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Investigation of Kidney Stone Using a Microstrip Patch Antenna Scanning System

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Abstract

The abnormalities of the kidney can be identified by ultrasound imaging. The kidney may have structural abnormalities like kidney swelling, or change in its position and appearance. Kidney abnormality may also arise due to the formation of stones, cysts, cancerous cells, congenital anomalies, blockage of urine etc. For surgical operations it is very important to identify the exact and accurate location of stone in the kidney. The ultrasound images are of low contrast and contain speckle noise and could affect human body in some situations like pregnancy. This makes the detection of kidney abnormalities rather challenging task.Thus, microwave imaging could be a good alternative. A microstrip patch antenna scanning system allows to identify the exact and accurate location of stone in the kidney.A physical testing system will be developed in order to generate antenna response surfaces on material which could represent the human body. The serum is used in the experimental measurement because it has similar dielectric properties as human body. In order to represent stone presence in an homogenous medium, small calcium stone bearings of different sizes embedded are used to simulate the abnormality. Compact microstrip patch antenna were designed and tested at different frequencies in ISM band : 2.26 GHz, 2.38 GHz, 2.49 GHz, 2.5 GHz, and 2.62 GHz for the RF investigation imaging system in order to detect and localize stones in the kidney.

Keywords: Kidney stone detection, Microwave imaging, Patch antenna, Reflection losses.

1. Introduction

Kidney stone disease is one of the major life threatening ailments persisting human life. The stone diseases remain unnoticed in the initial stage, which in turn damages the kidney as they develop. Since kidney malfunctioning can be menacing, diagnosis of the problem in the initial stages is advisable. Ultrasound image is one of the currently available methods with noninvasive low cost and widely used imaging techniques for analyzing kidney diseases (Rahman and Uddin, 2013).

The kidney may have structural abnormalities like kidney swelling, or change in its position and appearance. Kidney abnormality may also arise due to the formation of stones, cysts, cancerous cells, congenital anomalies, blockage of urine etc (Viswanath and Gunasundari, 2014) and mostly causes a very painful situation for the patient. For surgical operations it is very important to identify the exact and accurate location of stone in the kidney. The ultrasound images are of low contrast and contain speckle noise and could affect human body (Wan, 2012; Tanzila and Mohammad, 2013). This makes the detection of kidney abnormalities rather challenging task. Thus, microwave imaging could be a good alternative. In this paper a physical testing system will be developed in order to generate antenna response surfaces on material which could represent the human body.The serum is used in the experimental measurement because it has similar dielectric properties as human body. In order to represent kidney stone presence in homogenous medium, small embedded calcium stone are used to simulate the stone presence in human body parts. Compact microstrip patch antennas were designed and tested at different frequencies in ISM band: 2.26 GHz, 2.38 GHz, 2.49 GHz, 2.5 GHz, and 2.62 GHz for the RF investigation imaging system in order to detect and localize stone inside the human body. Different frequencies are used in order to determine the most appropriate one capable to detect the stone's presence.

This study is one of very few studies which have investigated to detect experimentally the stone's presence in a kidney by microwave. The human body was represented by a serum with similar dielectric properties. The detection was made using microwave patch antennas with different resonance frequencies and a network analyzer. In this paper, the detection method for stones using an antenna scanning system is presented. In the theoretical part, the dielectric properties for human body and the First-order Debye model are developed. In the experiment work, the physical testing system is developed. Results and discussion are presented in the third part and the fourth part is the conclusion.

2. Theoretical Analyses

With an antenna located along the *z* direction, a TE wave is propagated in the *x-y* plane and the electric Helmholtz equation in free space is Staelin *et al.* (1994):

$$(\nabla^2 + k^2)E_z = 0 \qquad (1)$$

Where:

$$k^2 = k_0^2\left(\varepsilon_r + i\frac{\sigma}{\omega\varepsilon_0}\right) \qquad (2)$$

$$k_0 = \omega\sqrt{\mu_0\varepsilon_0} \qquad (3)$$

In the above equations, ∇^2 is the 2-D Laplacian operator, *k* is the medium wave number, $E_z$is the electric field in *z* direction, $k_0$is the free-space wave number, $\varepsilon_r$is the relative permittivity of the medium, σ is the medium conductivity, ω is the angular frequency, ε_0 is the free space permittivity, and μ_0 is the free space permeability.

Non-zero magnetic field components are derived from $E_z$by using Faraday's law in frequency domain as follows:

$$\nabla \times \vec{E} = i\omega\mu_0\vec{H} \qquad (4)$$

or:

$$H_x = -i\frac{1}{\omega\mu_0}\frac{dE_z}{dy} \qquad (5)$$

$$H_y = i\frac{1}{\omega\mu_0}\frac{dE_z}{dx} \qquad (6)$$

The dispersive dielectric properties of human body are required to be identified versus frequency. Debye formulation of the first or second order has been widely used to model the dispersive media (Ghandi *et al.*, 1993). This model fits the equation coefficients to the measured data and determines the relation between the electric displacement (D) and electric field (E). First-order Debye model is of the form:

$$\varepsilon_{rc}(\omega) = \varepsilon_r(\omega) + i\frac{\sigma(\omega)}{\omega\varepsilon_0} = \varepsilon_\infty + \frac{\varepsilon_s - \varepsilon_\infty}{1 - i\omega\tau} + i\frac{\sigma_s}{\omega\varepsilon_0} \qquad (7)$$

where $\varepsilon_{rc}$is the relative complex permittivity, ω is the angular frequency, $\varepsilon_r$is the relative permittivity, σ is the conductivity, ε_0 is the free-space permittivity, ε_∞ is the relative permittivity at infinite frequency, $\varepsilon_s$is the static relative permittivity, τ is the relaxation time constant, and $\sigma_s$is the static conductivity.

Hence, the relative permittivity and conductivity are formulated as follows, respectively:

$$\varepsilon_r(\omega) = \varepsilon_\infty + \frac{\varepsilon_s}{1+(\omega\tau)^2} \qquad (8)$$

$$\sigma(\omega) = \omega^2\tau\epsilon_0\frac{\varepsilon_s - \varepsilon_\infty}{1+(\omega\tau)^2} + \sigma_s \qquad (9)$$

With respect to the serum which is a solution of proteins and salts in water. The following assumptions have been made (Morgavi and Mela, 1982):

i. The protein permittivity is constant and equal to 2.
ii. The water has an equivalent NaCl normality N, which takes into account the effect of all ions; its permittivity is given by Stogryn's formula.
iii. The water bound to the protein has a Debye-type behavior with ε_0 =80, ε_∞=4.9 and relaxation f_δ.
iv. The permittivity of the mixture protein-bound water and the permittivity of the mixture of salt water with proteins and their bound water are given by Maxwell-Wagner-Fricke's formula.

3. Experimental Procedure

The calcium stones used in the experimental measurement are put in a flask filled with serum of 2 cm thickness.Different patch antennas are placed at 2 cm from the serum surface in order to investigate and to localize the stones.

The patch antenna is scanned on the serum surface using an X-Y scanning system in order to move on the target surface in X-pixels and Y-pixels.The spectrum analyzer will be used to measure the antenna response at discrete points along the target domain. The return losses measurements are taken for every X and Y target position at every indentation.In order to measure the reflection coefficient S_{11}, we use a Rhode and Schwartz Handheld spectrum analyzer FSH4View going up to 8 GHz with a tracking generator which allowed us to perform reflection measurements. Therefore, the antenna is connected to the spectrum analyzer and then the measured data is collected withthe handheld spectrum analyzer FSH4View which is also connected to a laptop in order to analyse and display results. Fig. 1 shows the test bench for the antenna scanning system for heterogeneity detection.

Fig-1. Test bench of heterogeneity detection.

4. Results and Discussion

The first experiment is done on an empty flask to investigate the resonance of the each antenna in the free space. For example, the patch antenna of 2.5 GHz, we obtained in the free space the reflection loss (S_{11}) is -10 dB as shown in Fig. 2.

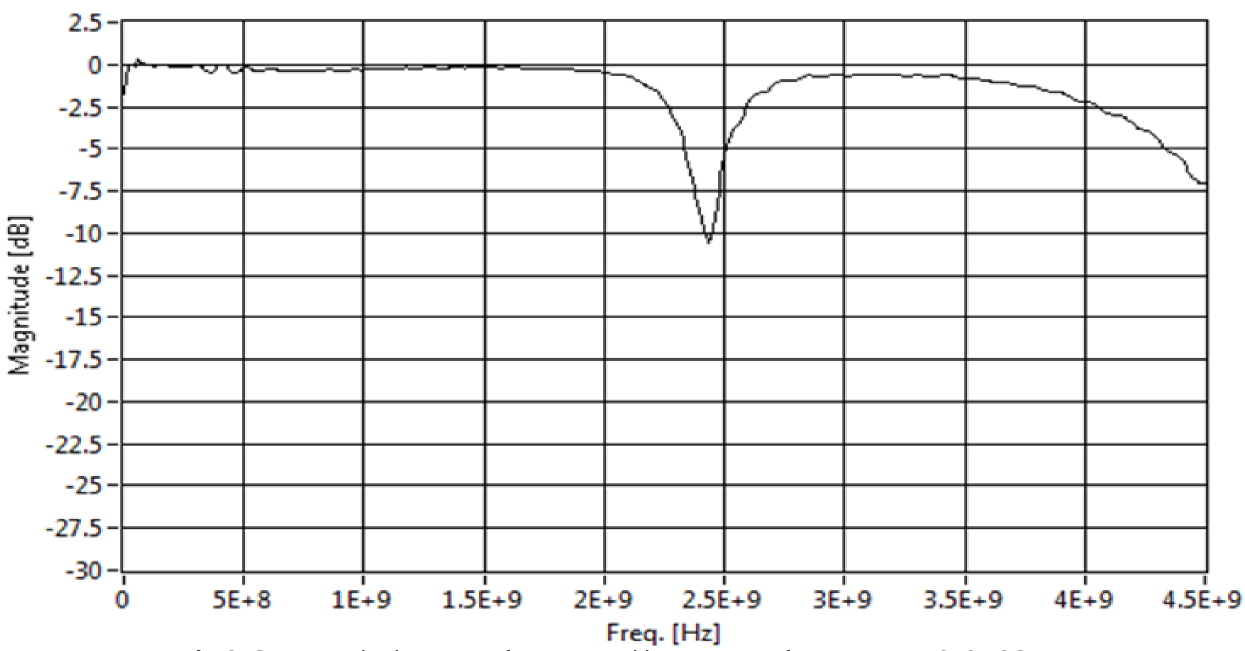

Fig-2. S11 magnitude versus frequency with resonance frequency at F0=2.42GHz.

The next step is to fill the flask with serum (2 cm thickness) which represents an homogenous human body. Fig. 3 represents the measured S_{11}. We notice that at the resonance frequency f_0=2.52 GHz the reflection loss (S_{11}) is -20.8dB. For S_{11} = -10dB the corresponding frequencies are 2.49 GHz and 2.56 GHz.

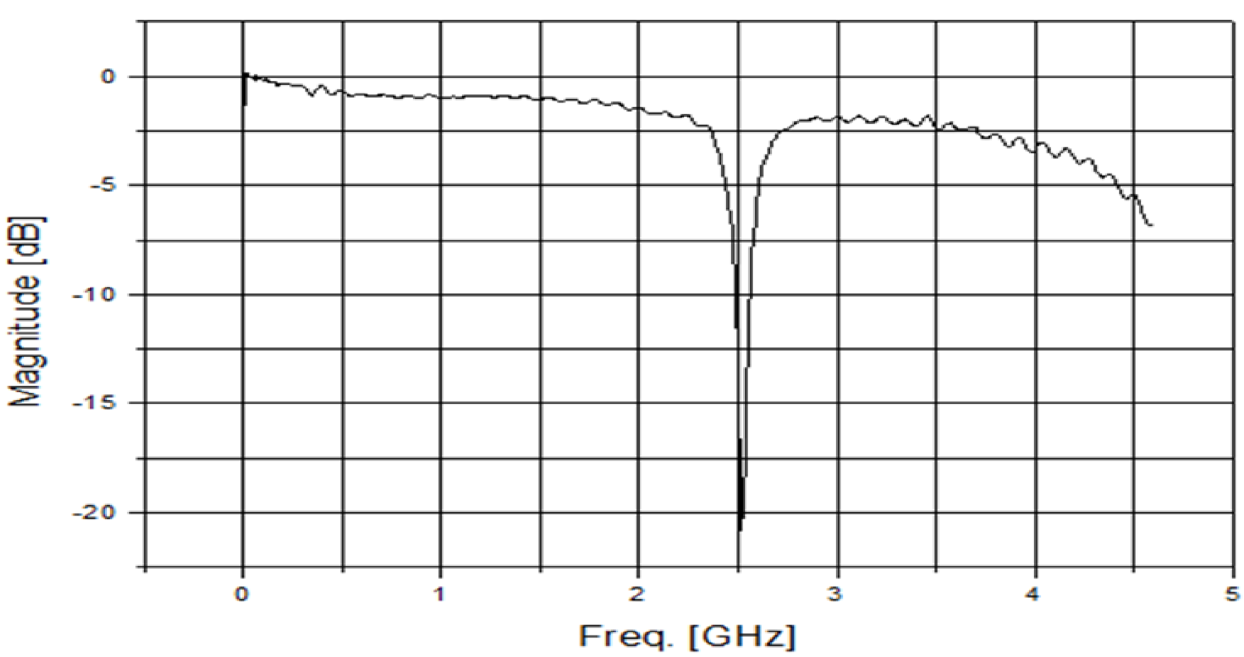

Fig-3. S_{11}magnitude versus frequency for serum with 2cm thickness.

Measurements are achieved in order to demonstrate that serum used in the experiment has similar dielectric properties as human body. Therefore; we compare reflection losses of human body and serum using the same antenna at 2 cm from both surfaces. Fig.4 shows the obtained results of the two surfaces. The reflections losses have the same form but shifted in terms of frequency.

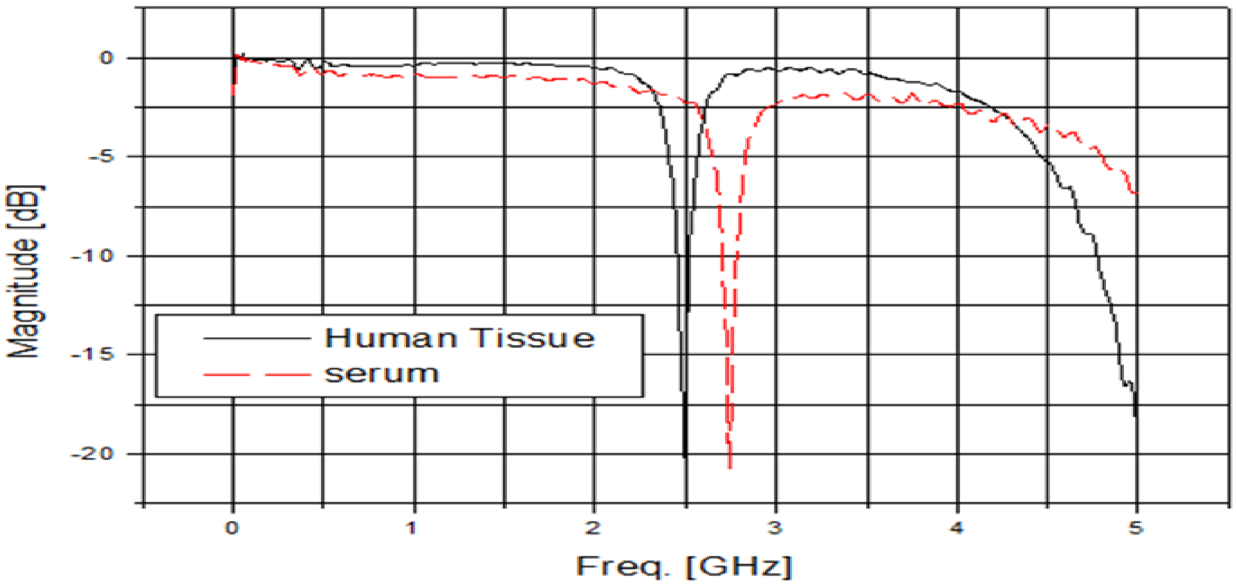

Fig-4. Comparison of S_{11} magnitude with respect to the frequency for serum and human body.

We designed and used many patch antennas with different frequencies in ISM bands: 2.26 GHz, 2.38 GHz, 2.49 GHz, 2.5 GHz, and 2.62 GHz for the RF investigation imaging system in order to detect and localize the kidney stone.

Many tests were done to determine appropriate frequency and select the suitable antenna to detects the stones. In the experimentation, we immerse 0.5 cm **c**alcium stone in the flask. For the first patch antenna which has a resonance frequency at 2.26 GHz, we measure the reflection loss for three mediums: free space, homogenous serum andheterogeneity medium when **c**alcium stone is immersed. Fig. 5 shows the reflection losses of the three mediums regarding to the frequencies between 1 and 8 GHz.

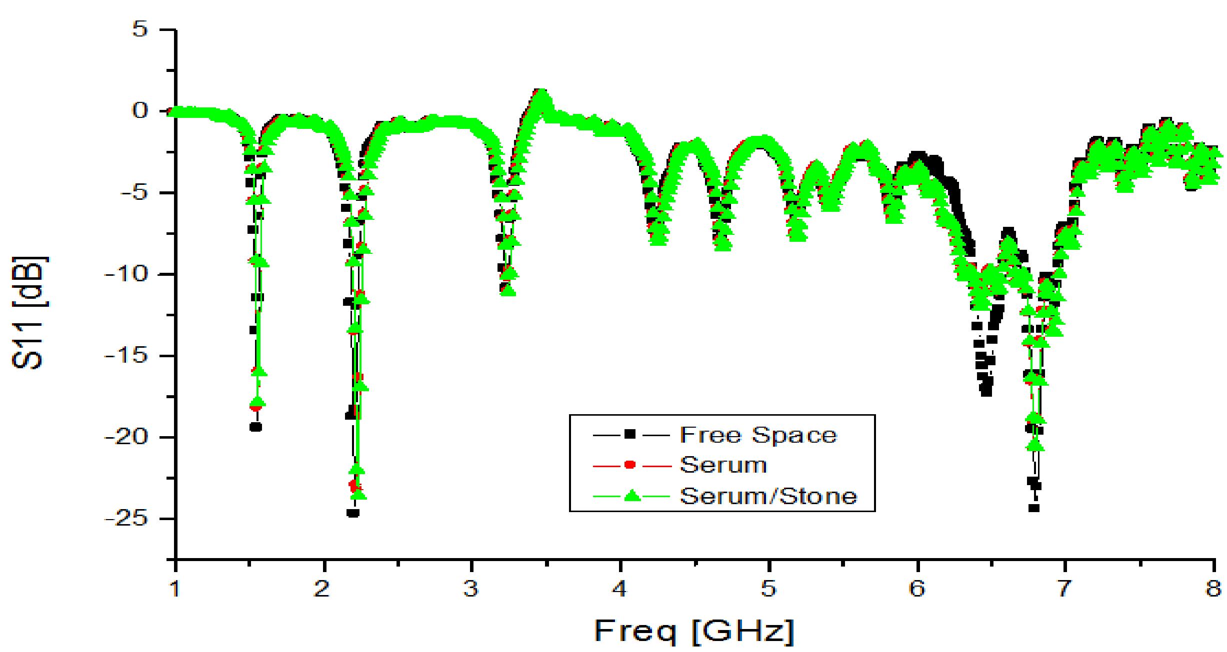

Fig-5. S_{11} magnitudes toward frequency for the different mediums with patch antenna at resonance frequency f_r=2.26 GHz.

Around resonance frequency of 2.26 GHz, the reflection losses values are presented in the table1. When the antenna detect the stone the refraction losses slightly increased to -23.57 dB.

Table-1. Comparison of S_{11} for the different medium at resonance frequency f_r=2.26 GHz

Medium	S_{11} [dB]
Free Space	-24.50
Serum	-23.25
Serum/stone	-23.57

We can deduce that no real difference is observed in resonance frequency. Therefore, we cannot use this antenna to detect the stone's presence. Other patch antennas must be examined in the same experiment conditions to select the appropriate one.

For the second patch antenna which has a resonance frequency f_r=2.38GHz, the reflection losses measurements are shown in the fig. 6 for the different mediums.

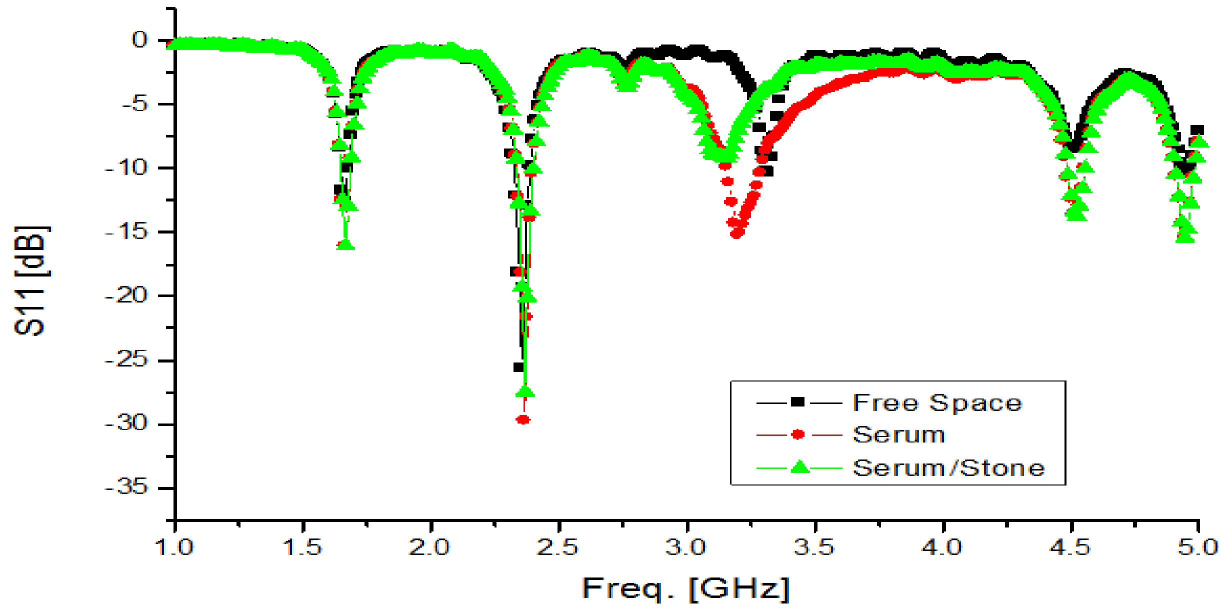

Fig-6. S_{11} versus frequency for the different medium with antenna at resonance frequency f_r =2.38 GHz.

For this type of antenna, when it detects the stone a small variation in the reflection losses is observed. The reflection losses values at the resonance frequency are shown in the table 2.

We noticed that the reflection losses are shifted at resonance frequency f_r=2.38 GHz. The value of S_{11} in stone medium is decreased to-28.9dB comparison to the homogenous serum (-31.2 dB).

On the other hand, the reflection losses has strong shift value between 3 and 3.5 GHz which is approximately 6 dB .

Table-2. Comparison of S_{11} for the different medium at resonance frequency f_r=2.38 GHz.

Medium	S_{11} [dB]
Free Space	-26.3
Serum	-31.2
Serum/stone	-28.9

For the third patch antenna with resonance frequency of f_r=2.49 GHz, the reflection losses measurements are shown in the fig.7 for the different medium.

When the antenna detect the stone in the serum the refraction losses slightly increased to -26.50 dB.

The reflection losses values at the resonance frequency are shown in the table 3 for the three mediums.

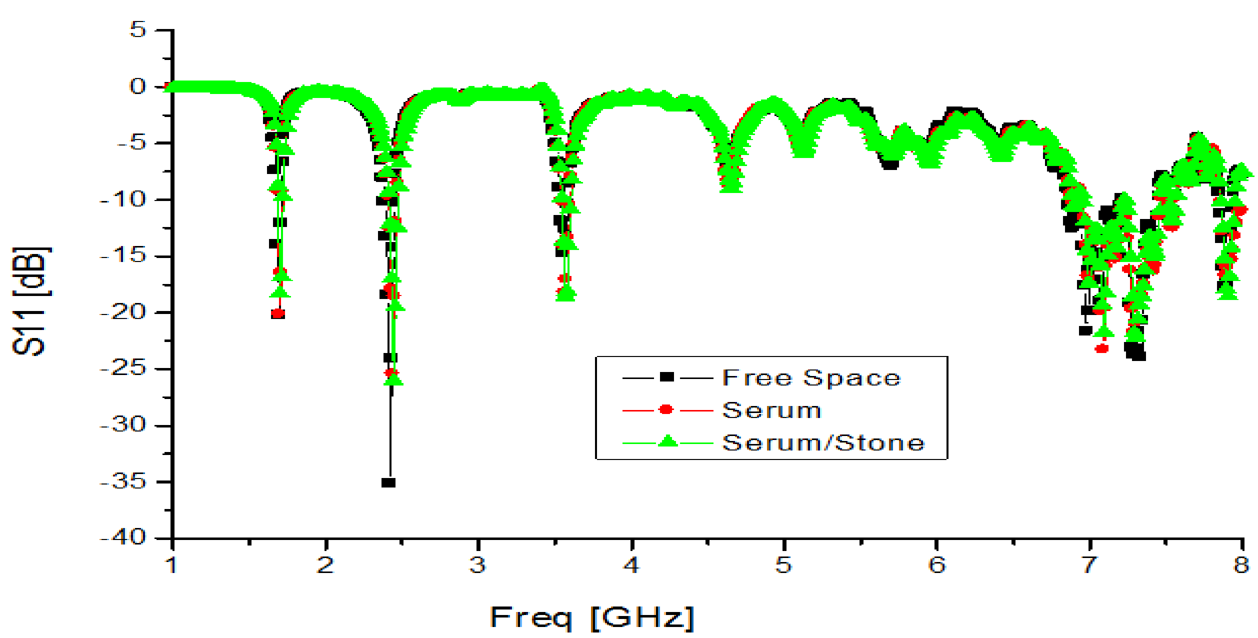

Fig-7. S11 magnitudes with respect to the frequency for the different medium with antenna at resonance frequency f_r =2.49 GHz.

Table-3. Comparison of S_{11} for the different medium at resonance frequency f_r=2.49 GHz

Medium	S_{11} [dB]
Free Space	-35.19
Serum	-25
Serum/stone	-26.50

For the fourth patch antenna has a resonance frequency f_r =2.5 GHz. The reflection losses measure shown in the fig. 8 for the different medium. For this antenna, we observed that the value of S_{11} in stone medium is shifted 12% with respect to the homogenous serum. The reflection losses values at the resonance frequency of the fourth antenna are shown in the table 4 for the three mediums.

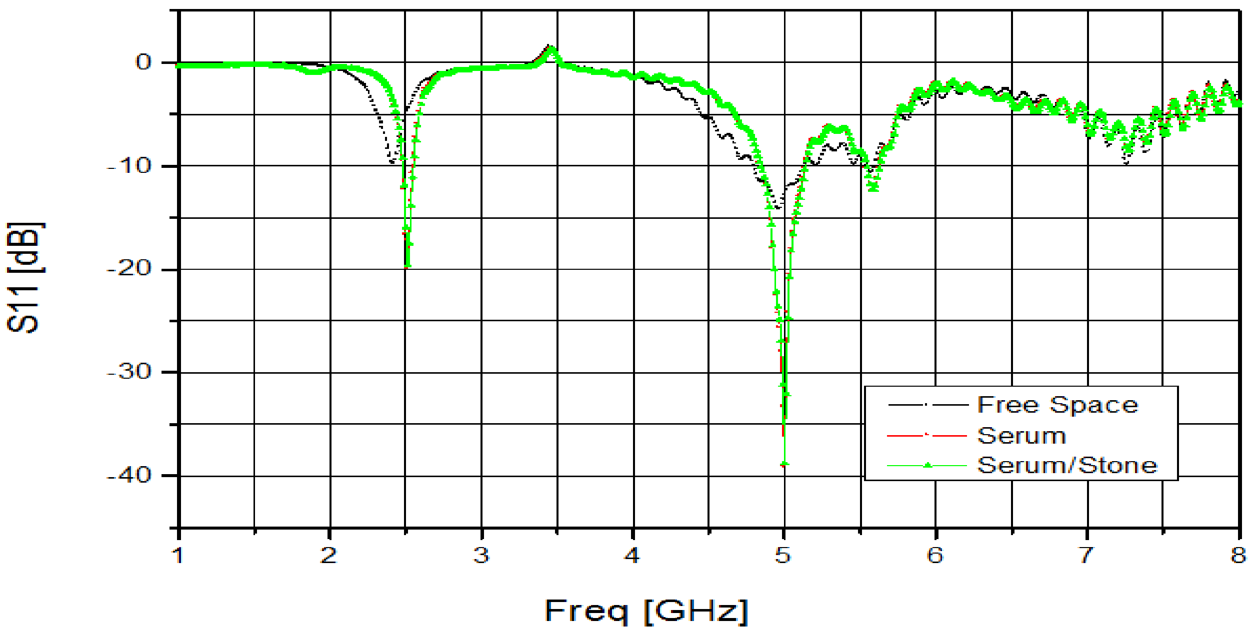

Fig-8. S11 magnitudes with respect to the frequency for the different medium with antenna at resonance frequency f_r =2.5 GHz.

Table-4. Comparison of S_{11} for the different medium at resonance frequency f_r=2.5 GHz.

Medium	S_{11} [dB]
Free Space	-10
With Serum	-17.5
Serum/stone	-20.00

For the fifth patch antenna of resonance frequency f_r=2.62 GHz, We notice that the value of S_{11} of the stone medium is clearly shifted, 14% compared to the homogenous serum.

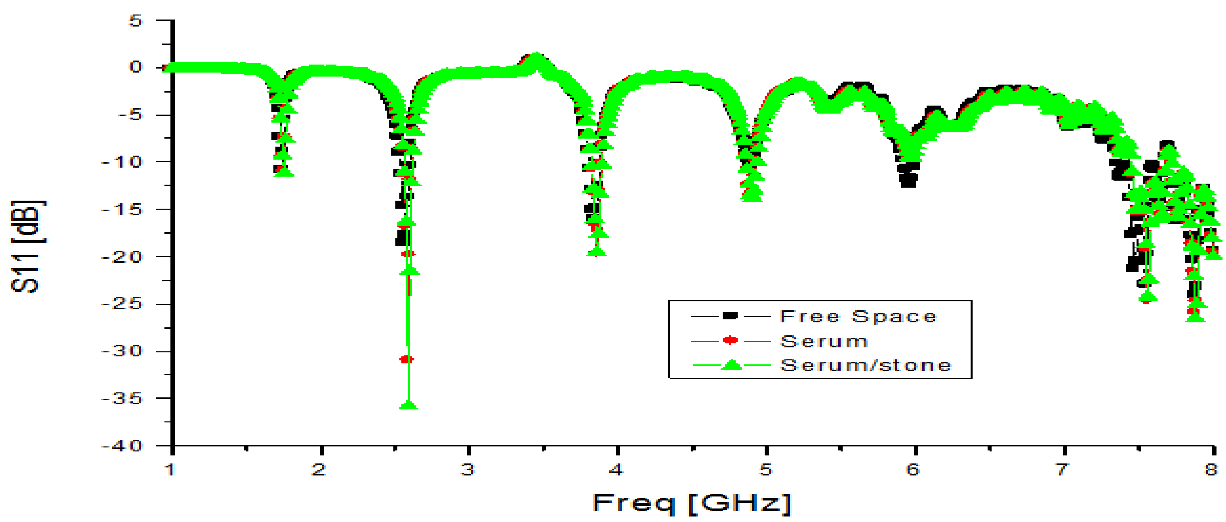

Fig-9. S11 magnitudes with respect to the frequency for the different medium with antenna at resonance frequency f_r=2.62 GHz.

The reflection losses values at the resonance frequency of the fifth antenna are shown in the table 4 for the three media.

Table-5. Comparison of S_{11} for the different medium at resonance frequency f_r=2.62 GHz.

Medium	S_{11} [dB]
Free Space	-18.53
With Serum	-31.00
Serum/stone	-36.00

5. Conclusion

Microwave imaging using antenna scanning system is a hopeful method for the detection of stones inside the human body, especially in the kidney. The antenna is put two centimeters above the target tissue for the detection of stone's presence in serum medium. In the paper, we detailed the dielectric properties of the human body and the

First-order Debye model. Based on the serum model, reflection losses on the homogenous serum are measured. The heterogeneity represented by stones is detected using different patch antenna along the flask domain**.** Compact microstrip patch antennas were designed and tested at different frequencies in ISM band for the RF investigation imaging system in order to detect the stone. First experiments demonstrated that when the antenna resonance frequency increased, the shifting in S_{11} between homogenous serum and serum with stone's presence increase More studies will be conducted on two levels: antenna resonance frequency and more real model of kidney of human body.

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