Electromagnetic Based Fluid Sensor Using Metamaterial

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***Abstract*:** Meta means beyond and meta-material is a material that exhibits a property that is beyond nature's scope, or in other words, it exhibits a property that is not found in the nature, in short, an artificial material. These are made from assemblies of multiple elements fashioned from composite materials such as metals and dielectrics. To synthesize a meta-material, it has to be arranged in repeating patterns, in such a way that the scales are smaller than the wavelengths of the phenomena they influence. The properties of the base materials are hardly reflected in the properties of the meta-materials. It is the structures in which the base materials are arranged that define the properties of the meta-materials. Meticulously arranged in precise shape, geometry, orientation and arrangement, meta-materials are equipped with some smart properties that are capable of manipulating electromagnetic waves. This includes blocking, absorbing, enhancing, or bending waves. This benefits us with something that cannot be achieved with the materials that are already existing in the nature. We propose an extremely compact metamaterial microstrip sensor which is realized by using a metamaterial absorber. The metamaterial absorber comprises complementary split-ring resonators (CSRR). The CSRR can generate LC resonance that is very sensitive to change in the effective dielectric constant around the capacitive gap. As the value of dielectric constant changes, the resonance frequency of the complementary split-ring resonator (CSRR) changes.

***Index Terms* –** sensor, microwave, split ring resonator, Q-factor, permittivity, resonance.

I. INTRODUCTION

We know about sensor gadget that identifies and reacts to some sort of contribution from the actual climate. The particular information could be light, heat, movement, dampness, pressure, or on the other hand any of an incredible number of other ecological wonders. The yield is for the most part a sign that is changed over to comprehensible presentation at the sensor area or sent electronically over an organization for perusing or further handling. As of late, huge progresses have been accomplished for material portrayal utilizing properties procedures. A few of these strategies are introduced for the genuine piece of the dielectric consistent estimation; then again, every procedure is appropriate and significant for specific sorts of recurrence ranges also, particular sorts of materials. Material portrayal has an application in different zones, for example, bio-detecting, quality control in the food business, substrate properties and so on. In present day years, Metamaterial got one of the primary subjects of flow research in the field of high-recurrence innovation.

A metamaterial-based microwave sensor with complimentary split ring resonator (CSRR) is executed for dielectric portrayal of fluids. The curiosity in the proposed contactless sensor is the utilization of fluid examples put ordinary to the sensor surface. Set within glass hair-like cylinders, it is rapidly conceivable to break down the dielectric properties of fluids essentially by supplanting the slender cylinders with new examples. The fluid examples inside the glass fine cylinders alter the resonant frequency and Q-factor of the CSRR sensor. Accordingly, a connection between the sensor resonant frequency, Q-factor, and complex permittivity of the fluid examples can be assessed. The proposed sensor is minimized, ease, contactless, reusable, effortlessly manufactured, and simple to work.

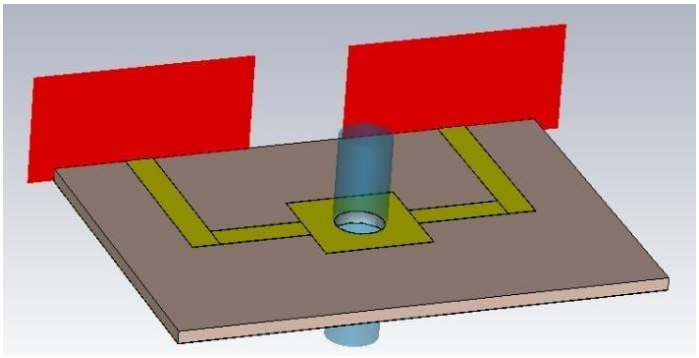
A new metamaterial-inspired microwave sensor can be implemented by analysing the paper. A microstrip coupled CSRR is used as the sensor. Air, fuel, and ethanol are the three liquids that are tested for their sensing abilities. The liquids change the CSRR loaded microstrip device's resonance frequency and strength. The designated sensors only need a small amount of sample, resulting in extremely quick sensing and recovery times comparable to the system's data acquisition time. Since each

material has its own permittivity value, the selectivity is fine. As a result, a highly sensitive, selective, and repeatable sensor can be implemented, which is particularly useful for hybrid fuel sensing. Also, many other liquids suchas sea water, sugar content (Glucose) in human blood can also be sensed in future with more advance technologies.

The sensor has successfully detected the change in the value of permittivity for four different liquids that are oil, distilled water, sea water and glycerin by taking air as the reference parameter. Shift of resonant frequencies for all the four liquids with respect to air has been observed in simulation.

II. SENSOR DESIGN AND THEORETICAL STUDY

The main parts of the proposed sensor are the CSRR on the ground plane side and the transmission line on the other side of the board. CSRR structure and the transmission line must be aligned. The hole in the center of CSRR and the transmission line is used to place the samples under test. Fig.1 shows the3D view of the structure its dimensions.



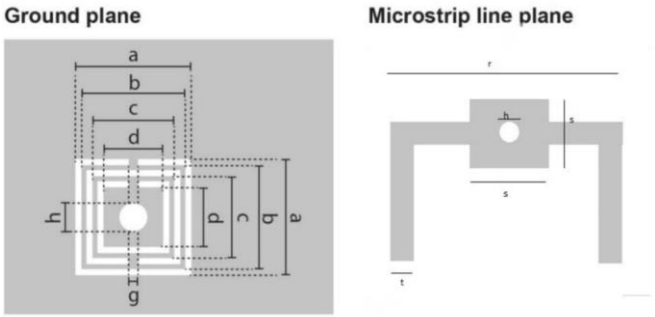


fig.1: Sensor Structure and its dimensions a ≡ 6.2 mm, b ≡ 5.55 mm, c ≡ 4.37 mm, d ≡ 3.19 mm,g ≡ 0.5 mm, h ≡ 1.5 mm, l ≡ 20 mm, r ≡ 16.6 mm, s = 6.2mm, t ≡ 1.6 mm, w ≡ 28 mm

The simplest and quickest way to excite the CSRR with an electric field is to use a microstrip transmission line. The CSRR is carved out at the microstrip's ground, actingas a band stop filter. The copper structure was fabricated on a commercially available ROGER RO3035. The CSRR's resonant frequency was set to 4.5GHz. The equivalent circuit of the fabricated structure is shown in Figure.1

When excited by a time-varying magnetic field portion in its axial direction, SRRs can inhibit signal propagation in a band near their resonant frequency. Since the CSSR is the opposite of the SRR, it needs a time-varying electric field excitation with a component parallel to its axis.

Despite the fact that both resonators have a strong stable frequency response, we used a CSSR instead of an SRR in our design. The Transmission line can be on the other face of the CSRR, which can be oriented on the ground plane. The sample can then be put in the middle of the resonator and transmission line. Since the uniformity of the field in the sample is supposed to be similar to theoretical

values, this isan important aspect to consider when designing sensors for measuring material properties. Furthermore, since the CSSR sensor does not require additional circuit space, the proposed sensor is more portable.

The CSRRs and SRRs exhibit quasi-static resonance, allowing for the construction of an analogous circuit model. SRRs and CSRRs have a number of advantages over traditional microwave resonators, including the ability to resonate witha much smaller scale, low radiation losses, and high-quality factors.

Multiple split-ring resonators were used to increase the Q factor of the proposed sensor. By considering the distributed capacitances (for SRR) or inductances (for CSRR) between adjacent rings, the equivalent circuit model cell may still be representative in terms of appropriate RLC elements in the case of three split rings resonators.

When a microwave signal is fed into a microstrip transmission line, it excites the CSRR by causing a voltage difference between the CSRR's capacitive plate and the ground plane. As a result, when the accumulated electric energy in the CC and Cr capacitors equals the magnetic energy in the inductive microstrip Lr, the resonance occurs.

An electric field is formed across the gap between the CSRR capacitive plate and the squared resonator during the resonance, making the region near and inside the CSRR responsive to dielectric changes. As a result, this area within the CSRR can be used to calculate dielectric properties of materials.

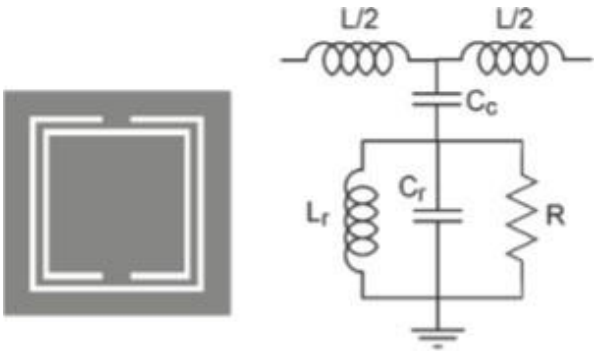


fig 2: Circuit model

The resonance frequency of the circuit model can be defined as

$$f_r = \frac{1}{2\pi\sqrt{L_r(C_c + C_r)}} \quad (1)$$

The Q factor of the resonance is:

$$Q = \sqrt{\frac{(C_c + C_r)}{L_r}} \quad (2)$$

The liquid sample to be examined fills a glass capillary tube, which is then inserted in a hole in the middle of the CSRRand the transmission line with the same external diameter as the capillary tube.

III. FABRICATION AND MEASUREMENT

The CSRR's dimensions were designed to resonate at the 2.4 GHz without the liquid sample and optimized using the full wave simulator Ansys HFSS. Fig.3 shows the simulated electric field into the water liquid sample inside of capillary glass tube.

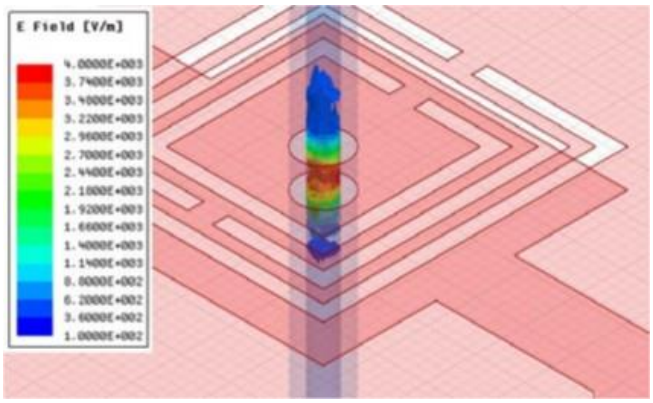


fig 3: simulation showing electric field inside the capillary tube

The substrate used in the design of the sensor was a Roger RO3035 with ϵ = 3.5, tan δ = 0.0015, and thickness of 0.75 mm. Fig. 3 shows the CSRR sensor prototype built, bottom side (left) and top side (right) with SMA connector.

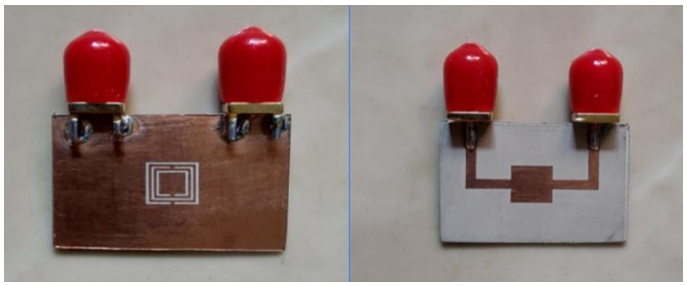


fig 4: Top and Bottom Structure of the Sensor

The measurement setup will be built using a vector net- work analyzer (VNA) connected to the sensor to obtain the S-parameters, magnitude and phase in terms of frequency. A support made of Teflon will be used to hold the CSRR sensor and keep the capillary tubes in right position during the measurements. The glass capillary tubes are common tubes used in clinical laboratories with external diameter of 1.5 mm, internal diameter of 1 mm, and 75 mm of length.

IV. SIMULATION ANALYSIS

CST Studio has been used for the simulation of the different liquids which are to be placed inside the cylindrical tube. As the cylindrical tube can be easily replaced, same senor can be used for the detection of the various liquids. Air, Oil, Glycerine and Distilled water are the materials used in this experiment.

The resonant frequency for air was observed at 3.07GHz which has a permittivity value of 1.

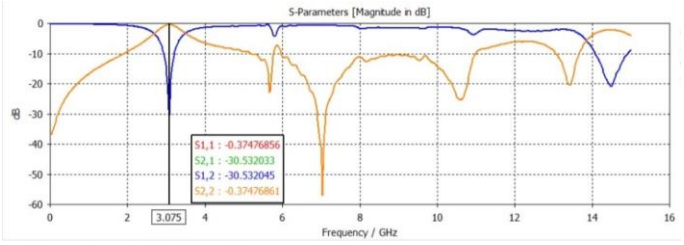


fig 5: simulation showing resonant frequency of air

The resonant frequency for oil was observed at 2.91GHz which has an permittivity value of 2.23.

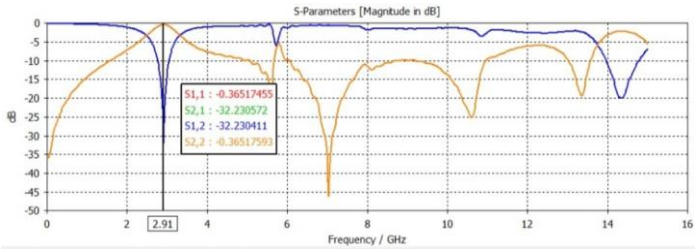


fig 6:simulation showing the resonant frequency of oil

The resonant frequency for glycerine was observed at 1.71GHz which has a permittivity value of 50.

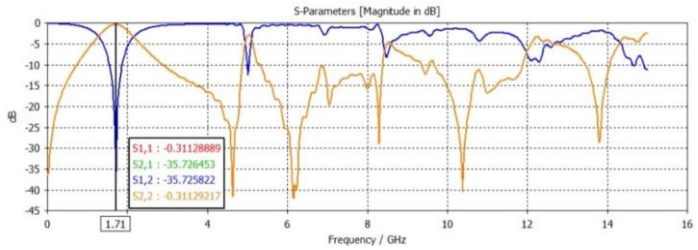


fig 7: simulation showing resonant frequency of glycerine

The resonant frequency for Distilled water was observed at 1.41GHz which has a permittivity value of 78.4.

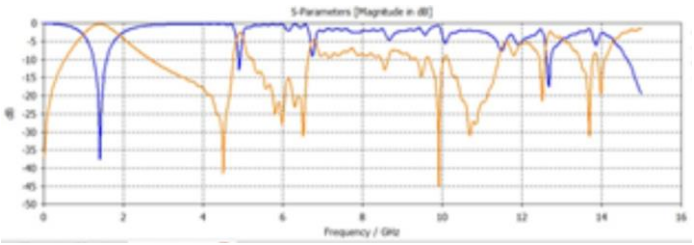


fig 8: simulation showing the resonant frequency of Distilled water

V. CONCLUSION

Material	Permittivity	Resonant frequency
Air	1	3.07
Oil	2.23	2.91
Glycerine	50	1.71
Distilled water	78.4	1.41

An Electromagnetic Based microwave sensor has been designed and simulated using CST Studio which shows resonant frequency in the range of 1-4GHz. The liquid to be sensed has been placed inside a cylindrical tube (capillary tube) at the center of sensor. As the frequency of the sensor resonates at level -30db its sensitivity is good.

From the simulated results, we can clearly conclude that as the permittivity value of the liquid inside the cylindrical tube increases, the sensor resonates at different frequencies and thus the graph between frequency and S2,1 can been seen shifting towards left side which is the lower frequencies The change in the properties of the liquid can be easily sensed by usingthis microwave sensor.

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