Meta-Atom Based on Split Ring Resonator for Bio Sensing Applications

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Abstract
This work presents a biosensor operating in the microwave frequencies. This structure is based on meta-atoms for S band applications such as quality sensing of consumable goods. Modelling and simulations are carried out through commercially available 3-D electromagnetic solver in this research. Initially, a square meta-atom resonator made up of a highly conductive copper based micro strip line with a small split gap in the centre was built and optimization was run to function at a particular frequency of 2.35 GHz. Transmission and reflection curves were obtained in the first stage when nothing is presented on the surface area of biosensor, and then three different dielectric materials with various dielectric constants, namely 3.4, 4.6, and 5.8, are applied in order to observe its characteristics. During each step of the dielectric coefficient adjustment, a maximum change of about 99.9 MHz in the core resonant frequency is noticed. This has shown that the proposed meta-atom split ring shape may be utilized as a biosensor for sensing biomaterials such as tissues and other cells. Our simulation results have also revealed that this device can also be used for biological materials with diverse dielectric constants which have been discovered by earlier open investigations, and that it is a reliable device for biomedical sensing.

Key words:
Meta-atom; bio sensing; Split Ring, S-band

1. Introduction

The meta-atom is a synthetic arrangement with exceptional significant features. The meta-atom is a fantastic modern discovery that has piqued the interest of experts all over the world. The majority of research in the fields of electrical engineering, material science, physics, and optics has focused on the construction of effective meta-atoms. The meta-atom is the artificial material's unit cell. The meta-atom structure is largely made up of sub-wavelength array components that may adjust electromagnetic (EM) wave propagation properties.
Meta-atoms have been used to achieve unique EM features such as negative refractive index, EM stealth, perfect prism, and good transmission. Filters [1], antennas, multiband components [2], bandwidth augmentation devices [3], absorber design [4], leaky wave antennas [5], super lenses, and biosensors [6] are among the uses. Biosensors are devices that can sense and turn a biological function into a signal that can be measured.
The utilization of microwave signals for biological detection applications using a meta-atom structure as a biosensor element for bio sample detection is illustrated in this research. Microwave sensing presents a significant challenge for biological detection since it has the appealing benefits of being contactless, non-invasive at low power levels, and label-free. The sensor's resonance frequency has been determined to be 2.35 GHz. During cardiovascular surgery, the first medical biosensor was reported to measure oxygen [7].
Ever since, biosensors have been employed to evaluate genetic abnormalities, cancer tissue, glucose level monitoring, and virus detection with enhancing the precision, delicacy, and specificity of in a wide variety of medicine [8-12]. Biosensors are classified based on the type of bio transducer they employ. The most common varieties include microwave biosensors, optical biosensors, and biosensors that integrate electrical and chemical operations, heat sensitive biosensors, transistorised biosensors, and gravity force applied biosensors.
Because of the non-ionizing nature, depth detecting capabilities, Microwave biosensors have a wide range of applications due to their non-invasive nature they are used in biological applications. The process of evaluating samples under test using copper strip line resonators is well-known and was initially proposed [13]. This technique was developed after significant investigation into changes in the sample's electrical characteristics, particularly the dielectric constants. As a result, in cancer cell detection, the principle of electromagnetic wave sensing is based on observing variations in dielectric coefficient, which is utilised to calculate sample concentration or intrinsic dielectric coefficient. The dielectric constants of many biomaterials, including liver cells, tissues, sugars, and malignancies, have been determined thus far [15]. At the end, a dielectric sensor could be employed as a biosensor.
Because changing water content ratios of different biomaterials cause their electrical characteristics to differ, this method's efficiency in cell and tissue research inquiries has increased. Tumor and malignant cells differ from normal cells not only in terms of their water content, but also in terms of their cytoplasmic content, resulting in a variation in dielectric constants. This dielectric constants contrast analysis method works for all liquid and solid materials except gases, which have exceptionally low dielectric constants [16].

2. Meta-Atom Unit cell Design

Figure 1 depicts a schematic of the proposed meta-atom, while table 1 lists its dimensions. The biosensor has a unique resonant frequency of 2.35 GHz when no sample is applied to its surface. During the binding of sample to the sensor, the near field dielectric constants of the sensor surface vary. The surface electric field is quite strong in the gap area. As shown in Eq. 1 [17],

$$f_c = \frac{1}{2\pi\sqrt{LC}} \qquad (1)$$

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this phenomena produces variations in effective capacitance and inductance, as well as changes in the perceived resonant frequency.

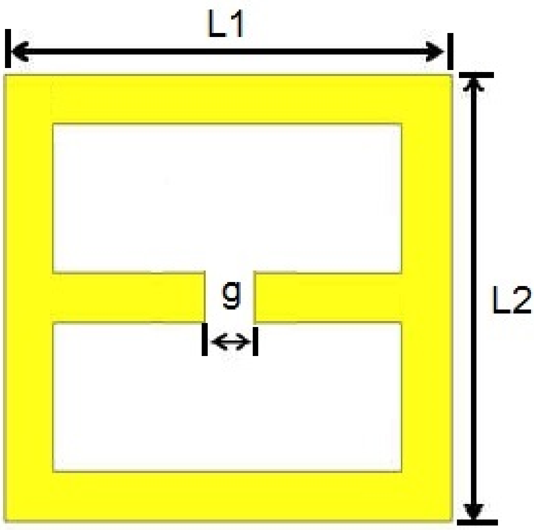

Fig. 1 Meta-atom unit cell showing split gap area.

Table 1: Meta-atom specifications

Parameters	Dimensions (mm)
Horizontal length (L1)	20
Vertical Length (L2)	20
Split Gap (g)	2
Thickness of Base (h)	1
Strip Width (w)	2

The proposed structure, which consists of a split ring resonator with a split gap in between, is modelled on a Rogers RO3006 (lossy) type dielectric substrate and improved in CST Microwave Studio to function at 2.35 GHz at central resonant frequency.
The device is then evaluated using simulations with three distinct substrates, each with a different dielectric constant, that are placed on the surface in turn, with the shift in the core resonant frequency being observed at each stage. The frequency shift is shown to be proportional in relation to the dielectric coefficient.
As a result, it is proposed that this structure be used as a biosensor in biomaterial diagnostic research. CST Microwave Studio uses waveguide ports to excite the unit cell. The simulation findings for the proposed meta-atom biosensor in terms of transmission and reflection coefficient under unloading circumstances are shown in Figure 2 and are given in Eqs. 2 and 3 [17]. The resonant frequency is 2.35 GHz, with a transmission coefficient of -46 dB and a reflection value of -3.12 dB.

$$S_{21} = \frac{Z_L - Z_o}{Z_{in} + Z_o} \tag{2}$$

$$S_{11} = \frac{Z_{in} - Z_o}{Z_{in} + Z_o} \tag{3}$$

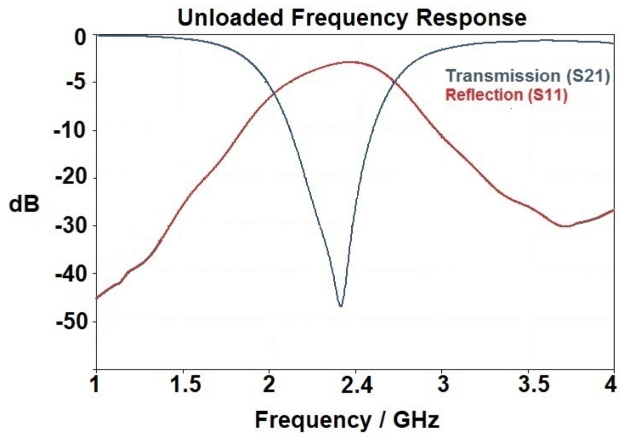

Fig. 2 Unloaded response of Proposed Meta-atom.

3. Results and Discussion

Before the affinity binding process, the meta-atom resonator built and simulated in the preceding section has an innate resonant frequency. When a dielectric material is placed on the surface of such split ring resonators, their electrical behaviour changes. Because of the presence of layers that operate as a sample material, the surface electric field is altered. When no sample is present, this modification causes the resonant frequency to deviate from the original resonance frequency.
The sample materials with dielectric constants 3.4, 4.6, and 5.8 overlaying the sensor surface are chosen to increase by a factor of 1.2 at each phase. These various dielectric materials were chosen from CST microwave Studio's material catalogue. Figure 3 shows the transmission coefficient (S21) data acquired for each new dielectric material loading.
As a transmission reaction, the disturbance over the biosensor region caused by the placement of bio sample material caused a 100 MHz change deviation towards lower frequency from its resonance frequency, as shown in figure 3.

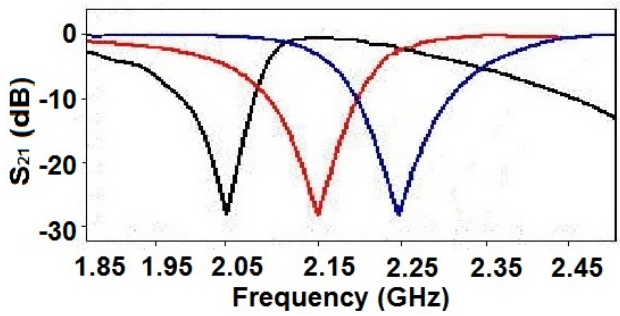

Fig. 3 Response of biosensor with testing of samples.

As long as the dielectric constant keeps increasing, this shift will continue to the lower side. The transmission dips that were produced are deeper and more distinct. Table 2 provides the results, whereas table 3 summarises the comparison of reported results.

Table 2: Summary of frequency shifts with dielectric constants.

Sample ε_r	Frequency Shift in GHz	Transmission Coefficient
3.4	2.25	-28.5dB
4.6	2.15	-28.5dB
5.8	2.05	-28.5dB

Table 3: Transmission Responses of reported biosensors.

S. No.	Reported Results	Transmission Coefficient
1.	[18]	-16 dB
2.	[19]	-18.5 dB
3.	[20]	-24.5dB

4. Conclusion

This research uses simulations using several layers of different dielectric materials as bio samples to evaluate a revolutionary geometrical design of meta-atom, which is a single unit cell of metamaterial. For biomedical applications, the meta-atom was successfully constructed to resonate at 2.35 GHz S Band frequency. The reactions of the biosensor were seen and recorded as distinct and unambiguous changes in its transmission coefficient (S21). It was also discovered that while the sample thickness was kept constant, the magnitude of S21 did not affected in proportional manner . With each sample of differing dielectric constant, however, the centre frequency linearly changes towards the lower frequencies by 100 MHz. The proposed meta-atom unit cell could be used as a biosensor by calculating the dielectric coefficient of any biomaterial placed on its surface, demonstrating its utility as a biosensor.

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