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Design and Simulation a Cancer Detection Based on Metamaterials Using COMSOL Multiphysics Software

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Abstract

In this essay, We present a design and simulation a low cost and high sensitivity biosensor based on metamaterials for cancer cell detection by COMSOL Multiphysics software. This biosensor worked in the microwave waves. In structure this biosensor using of SRR (Split-Ring Resonator) because it have high sensitivity to electromagnetic waves. We present structure have a high sensitivity approximately 0.56 GHz (560 MHz). This biosensor have also fine ability to separate the between cancer cell types. Important advantages of this biosensor are low cost manufacturing and free label that it can be produced locally.

Keywords: *Cancer Cells, COMSOL Multiphysics, Dielectric Constant, Metamaterials, Split-Ring Resonator.*

1. Introduction

The prefix "meta" means "beyond," and in this sense the terminology "metamaterials" implies artificially structured composite materials consisting of unit cells much smaller than the wavelength of the incident radiation and displaying properties not usually found in natural materials. More specifically, we are interested in a metamaterial with simultaneously negative electric permittivity ε and magnetic permeability μ. In general, both permittivity ε and permeability μ depend on the molecular and perhaps crystalline structure of the material, as well as bulk properties such as density and temperature [1]. Cancer is the uncontrolled growth of abnormal cells in the body, called as malignant cells. By developing microwave devices and combining it with structures inspired by metamaterials, it can lead to a very cost-effective device that can localize with high precision an abnormality within the human body. The basic principle behind the cancer detection is, a small change in the water content of biological tissues produces changes in the permittivity ε and conductivity σ values of the tissues. An electromagnetic source generates an electromagnetic wave impinging on the metamaterial array and a detector is placed to reveal the signal after the array. The biosensor without any material under test has a specific resonance frequency. The variation of the permittivity caused by the presence of the material under test, acts on the capacitance of the resonators, leading to a high-sensitive variation of the sensor resonant frequency. Thus the shift in resonance frequency and the shape of the response is extremely useful to detect the tumor [2]. Proposed biosensor has high sensitivity for the detection of biomolecular tissue. The sensitivity this biosensor approximately equal to 0.56 GHz.

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2. Design and Modelling of Biosensor

The structure proposed biosensor is shown in Figure 1. This structure is a SRR with four split and a microstrip line that placed input port and output port in the its initially and end, respectively. The input and output ports stimulated by TEM wave.

The substrate material is a TEFLON (PCTFE) with ε=2.8, and thickness of substrate is equal to with 1 mm and it is length and width equal to with 50mm. The material of SRR is a very thin layer of copper.

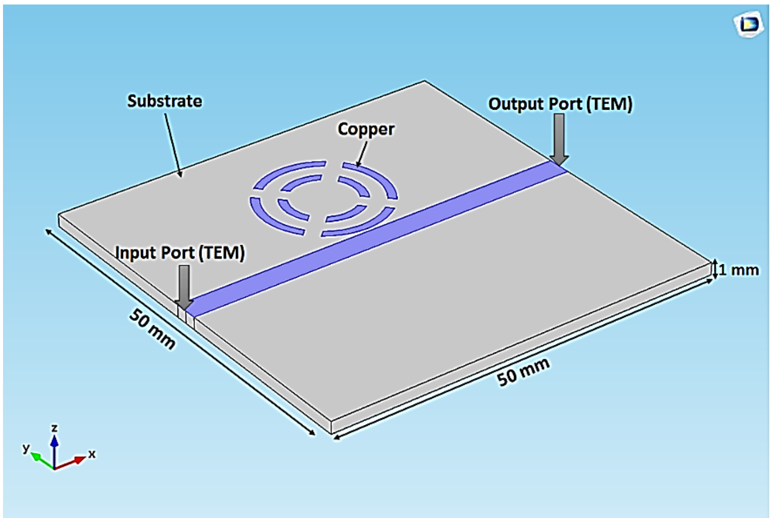

Figure 1: The physical structure of the biosensor

The SRR have a specific resonance frequency, which the sample is placed on it, the resonance frequency shifted to low frequency. Figure 2 shows the geometric dimensions of the proposed biosensor.

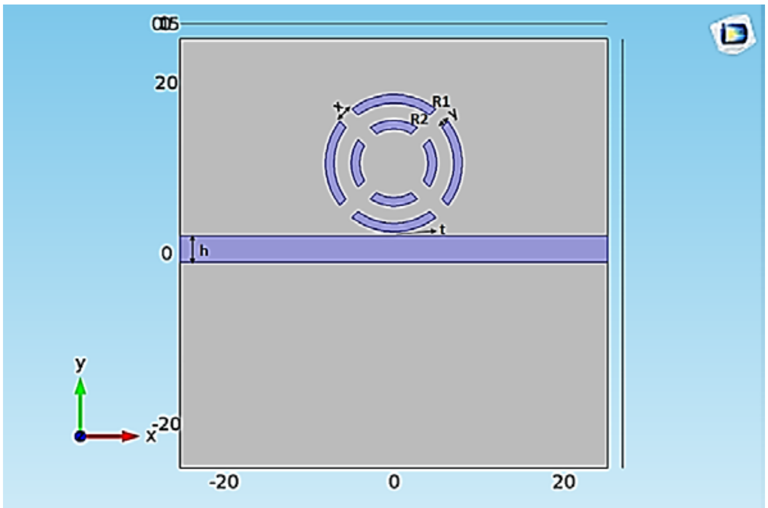

Figure 2: Unit cell of biosensor, h=3 mm, R1=8 mm, R2=5 mm, x=2 mm, y=1 mm, t=0.5 mm

Distribute of electric field norm in F=9.43 GHz is shown in Figure 3. As seen in the Figure, the density of the electric field is further near the gap lower.

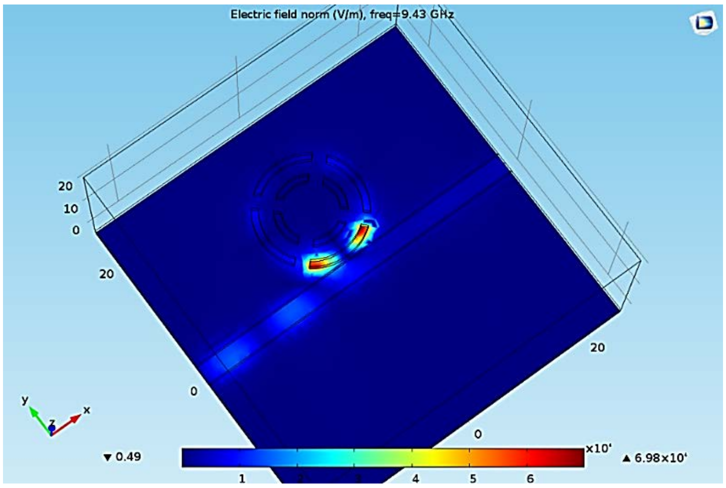

Figure 3: Electric field norm distribute at resonance frequency in the unit cell of biosensor

Figure 4 is shown a graph of direct transfer gain (S_{21}-parameter) and input reflection coefficient (S_{11}-parameter). This graphs Obtained in the case that there is no sample on the biosensor. The next section, we will provide the simulation results.

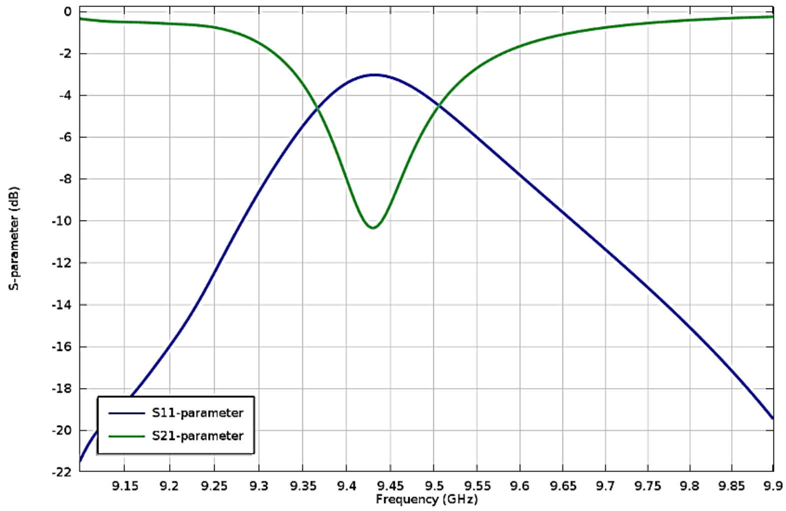

Figure 4: Direct transfer gain (S_{21}) and input reflection coefficient (S_{11}) graphs for case without sample

3. Functional Parameters For Simulation

In this section, we present result of simulation by COMSOL Multiphysics software. The method used in this simulation is Finite Element Method (FEM). The Finite Element Method (FEM) is an inherently more complex and universal method. FEM is a numerical procedure to find stable solutions to boundary-value partial differential equations. This approach was first reported in 1943 by Richard Courant in his study of elasticity and structural analysis, where the concept of mesh discretization of a simulation was introduced [3].

In this simulation, we using the Finite Element Method to solve the following equations [4].

$$\nabla \times \mu_r^{-1}\left(\nabla \times E\right) - k_0^2\left(\varepsilon_r - \frac{j\sigma}{\omega\varepsilon_0}\right)E = 0 \tag{1}$$

$$E(x,y,z)=\tilde{E}(x,y)e^{-ik_z z} \tag{2}$$

Where μr denotes the relative permeability tensor, ω is the angular frequency, σ is the conductivity tensor, ε_0 is the permittivity of vacuum, ε_r is the relative permittivity tensor, and K_0 is the free space wave number.

For high-frequency problems, voltage is not a well-defined entity, and it is necessary to define the scattering parameters (S-parameter) in terms of the electric field. To convert an electric field pattern on a port to a scalar complex number corresponding to the voltage in transmission line theory an eigenmode expansion of the electromagnetic fields on the ports needs to be performed. Assume that an eigenmode analysis has been performed on the ports 1, 2, 3… and that the electric field patterns E_1, E_2, E_3… of the fundamental modes on these ports are known. Further, assume that the fields are normalized with respect to the integral of the power flow across each port cross section, respectively. This normalization is frequency dependent unless TEM modes are being dealt with. The port excitation is applied using the fundamental eigenmode. The computed electric field E_C on the port consists of the excitation plus the reflected field. The S-parameters are given by equations 3-5 [5].

$$S_{11}=\frac{\int_{port1}\left((E_C-E_1).E_1^*\right)dA_1}{\int_{port1}\left(E_1.E_1^*\right)dA_1} \tag{3}$$

$$S_{21}=\frac{\int_{port2}\left((E_C-E_2).E_2^*\right)dA_2}{\int_{port2}\left(E_2.E_2^*\right)dA_2} \tag{4}$$

$$S_{31}=\frac{\int_{port3}\left((E_C-E_3).E_3^*\right)dA_3}{\int_{port3}\left(E_3.E_3^*\right)dA_3} \tag{5}$$

Table 1 to represent dielectric constant of normal cell and some of cancer cells [6], that we used of this values to simulate the sample on the biosensor.

Table 1: Dielectric Constant of Sample [14]

CANCER CELL	**Dielectric Constant**
Normal cell	1.8225
Hela	1.937660
PC12	1.946025
MDA-MB-231	1.957201
MCF-7	1.962801
Jurkat	1.932100

4. Simulated Result

Us for samples simulation used of a cube with very low height, as shown in Figure 5. Sample placed on the biosensor, and so is cause changes in the biosensor resonance frequency.

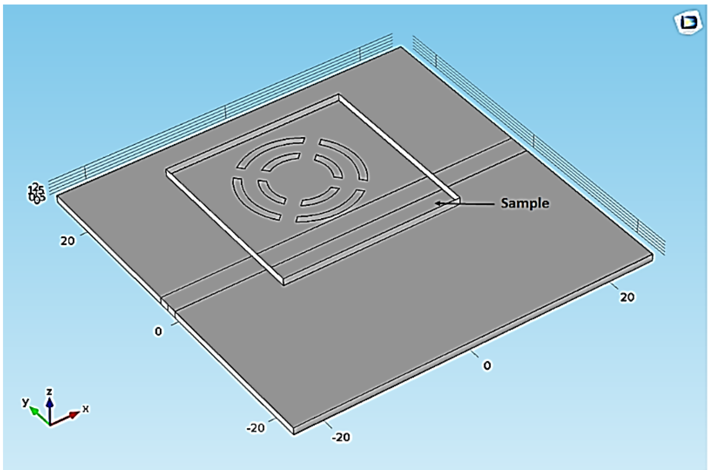

Figure 5: How to Placed sample to the biosensor

In the Figure 6 to 8, is shown electric field norm (V/m) in the resonant frequency for without sample, normal cell and cancer cell (Hela) states. According to the results, density electric field in the upper gaps in normal cell and Hela cases is slightly more of without sample case. As a result, amplitude value in the first 2 case is less than without sample case, will be displayed in the next Figure.

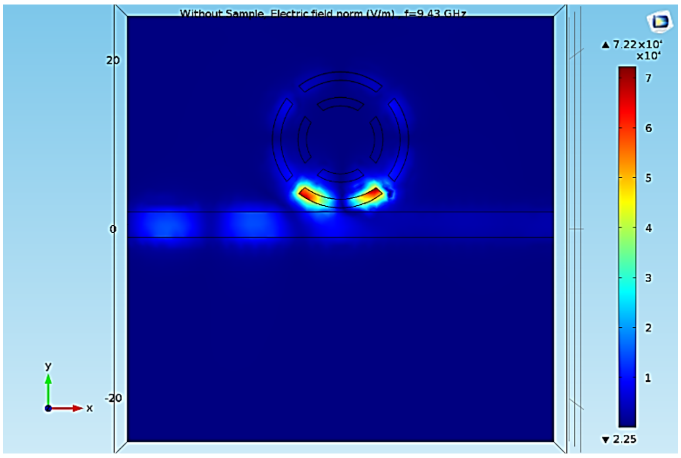

Figure 6: Electric field norm in the F=9.43 GHz for without sample state

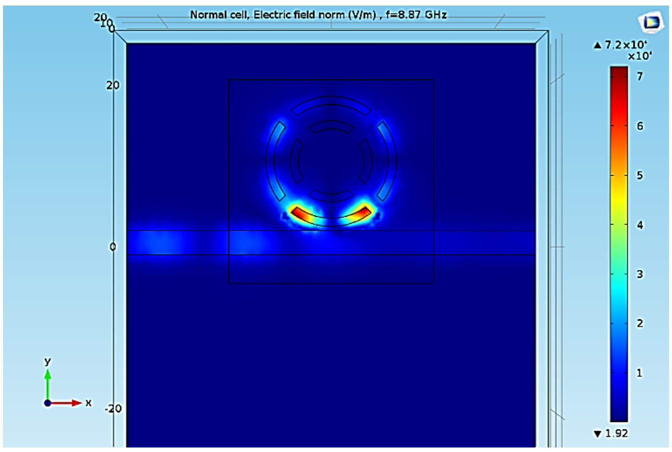

Figure 7: Electric field norm in the F=8.87 GHz for normal cell state

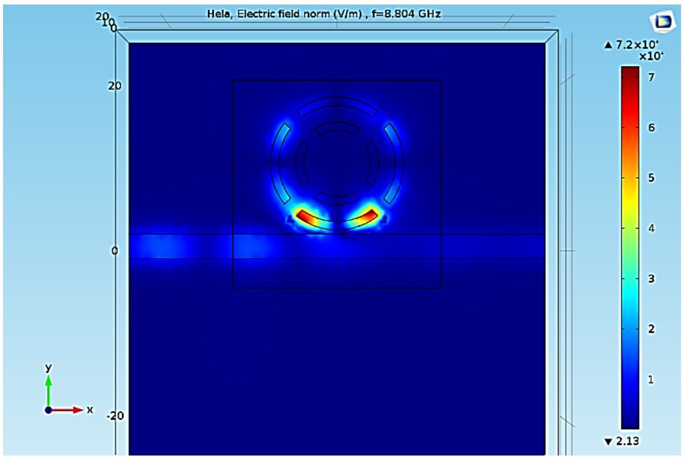

Figure 8: Electric field norm in the F=8.804 GHz for Hela state

In the Figure 9, it has been shown graph of direct transfer gain (S_{21}) for states without sample (blue line) and normal cell (red line). Be considerate that in state without sample resonant frequency of biosensor is about 9.43 GHz. While the resonant frequency of biosensor in state normal cell is approximately 8.87 GHz. we can say that the sensitivity of the biosensor to biological molecules is equal to 0.56 GHz (560 MHz).This structure SSRs in comparison to other structures has about two times more sensitivity.

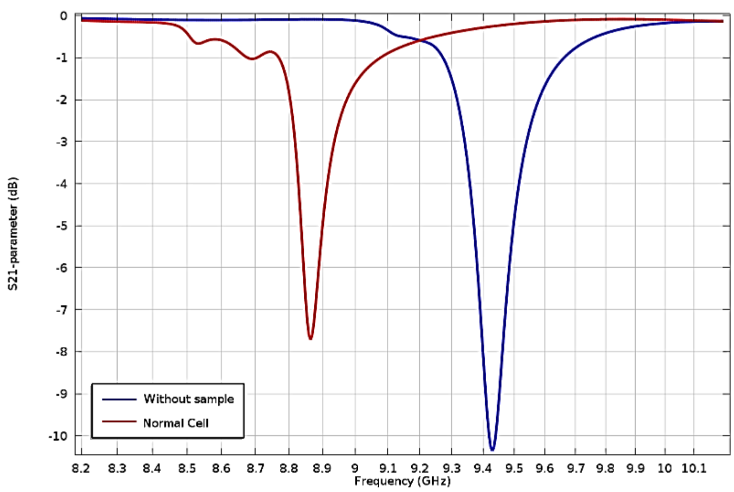

Figure 9: S_{21}-parameter graph for cases without sample and normal cell

Figure 10 Illustrate S_{21}-parameter for states normal cell and several types of cancer cells. As can be seen state normal cell and cancer cells are quite distinctive. Because the dielectric constant values in cancer cells is close together, as a result, it is also close together the graphs. However, the biosensor is able to distinguishing them from one another.

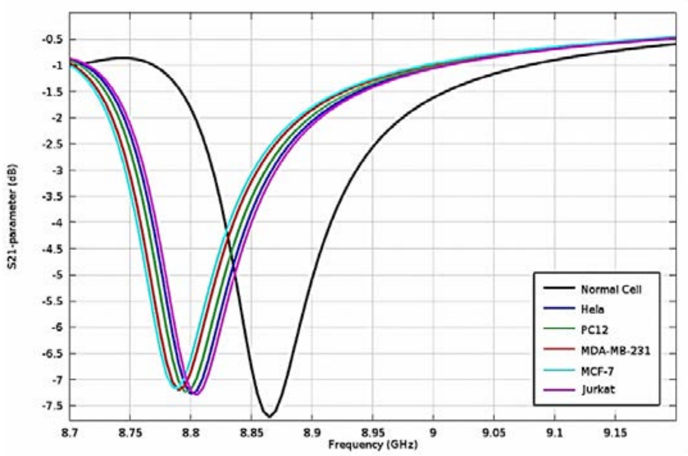

Figure 10: S_{21}-parameter graph for cases normal and cancer cells

Table 2 illustrate resonant frequency for all cases. The lowest amount of shifts is between cases PC12 to MDA-MB-231 and MDA-MB-231 to MC7 that this amount is equal to 0.005 GHz (5 MHz) that is acceptable. As a result, we can say that the ability to distinction between cancer cells in this structure is equal to 5 MHz.

Table 2: Resonance frequency values for all cases

Cases	Resonant Frequency
without sample	9.43 (GHz)
Normal cell	8.87 (GHz)
Jurkat	8.81 (GHz)
Hela	8.80 (GHz)
PC12	8.799 (GHz)
MDA-MB-231	8.794 (GHz)
MC7	8.789 (GHz)

Figure 11 illustrates input reflection coefficient graph (S_{11}) for normal cell and cancer cells. As well as Figure 12 shows graph of relation S_{21} to S_{11} (S_{21}/S_{11}). This graph obtained for 3 states without sample, normal cell and Hela. In this graph well is visible amplitude variations and frequency shift. Also the Figure 13 illustrates this graph for cancer cells and normal cell.

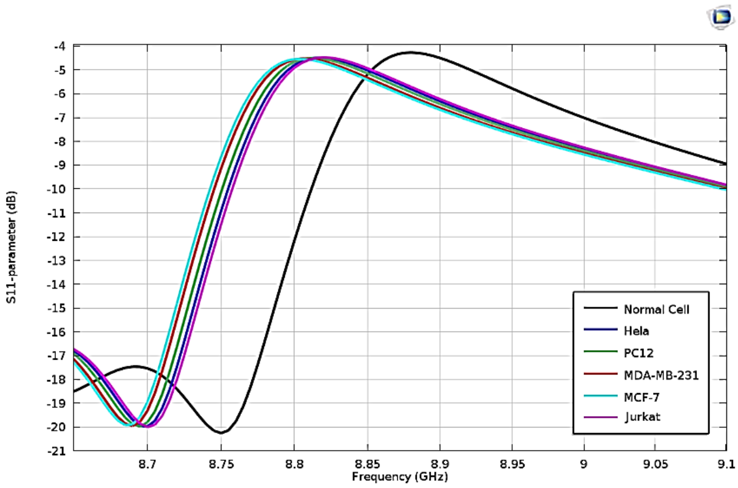

Figure 11: input reflection coefficient (S_{11}) graph for cases normal and cancer cells

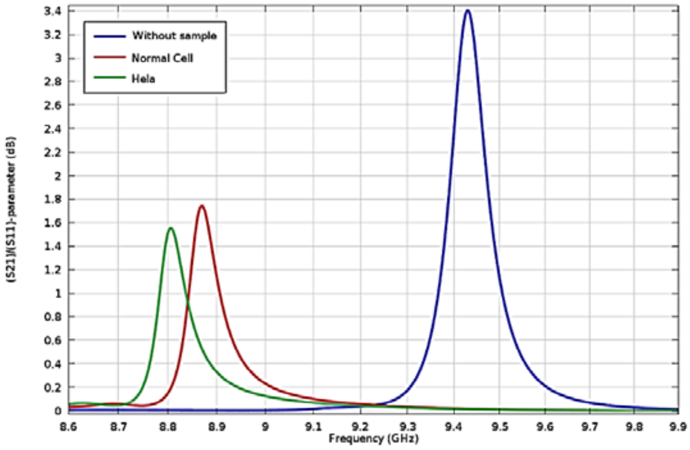

Figure 12: $(S_{21})/(S_{11})$-parameter graph for cases without sample, normal cell and Hela

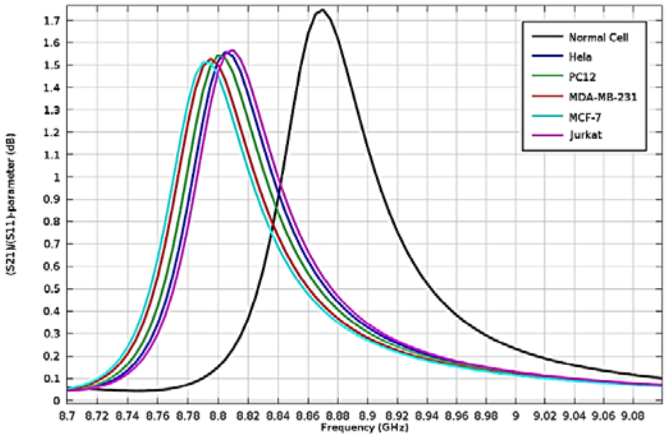

Figure 13: $(S_{21})/(S_{11})$-parameter graph for cases normal and cancer cells

Table 3 shows Amount amplitude (S_{21}/S_{11}) in resonance frequency for different scenarios. We can by measuring amplitude or frequency detected cancer cells.

Table 3: Amount amplitude (S_{21}/ S_{11}) in resonance frequency for all cases

Cases	Amount amplitude (S21/S11) in resonance frequency
without sample	3.411
Normal cell	1.745
Jurkat	1.567
Hela	1.560
PC12	1.545
MDA-MB-231	1.528
MC7	1.514

The graph shown in the Figure 14, exhibited the resonance frequency variations as a function of thickness of the sample for normal cell case. By reducing thickness of the sample the resonance frequency shifted to without sample case. The result can by decreasing thickness of the sample, reduced sensitivity of the biosensor and by increasing the thickness of the sample increases sensitivity.

Figure 15 shows this graph for HeLa case that indicate the same results. According to simulation results this biosensor can't detect samples with thickness less than 0.2 mm (200 µm).

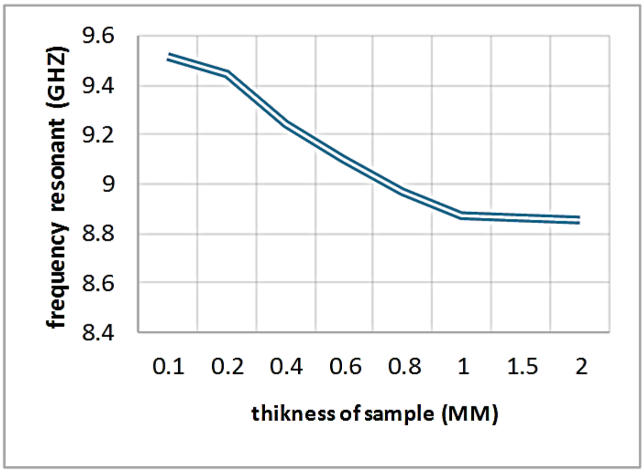

Figure 14: The resonance frequency variations as a function of thickness of the sample for normal cell case

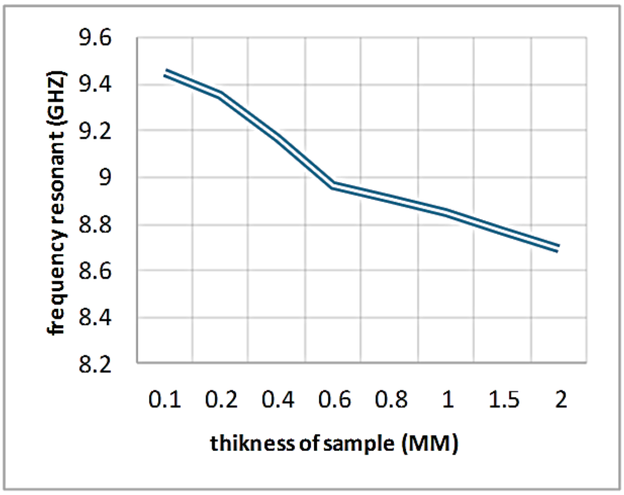

Figure 15: The resonance frequency variations as a function of thickness of the sample for normal cell case

CONCLUSION

This is article**,** we offered a design and simulation a low-cost and high sensitivity biosensor based on metamaterials for cancer cells detection by COMSOL Multiphysics software. The operating frequency this biosensor is in the microwave range (GHz). Application field it is detect binding of biomolecules. In structure this biosensor using of SRR (Split-Ring Resonator) because it have high sensitivity to electromagnetic waves. According to simulated result sensitivity this biosensor to biological molecules is about 0.56 GHz. Also manufacturing it is low-cost and can be produced locally. Our proposed biosensor has a lower cost than of the proposed biosensor [6] and a good sensitivity.

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