

High Sensitivity SSR Based Sensor Used for Permittivity Measurement

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Abstract

The proposed sensor is based on a Split Square Resonator (SRR), placed in the center of the transmission line above the SSR (most sensitive region) to improve the detection. The dimensions of the SRR have been chosen so that the resonance frequency of the filter will be close to 7.85 GHz in free space. The functional principle of the designed sensor is based on placing over the sensitive position the material under test (MUT). It is based on detecting changes in dielectric properties (permittivity) of MUT present in the near-field region of the sensor, along the changes of the resonance transmission frequency (S12), caused by perturbation of resonator's electric field through MUT. To validate this conjecture, three cubic MUTs were tested (PLA, FR4 and Rogers TMM10i). This proposed design exhibits a high sensitivity close to 56% as the relative permittivity of MUT's changes from 1 to 10.

1. Introduction

In recent years, robust, miniature, inexpensive, selective, and highly sensitive technologies used for agile sensing devices in various applications have placed high demands. Sensing technology based on microwave resonance is a recently developed technology, and many researchers have been studying it in the past ten years, including microwave sensors that are employed in material characterization, precision agriculture, biomolecule detection, and concentration research. Detecting material characteristics is based on acquire knowledge about its permittivity, since it is most crucial than the permeability to distinguish different dielectrics. The use of planar transmission lines with metamaterial for material characterization is one of the technologies that become used. This technique relies on the direct interaction between the material under test (MUT) and the evanescent field of the transmission line to achieve high measurement accuracy and excellent imaging capabilities.

The most popular methods for material characterization utilize dielectric measurement technology based on microwave resonators are measuring the change of magnitude/ frequency of reflection/transmission coefficient, phase, and quality factor (Q-factor). Many researchers have proposed planar metamaterials with different topologies for several application, among them, dielectric constant measurement [1-5]

In this paper, we introduce a simple shape consist of a split ring resonator (SSR) based on MTL (Microwave Transmission line) feeding, used as a sensor for dielectric material characterization.

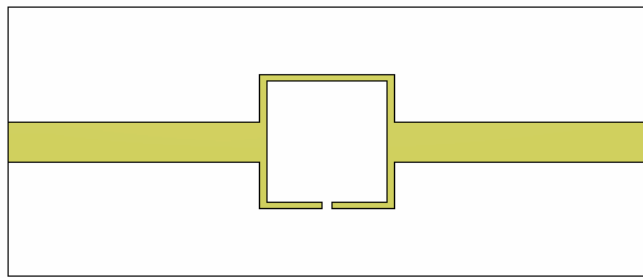
The concept is given in Fig.1. The simplicity of the sensor permits to measure the transmission coefficient, by placing a small cubic in direct contact to the sensitive region. The structure will be as follow: Section II describes the design and an analysis of sensitivity where we discussed, the effect of MUT size. Section III includes simulation results and discussion. Finally, a conclusion of the presented work in section IV.

2. Design and Simulations

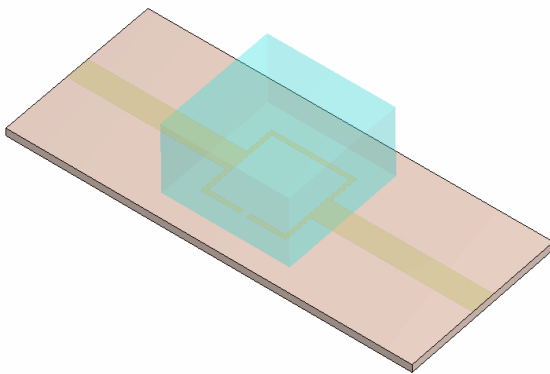
The designed device shown in Fig.2 is simulated on Rogers 5880 substrate with a dielectric constant of 2.2, TanD of 0.009 and a thickness of 0.787mm. The choice of such substrate allows to produce a relevant fringe electromagnetic field in the sensing area, in order that the characteristics of the MUT can be well detected, thereby improving the sensitivity. In this present paper, the design is based on a single split square resonator (SSR), placed in the center of a transmission line, designed to be suitable for a resonance at 7.76GHz, with a side length of 8 mm. The path of the SSR is $c=0.4\text{mm}$ and the SSR split length is $g=0.6\text{mm}$. The transmission line is designed with 16mm strip length both sides and $a=2.34\text{mm}$ strip width connected to a 50Ω coaxial SMA connector to ensure the impedance matching. The substrate length and width are both 40mm

(about half the length of the long edge of a credit card), with a copper layer of 35um.

Generally, a part of the guided EM waves propagating in the transmission line, will polarize the adjacent dielectric substrate, and a part of the loaded MUT. The polarized dielectric substrate could be presented by an equivalent capacitance. In case of using a CSRR etched in the ground plane, decreasing the polarized portion of the dielectric substrate (thickness) enhances the resonating electric field to interact with MUT, thus increasing the sensitivity. While in this work, using a SRR centered in the transmission line in direct contact with MUT, increasing the polarized substrate part, guarantee an effective propagation and radiation of the electric field with the MUT, hence, increases the dependence of the minimum transmission frequency, and ensure an efficient interaction of the electric field with the MUT, and increase the sensitivity.



(a)



(b)

Figure 1: (a) Top view of the sensor (b) Side view of the sensor.

The sensor's sensitivity will be determined by the percentage of change in the minimum transmission frequency. It is calculated for each study and determined by (1).

$$\Delta f^{t_{min}} \% = \left(\frac{f_{MUT0}^{t_{min}} - f_{free}^{t_{min}}}{f_{free}^{t_{min}}} \right) * 100 \quad (1)$$

where, $f_{MUT0}^{t_{min}}$ is the minimum transmission frequency with the presence of MUT, and $f_{free}^{t_{min}}$ is the free space minimum transmission frequency. Various simulations were done to choose the most sensitive sensor depending on substrate thickness. Seven cases were examined with different transmission line width to have a matching with the feeding network 50ohm impedance. All simulations were done with a variation of loaded MUT permittivity from 1 to 10 with a 1-step and Tan = 0.0012 is kept constant.

2.1. MUT size effect:

As mentioned in the previous section, the portion polarized by the EM waves changes the minimum transmission frequency by changing its size. Reducing the MUT polarized portion by the electric field will directly decrease the equivalent capacity value of MUT, therefore, affects and reduces the correlation with the minimum transmission frequency, thus decreases the sensitivity of the sensor.

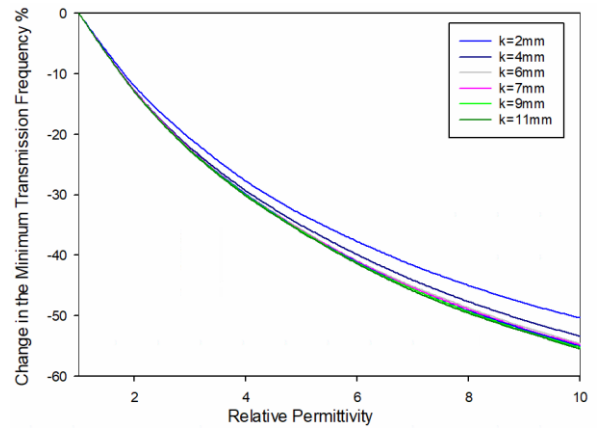


Figure 2: Change in the minimum transmission frequency versus MUT's relative permittivity with different thickness.

In this studied case, the MUT cover the SSR and a simulation of both width and thickness were done to define the accurate size that result saturation of the electric field. At a certain MUT size (thickness K), the MUT portion get polarized, and any added size will add up extra dielectric layers which will not be affected by the resonant electric field, and this is because of the achievement of saturation interaction among the resonator's field and the MUT.

The achieved results (Fig.2) proves that the sensor arrives to a specifics level of saturation, with an optimum value of K=7mm in thickness. However, same study has been done, and conclude with W=13mm.

any extra material above these values has no effect on the transmission frequency response, hence, the sensor's sensitivity will be unaffected by MUT size.

3. Simulation Results and discussion

The suggested sensor design is simulated using a commercial CST Microwave studio with the goal of examining the influence of MUT and gap size, demonstrating the reaction of different materials, and concluding with the function of permittivity versus change in minimum transmission frequency.

To perform the simulation with the setup shown in Fig.7, we are using PNA-L Network analyzer N5234B. PLA, FR-4, and ROTMM10i were used to create three cubic MUTs. These samples have been fabricated nominal relative permittivity's of 2.3, 4.3, and 9.8, respectively. Over the split ring resonator, the MUT is charged. The transmission frequency resonances produced by various samples are shown in Fig.4. Understanding the Cavity Perturbation Theory, MUTs with a bigger relative permittivity result in a lower transmission frequency. The first simulation was done at 7.85 GHz, which is the open space transmission frequency. The three other transmission frequency corresponding to PLA, FR-4, and RO TMM10i are 6.78 GHz, 5.59 GHz, and 3.86 GHz, respectively, for The MUT the results reveal a remarkable performance of the sensing method used in this paper.

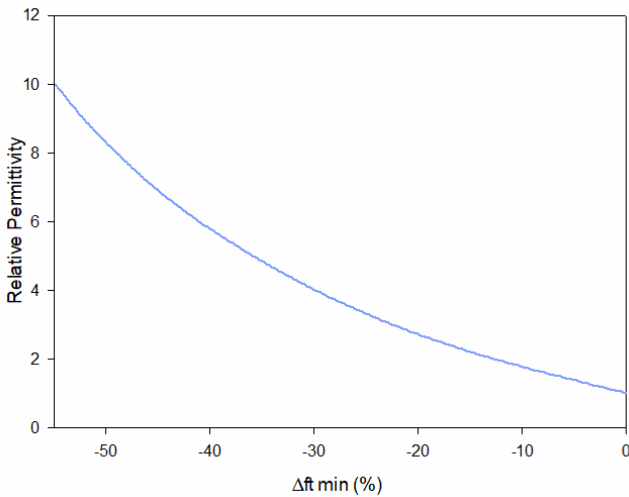


Figure 3: results obtained by model (2).

Relation 2 shows a link between the relative permittivity of the MUT and the change in the minimum transmission frequency for the sensor evaluated in the experiment. The simulations results presented in Fig.4 are extracted using a 0.757 mm substrate load with different MUT.

$$\epsilon_{MUT} = -4 \times 10^{-5} * (\Delta f_{min\%})^3 - 0.001 * (\Delta f_{min\%})^2 - 0.0742 * \Delta f_{min\%} + 1 \quad (2)$$

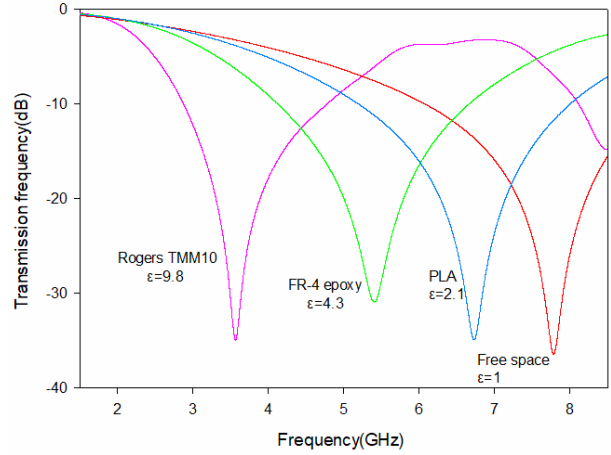


Figure 4: Comparison between numerical (solid lines) and experimental (dashed lines).

4. Conclusion

The design and testing of a sensitive sensor based on SSR, centered in a transmission line is reported in this paper. The sensor's major monitored characteristics is the change in the minimum transmission frequency of the microwave device. the design is configured to be suitable to small size of different MUT. It demonstrates a high sensitivity close to 56% while changing the MUT permittivity from 1 to 10. The use of such a sensor to detect glucose levels with large and high sensitivity might be the subject of future research.

5. References

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