Designed and Fabrication of Optimized Microstrip Resonator Sensor for Dielectric Constant Measurement

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ABSTRACT
A micro strip step resonator sensor for measurement of dielectric constant in a compact area of material under test is proposed. The resonant characteristics of resonator vary with dielectric constant of material. Limitations in the microwave frequency response performances of the proposed sensors have been carefully studied in a special GHZ range. It has been found that the proposed sensor has great potentials for practical applications in view of low cost and monolithic integration capability with a driving circuit. The structure of this sensor is based on changing the with changes of overall surface of micro strip resonator. As a result of this changes, the resonator resonance frequency is identified as . This micro strip sensor is designed, optimized and fabricated on Rogers 4003 substrate and the results shows the accuracy of the designed sensor.

INTRODUCTION

Purpose of the Study:

The main purpose of using micro strip sensors and applying improved stepped resonators for recognizing de-electric stability can be defined as below:

- Using new and improved sensor that works at resonance
- Insert the appropriate size of the coupling capacitors that transmitted effect to the outer surface.
- Use an appropriate algorithm to apply the sensor results to laboratory level.
- Testing different resonances and find a new form of higher sensitivity than other resonator that is associated with changes.
- Measure ingredients at different temperatures
- Measurement of for non-corrosive liquids at different temperatures
- Generalizing the above conditions for temperature measurement.
- Create an integrated structure for building software using a combination of the above into account and install the sensor substrate ports on its frequency.

Studies related to the subject:

In this section, review papers, theses, conferences are given. Also in each sector, according to research (design and construction of bridges optimized for the detection of sensor microstrip resonator using dielectric constant materials) and the issues or topics related to the analysis of microstrip sensors, effective dielectric constant and the dielectric constant of the stepped resonator for recognizing de-electric constant are dealt with. Examples of titles published articles in improving the performance and evaluation of microstrip sensors to detect the dielectric constant of the resonator using bridges as follows: A.K.Verma, Nasimuddin, A.S.Omar in [1], to determine the permeability coefficient of materials forms of sheet, using microstrip resonator sensors have liquid glue. Figure 1 shows a built sensor.

In this study microstrip resonator connected in multiple configurations can be used to determine the dielectric constant and loss tangent of the liquid paper and glue material. Several types of microstrip resonator circuit are presented to determine the dielectric constant and loss tangent of the liquid paper and glue material. A detailed structural analysis of the suspended cavity is also provided to determine the dielectric constant and the
tangent of the difference of oil, gasoline, wax and petrolatum has been tested successfully. The structure can determine the dielectric constant and loss tangent of the material between 2% with 0/001 change. Unlike metal cavity, the cavity loss depends on several factors that led to uncertainty in the measured loss tangent of the sample.

Fig. 1: the built sensor for recognizing de-electric constant (1).

The method for determining the relative permeability coefficient in generator with an average loss of rice from 002/0 to 1/0 is used to improve the model of the resonator coupling, better couplings adjust and improved calibration process and unlike the dielectric constant and loss tangent known values, it can further improve the accuracy of the sensor.

In Elisa Fratticcioli, Marco Dionigi and Roberto Sorrention dealt with a low-cost and simple measuring system for characterization of materials for permeability coefficient. In this paper, the microwave resonance sensors, and actuators are used to measure the permeability coefficient complex electrolyte material under test in a compact space. Compared with sensors to measure transmission or reflection of the choice of a two-port system, it reduces costs and improves the strength.

Measurement system needs to calculate two parameters, namely the resonant frequency, 3db bandwidth and gaining dramatically reduced cost and time of computation. The sensor can be selected as moisture content and low cost system that allows the delivery mode to use. In this paper a measuring system has been developed using two-dimensional resonant sensor. These sensors are good to measure the permeability coefficient of materials in compact spaces, of port 2. Measurement system will reduce costs and improve its strength.

Low cost of the sensor makes it available; the application calibration model leads to a simple method for calculating the permeability complex coefficient. The results of the experiments show that this sensor is useful for fixed detecting moisture in wet powder.

Abegaonkar and Aiyer in their research [3] have used the microstrip ring resonator as a humidity sensor for wheat grains. Method was so that the resonant frequency of microwave is measured as resonator quality factor ring with a simple seed coating on the ring. And variables are detected as constant impedance kernel weight moisture. Microstrip ring resonator quality factor and frequency shift measurements may be highly sensitive to moisture measurement independent of using seed weight.

In this study, the instantaneous measurement technique is developed with a very simple method of Loading and unloading. Figure 2 is the result of simulating the resonant frequency of the resonator moisture for seed weight.

Fig. 2: results of simulation of humidity present b changing resonance.

Frequency of resonator for grain weight 3 in 4 the penetration coefficient of grain seeds was used for receiving the quality by determining the humidity. in this article, a short review of measuring the humidity of the grain by receiving electric features is offered for the grain. in addition, main rules of radio frequency and de-electric feature of microwave with grain penetration coefficient are provided for receiving humidity through their relation with humidity constant. Developing penetration coefficient can be a function of density which can show the reliability of determining density of humidity constant and measuring on radio frequency is done on the grain and inn microwave frequencies. Developing this technique leads to providing proper facilities for
online control of humidity constant in seed for managing the humidity in grains and preventing the source loss and improving the processing and also creates important information for deciding precisely for farming. Figure 3 shows the simulation.

![Figure 3: the results of measuring grain humidity by receiving the electric features of the grain.](image)

Many researchers have used Microstrip resonator for determining the dielectric constant. Sarabandi and colleagues in 5, have used ring microstrip resonator for measuring dielectric parameters of soil. The present research ring microstrip resonator is used for reflection coefficient of soil.

In this technique, the ring microstrip resonator is related to the minimum soil and real parts of the soil constant. Furthermore, reverse algorithm is obtained based on regression analysis which shows the correct dynamic width in measuring dielectric constant.

![Figure 4:](image)

Figure 5 the microstrip ring for reflection coefficient of dielectric constant of soil (5).

Moreover, the percent of humidity in soil can be measured up to 40 percent by dielectric constant techniques. Dielectric can be determined from every resonance frequency and lead to dielectric constant according to the following equation: where n is the resonance number, C is the light speed, Fr is the frequency resonance and Leff is the effective wave length of the resonator(4).

Common microstrip resonators have same length in the wave length that is they have one wave length. Effective wave length of the resonator ring of a circle equals to $2\pi r$. Results of simulation for microstrip rings of reflection coefficient of dielectric constant of the soil can be seen in figure below.

In this system which uses one fourth of wave length measuring the dielectric constant can be done by selecting the sensor which had the best features for the user. In 6, sensitivity analysis and experimental studies are done by using the microstrip resonator technique for processing and measuring the penetration coefficient and humidity of the petrochemical materials and mix of water and row oil. Microstrip resonator technique is an immediate, correct and non-destructive technique which measures the penetration coefficient and humidity in the mix of row oil and water. In this technique the simple parameter of resonance frequency of the resonator is necessary for measuring the real penetration coefficient. This is an online measuring advantage. Furthermore, for measuring the humidity percent in row oil the frequency of the resonator is applied in a way that the real part of penetration of material is measured with analyzing the domain of light spectrum which is mixed on dielectric cover. This test shows the correctness and speed of measuring water humidity by using microstrip resonator. These tests are done by using the ring resonators on FR4 sub layer with 4.7 dielectric constant. Material is put on the microstrip probe. The results of the study are in line with the published data of numerical analysis which
can be used for measuring the water and oil constants. This technique just takes a few seconds for measuring the penetration coefficient and can be used as an online method of measurement.

**Fig. 5:** results of simulating the ring microstrip for reflection coefficient of dielectric constant of the soil (5)

Verma, Nassimudm and Grag used a resonator sensor attached to Microstrip for measuring the correctness of penetration of gasoline, oil, Vaseline and vex. They have shown that dielectric constant and tangent loss are obtained by measuring the resonance frequency and bandwidth of resonator (7). In this research the resonance frequency which is loaded by factor Q of two layers resonators of Microstrip and are measured by the Cavity model which is called MWM.

Frequency resonance theory is measured from the microstrip resonator attachment using MWM as below:

\[
\frac{1}{\omega} = \frac{1}{2}\pi \left[ \frac{n}{L_{ef}} + \left( \frac{m}{W_{ef}} \right)^2 \right]
\]

In which \( \varepsilon_{\text{design}} \) is the diversity of the model by numbers m and n and loss is maintained at all dielectric layers.
\( \nu \) is the speed of the electromagnetic wave in free space
\( L_{ef} \) is the effective length of erect attachment
\( W_{ef} \) is the width of erect attachment

In addition, the general factors of Q \( \{ Q_{\alpha} \} \), is calculated from the Cavity resonator microstrip:

\[
\frac{1}{Q_{\alpha}} = \frac{1}{Q_{r}} \cdot \frac{1}{Q_{w}} \cdot \frac{1}{Q_{c}} \cdot \frac{1}{Q_{d}}
\]

In which \( Q_{r} \), \( Q_{w} \), \( Q_{c} \), \( Q_{d} \) are Q factors.

Finally this article calculates the tangent loss of signal layer by transforming all the losses same as the signal layer.

\[
tan\delta_{\alpha} = \frac{1}{Q_{\alpha}}
\]

**Research Method:**

The present research has applied the microstrip sensor and stepped resonator to recognize the dielectric constant. Dielectric constant is shown by “and has a significant role in this research. Dielectric constants of different materials are different in various temperatures and so, they have to be measured in fixed temperature whether in simulation or in laboratory condition.

Even temperature difference at 1 degree centigrade can be effective. The best method is to use a mechanism which changes by temperature. So, the applied software can be related to different volumes and different places of simulation space and the form can be seen. Another variable is the sub layer features. By changing the dielectric constant of the sub layer, the amount of effective dielectric constant to the free space changes and if measuring is done in free space, pressure will be effective. In addition, optimizing the sensor can affect its selection. In this research, a stepped resonator is used and for simulation of the sensor, the electromagnetic software of ADS is applied to study the correct function of resonator mode.

**Modeling:**

Microwave has become used frequently in industry for determining the penetration control and the humidity level of the material. Various sensors are used and one of them is for measuring the ” by the microstrip sensor.
One of the most common structures of the microstrip for this type of measurements is microstrip technique by stepped resonator. The tested materials are put on the microstrip and its features are determined by changing return loss and insertion loss. These changes show the change in material nature compared to air. So, that the basic resonator of the sensor measures the resonance by moving the frequency. The designed model is described for measuring the dielectric constant by moving the frequency resonance. Here, the stepped resonator method is used for recognizing the dielectric constant. These resonators can be used in communication systems, telephones and satellites.

One of the advantages for these resonators is the simplicity of them, smaller size and low cost and ease of construction.

**Analysis of the stepped impedance resonator:**

First, total construct of the stepped impedance resonator is designed in a way that it has a weak pole in GHZ3 frequency with the weakness of dB 25. Picture of the resonator is shown in figure 6.

\[ n = \tan(\theta) \tan(\theta) \]

\[ F_{SB1} = \frac{2}{\tan^{-1}(\sqrt{Z_2})} \]

In which \( \theta \) 1 and 2 are the electric length, \( Z_1 \) is the high impedance and \( Z_2 \) is the low impedance. Furthermore, \( F_{SB1} \) is the first deleted frequency and \( F_0 \) is the basic frequency of the resonator.

**Designed Sensor:**

Intermediate filter has an index frequency and for recognizing it a frequency index of resonance is needed. The applied index for designing the sensor is intermediate filter. So, the Coupling technique is used and a couple is added (figure 6). Adding the coupled lines from both sides caused the frequency to be lowered and its sensitivity to increase. Figure 7 shows the suggested sensor structure.

![Fig. 6: structure of stepped resonator](image)

![Fig. 7: the structure of the suggested sensor](image)

Figure 9 is a 3D scheme of the microstrip sensor construct with stepped resonator in the presence of dielectric layer, land and free upper surface. By changing it in free space from 1 to 10, the resonance frequency...
changes as shown in figure 10. Furthermore, the changes are shown based on application of different materials in table 1.

**Fig. 9:** 3D sensor.

**Fig. 10:** changing Er in free space from 1 to 10.

**Table 1:** frequency changes of resonator based on different materials.

<table>
<thead>
<tr>
<th>substance</th>
<th>$\varepsilon_r$</th>
<th>$\delta f$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air</td>
<td>1</td>
<td>3.839</td>
</tr>
<tr>
<td>Chlorine</td>
<td>2</td>
<td>3.622</td>
</tr>
<tr>
<td>Olive Oil</td>
<td>3</td>
<td>3.443</td>
</tr>
<tr>
<td>Anisole</td>
<td>4</td>
<td>3.290</td>
</tr>
<tr>
<td>Amyl Benzoate</td>
<td>5</td>
<td>3.158</td>
</tr>
<tr>
<td>Beryllium</td>
<td>6</td>
<td>3.041</td>
</tr>
<tr>
<td>Anthline</td>
<td>7</td>
<td>2.939</td>
</tr>
<tr>
<td>Calcite</td>
<td>8</td>
<td>2.845</td>
</tr>
<tr>
<td>Amyl Nitrate</td>
<td>9</td>
<td>2.763</td>
</tr>
<tr>
<td>Liquid Crystal</td>
<td>10</td>
<td>2.684</td>
</tr>
</tbody>
</table>

Changes in sub-layer lead to changes in resonance frequency and Er. These changes are shown in figure 11 and 12.

**Fig. 11:** frequency changes by changing the sub-layer.

**Fig. 12:** frequency changes with sub-layer changes (sub-layer with more Er has less decline)

The results of the frequency changes of Sub-layer can be seen in digital form in table 2.
Table 2: resonance frequency change and Er changes with sub-layer changes.

<table>
<thead>
<tr>
<th>sub-layer name</th>
<th>sub-layer</th>
<th>sub-layer thickness (mil)</th>
<th>resonance frequency (GHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ro 4003</td>
<td>3.38</td>
<td>H= 20</td>
<td>3.839</td>
</tr>
<tr>
<td>RO 3003</td>
<td>3.0</td>
<td>H= 10.3</td>
<td>3.608</td>
</tr>
<tr>
<td>NY9220</td>
<td>2.2</td>
<td>H= 9.64</td>
<td>4.138</td>
</tr>
<tr>
<td>RO6002</td>
<td>2.94</td>
<td>H= 15.5</td>
<td>3.911</td>
</tr>
<tr>
<td>RO 3880</td>
<td>2.2</td>
<td>H= 4.7</td>
<td>3.658</td>
</tr>
<tr>
<td>RO 3730</td>
<td>3.0</td>
<td>H= 30</td>
<td>4.247</td>
</tr>
<tr>
<td>RO 3203</td>
<td>3.02</td>
<td>H= 9.8</td>
<td>3.582</td>
</tr>
</tbody>
</table>

Different materials at different temperatures have different Er. Changes are measured by temperature change and are shown with frequency changes. Figures 13 and 14 indicate the changes. Oil and water are used as sample and digits of changes based on resonance frequency are shown in tables 3 and 4.

**Fig. 13:** changes of Er based on temperature in oil which is shown as resonance frequency changes.

**Table 3:** changes of Er based on temperature in oil.

<table>
<thead>
<tr>
<th>εr</th>
<th>θ-⁣50⁣c</th>
<th>Frequency (GHz)</th>
<th>Insertion Loss (db)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.7</td>
<td>60</td>
<td>3.197</td>
<td>-0.318</td>
</tr>
<tr>
<td>2.6</td>
<td>80</td>
<td>3.503</td>
<td>-0.558</td>
</tr>
<tr>
<td>10.3</td>
<td>80</td>
<td>2.686</td>
<td>-1.194</td>
</tr>
<tr>
<td>3.2</td>
<td>76</td>
<td>3.409</td>
<td>-0.403</td>
</tr>
</tbody>
</table>

**Fig. 14:** changes of Er based on temperature in water which are shown as resonance frequency changes.

**Table 4:** changes of Er based on temperature in water.

<table>
<thead>
<tr>
<th>εr</th>
<th>θ-⁣50⁣c</th>
<th>Frequency (GHz)</th>
<th>Insertion Loss (db)</th>
</tr>
</thead>
<tbody>
<tr>
<td>80</td>
<td>20</td>
<td>1.137</td>
<td>-8.345</td>
</tr>
<tr>
<td>48</td>
<td>100</td>
<td>1.354</td>
<td>-3.750</td>
</tr>
<tr>
<td>55.3</td>
<td>212</td>
<td>1.289</td>
<td>-4.815</td>
</tr>
<tr>
<td>34.5</td>
<td>390</td>
<td>1.5</td>
<td>-2.005</td>
</tr>
<tr>
<td>80.4</td>
<td>68</td>
<td>1.137</td>
<td>-8.825</td>
</tr>
</tbody>
</table>

Internalizing the changes based on temperature in oil by MATLAB in first sensor: Based on internalization, the chart of changes are shown based on resonance frequency changes in figure 15.
Internalizing the changes based on resonance frequency change in water by MATLAB in first sensor:

Based on the internalizing, the changes based on resonance frequency changes are shown in figure 16.

The process of building sensor:

1. Filming the designed sensor (Output in Gerber form) which is called photoplater stage.
2. CNC
3. Metalizing: in this process some holes are built inside the copper at the second stage.
4. Laminate: lighting is done and film is glued on the fiber
5. Second stage plating: in this part a weak layer of lead and tin are put on some parts of the copper.
6. Aching: copper is taken out by ammonium
7. Banner and Markaj: board is taken to the silk unit and printing is done, first printing is done.
8. Hot air: lead and tin are set by hot air.
9. Final cutting (CNC)

Now the sensor is ready for doing experiment and related measuring:

In order to show the correctness of the process shows that sensor is measured without material. Figures 18 and 19 shows the similarity of measuring results and simulation results.

Oil and water are used as under experiment materials. The results of measurement are shown by Network Analyzer.

Based on figures 20, 21 and 22, it is seen that by changing the material, resonance frequency and Er change, too.

Water and its derivatives have high Er and it is about 80 to 88. This high amount causes that simulation is not done correctly. So, a sensor should be designed that is not abnormal compared to sub-layer and frequency.
Conclusion:

Today sensors have important roles in most aspects of our daily life. By emergence and evolution of technology and then nano technology, a great change was made in building sensors and designing microstrip circuits and by using the stepped resonators, the microstrip is designed and built. Microstrip technique uses a layer as the land layer under the electric board which reduces noise and designer can implement the microwave layer on another layer. By help of this sensor, dielectric constant parameter is one of the main features of materials and is very important in oil and gas industry and is measured by changing resonance frequency. Simplicity of building, small dimensions, efficiency in MMIC and diversity of structures which can be used for obtaining unique features are the advantages of this sensor. Passive feature of the sensor can be used or designing wireless sensors and microstrip antenna. That is instead of using waves through ports and wired, they are sent wireless. So, we need two antennas which can be installed at the beginning and end of the sensors and
material is poured on the sensor and waves passed the first antenna and then after processing the data, waves reached to next antenna.

REFERENCES


