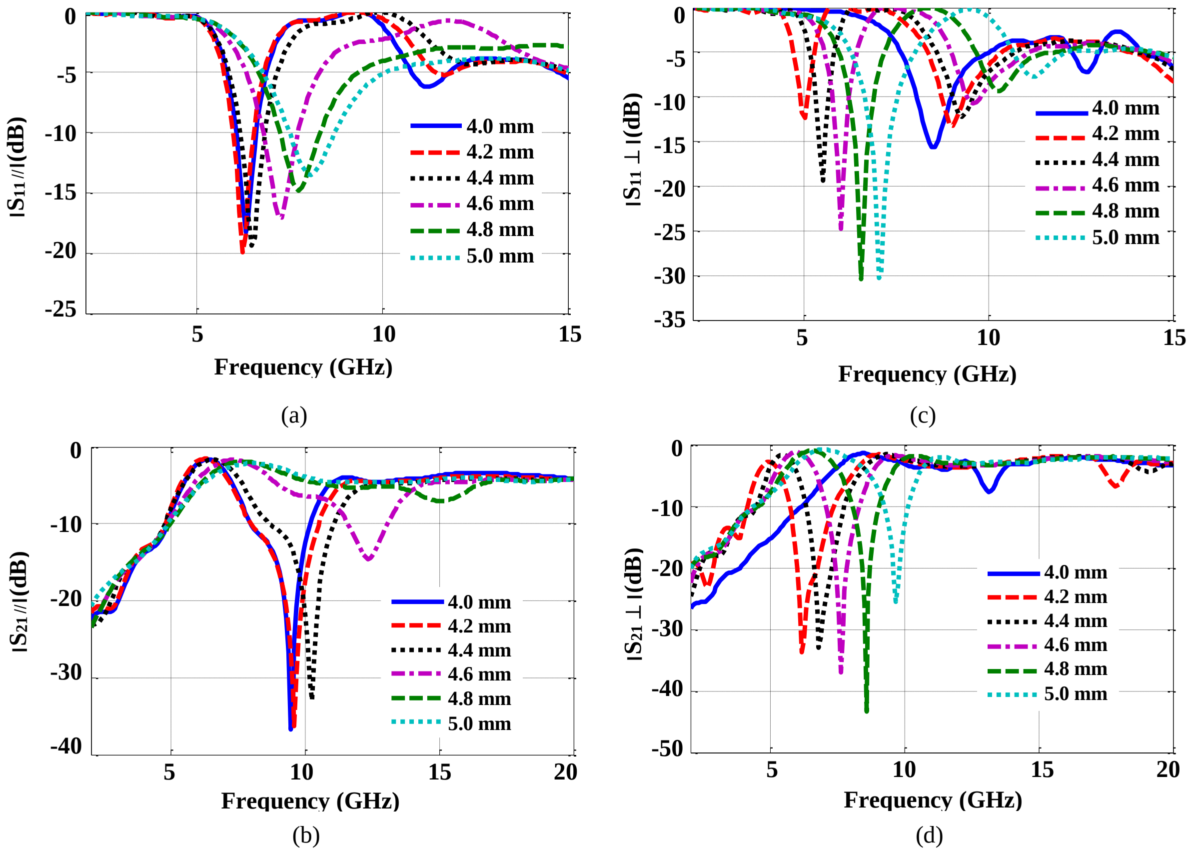


Figure 7 Scattering parameters: S_{11} of (a) parallel and (b) perpendicular excitation, and S_{21} of (c) parallel and (d) perpendicular excitation.

4. Conclusions

A helical structure is proposed as a sensor element in microwave sensors. Based on its dimensional changes, the helical structure is significantly sensitive to electromagnetic waves, as well as selective due to excitation direction. This proposed helical structure is an excellent sensor element to be employed in microwave sensors, which will benefit a multitude of sensor applications.

5. Acknowledgements

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