Materials recognition based on electromagnetic metamaterial absorber

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Abstract. In this study, squire ring resonator structure (SRR), which can be used as an materials sensor based on electromagnetic metamaterials absorber in microwave S-band regime. The SRR is contain squire copper ring and hole on the top, FR4 in the middle layer and copper film at the bottom. The sensitivity of the resonance frequency to the material type was numerically examined in the CST Microwave Studio (MWS) environment. In these analyzes, the hole dielectric constant of material was changed from 4.3 to 1. Within the three different materials (FR4, oil and vacuum). It is shown that the absorption wavelength displays worthy blue-shift with the increasing dielectric constant of material. Furthermore, the simulation results indicate that the sensitivity of SRR is very good, which makes SRR structure be an ideal detection for material type.

1. Introduction
The first theoretically metamaterials proposed by Veselago in 1968. They are artificial materials that can exhibit extraordinary electromagnetic properties such as negative dielectric constant, negative magnetic permeability, negative reflective index and inverse doppler effect in the same frequency band [1-3], and there are provide many applications in the microwave area [4-17]. Split ring resonators (SRR) [5-9, 15-17], ring resonaters, pach resonartors and electric-LC resonators (ELC) are widely preferred resonator structures in metamaterial design.

These resonators are often modeled as LC resonance circuits in the literature [10-12,18]. Where L and C are the total inductance and total capacitance values indicated by the structure, respectively. The L value depends on the size and shape of the conducting line that forms the structure, while the C value depends on the thickness of the dielectric substrate and the dielectric constant on which this resonator is printed on [12].

As can be seen in equation (1), the angular resonance frequency value depends on the L and C values used in the circuit model [11].

\[ \omega_0 = \frac{1}{\sqrt{LC}} \]  

One of the current applications in which metamaterial structures are widely used is sensor applications [4, 5, 8- 14, 19, 24-25]. In particular, Al-badri et al. reveals that the sensor based on rotation angle along the centre line, can be monochromatic tuning of absorption strength, at selected frequency, at S-band. In addition, literatures [20-23,25] are possible to use in sensor applications and may be more sensitive to be used in many applications [19, 24] compared to unilateral alternatives of these structures, thereby making their structures such as temperature, humidity, density, concentration,
It has been suggested that it can be used in sensor applications to detect environmental changes.[8]

As part of this paper, SRR ring resonator structure was proposed as a material sensor based on electromagnetic structure, which are not previously studied in the literature, and their sensitivity to the several materials were examined.

2. Design procedure

The schematic views and design parameters of SRR resonator with the values are shown in Figure 1. The purpose of designing the hollow structure; to increase the sensitivity of the structure by holing the center of SRR for containing the material inside the hole [8, 17]. Changing the common capacity can be explained by the equations (2) - (4) previously presented in the literature [8]:

\[
C_{\text{sub}} = \frac{A \times \varepsilon_{\text{sub}}}{d_{\text{sub}}} \tag{2}
\]

\[
C_{\text{mat}} = \frac{A \times \varepsilon_{\text{mat}}}{d_{\text{mat}}} \tag{3}
\]

\[
\frac{1}{C_{\text{total}}} = \frac{1}{C_{\text{sub}}} + \frac{1}{C_{\text{mat}}} \tag{4}
\]

Here, the \( C_{\text{sub}} \) substrate material's (FR4) capacity, \( C_{\text{mat}} \) shows the capacity of the material that we want to explore, while \( C_{\text{total}} \) shows the total capacity of the designed structure. \( d_{\text{sub}} \) and \( d_{\text{mat}} \) are

![Figure 1: Schematic view of the resonator structure (a) front view (b) Side view](image-url)
substrate layer and material thicknesses, respectively. While $\varepsilon_{\text{sub}}$ and $\varepsilon_{\text{mat}}$ are substrate and material relative dielectric constants, respectively. $A$ is defined as the surface area of parallel plates. As seen in equation (4), it has been shown that the common capacity can be change by changing the material [8, 17].

FR4 with dielectric constant $\varepsilon_{\text{sub}} = 4.3$ and dielectric loss tangent $\tan\delta = 0.025$ at base material of 10 GHz was used in all materials studied. Dimensions of proposed sensor are chosen as $L_x = 72.136$ mm, $L_y = 34.036$mm, and substrate thickness $d_{\text{sub}} = 3$ mm. In addition, for the SRR structure in Figure 1 (a), copper line lengths $s = 16$ mm, copper line width $w = 0.2$ mm, $5.8 \times 10^7$ S / m and 0.035 mm thickness.

In this study, structure designed in S band microwave frequency region was studied numerically in frequency domain analyzer in CST Microwave Studio (MWS) simulation environment. As the resonator is stimulated, the propagation vector $k$, the electric field vector $E$ and the magnetic field vector $H$ change along $-z$, $y$ and $x$, respectively. In the simulation environment shown in Figure 1 (c), in the CST MWS simulation environment, the open space of the electromagnetic wave is selected as open-add, while the walls that are not in the direction of the electromagnetic wave are selected as the perfect electrical conductor ($E_t = 0$) and all ports are in the basic mode TE10 mode it is selected. In simulation environment, port1 is used as the transmuted port and port 2 is used as the receiving port.

3. Numerical analysis

EM wave transmit from port1 then hit the SRR sensor, therefore some of EM wave can be pass through the structure or reflect back but according to design condition at resonance frequency we get perfect absorption peak. In this work, absorption spectrum calculated using will know equation 5:

$$A (\omega) = 1 - |S_{11}|^2 - |S_{12}|^2$$  \hspace{1cm} (5)

Where, $A (\omega)$ is a absorption depend on angular frequency of reflection ($S_{11}$) EM wave and transmission ($S_{12}$) EM wave. According to use a copper at the back of the SRR, therefore the all transmission wave is prevented, i.e. $A (\omega)$ value dependent totally on S11 coefficient. In this case, equation (5) can be written as:

$$A (\omega) = 1 - |S_{11}|^2$$  \hspace{1cm} (6)

It is clearly from equation (5) to reach maximum absorption we should be minimized the reflection S11. This condition is as it were conceivable by tuning the impedance of the SRR structure with the impedance of the free space. In this way, excellent absorption can be achieved by ensuring the impedance matching and by fulfilling the requirements of the metal plate and the transmission inhibition.
Figure 2. electromagnetic absorption response (a) filling the hole with FR4, (b) filling the hole with oil, (c) filling the hole with vacuum.
The results obtained in CST MWS environment are presented in Figure 2. Three different materials were examined FR4 with 4.3 dielectric constant and 0.025 tangent losses figure 2(a), in the second simulation examined oil with permittivity constant 2.33 and tangent losses 0 figure 2(b), finally is simulated vacuum with permittivity constant 1 and tangent losses 0 figure 2(c).

When the dielectric constant value of material $\varepsilon_{\text{mat}}$ is decreased from 4.3 to 1 in the SRR structure, the resonance frequency has increased from 3.139 GHz to 3.374 GHz. According to the results obtained here, Table 1 was created by using equation (6) comparison was made for the different materials. The results show that the SRR structure is the good sensitive structure to the material change.

Table 1: Materials sensitivity according to the resonance frequency and absorption level.

| Material | $\varepsilon_{\text{mat}}$ | $\tan\delta$ | Resonance frequency GHz | Absorption |
|----------|-----------------|------------|-----------------|-----------|
| FR4      | 4.3             | 0.025      | 3.139           | 0.99      |
| Oil      | 2.33            | 1          | 3.304           | 0.981     |
| Vacuum   | 1               | 1          | 3.374           | 0.97      |

4. Conclusion

Within the scope of this study, It has been proposed and investigated a material detection sensor based on EMA electromagnetic metamaterial absorber. The CST simulation results present that the absorption resonance frequency can be tuned by the changing the material type, which is applied by filling the hole in the structure with the material to be identified.

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