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Research Article

LUNG TUMOUR DETECTION USING ULTRA-WIDEBAND MICROWAVE IMAGING APPROACH

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ABSTRACT

The use of Ultra-Wideband (UWB) microwave imaging for tumour detection has gained increasing popularity within the bio-medical field. Microwave imaging turned out more efficiently accurate to some body parts such as breast and brain imaging. This work presents on the possibility and the effectiveness of UWB microwave imaging technique on lung tumour detection. Simple technique of using reflection method was studied and then applied for lung tumour detection by using UWB antenna. The simulated results show that the proposed method is capable to detect a lung tumour with minimum radius size of 4 mm for different positions inside the lungs at the frequency of 3.67 GHz. It is a promising technique to be further developed in modern UWB imaging systems which demand perfect results at very low cost.

Keywords: ultra-wideband; microwave imaging; lung tumour; Antenna.

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1. INTRODUCTION

Diseases are the most terrifying threat to human existence. Cancer is one of the major leading morbidity nowadays. According to GLOBOCAN 2012, there were 14.1 million new cancer cases and 8.2 million cancer-related mortality rate recorded around the world [1]. Among them, lung cancer is the most frequently diagnosed cancer at a total of 1.8 million cases (13%) [1]. Ironically, the researches on detection techniques for this type of cancer are far behind the development for breast cancer (at 11% of incidence). However, there are researches proving that microwave techniques are capable to successfully diagnose lung and heart diseases other than cancer related problem [2-7]. So, there must be possibility to design suitable microwave techniques that is also efficient for lung cancer detection.

Cancer is a type of tumor. It is a result from abnormal multiplication of tissue mass usually classified by the organ it originates. It can be detected as either malignant (cancerous) or benign (non-cancerous) in nature [8]. However, the main concern is for the cancerous type, which needs to be stopped from multiplying uncontrollably into bigger mass or worse, by time, it can metastasize outside the host. Sometimes, due to certain factors known or unknown to the medical world, it can ferociously accelerate its growth within short duration of time. The worst scenario of all, it can even spread to the whole body system, thus, hijack the normal system and cause unbearable pain or even mortality.

Yet, the existing treatment of cancer is more effective only when detected at an earlier stage. Also, it is important to determine whether a tumour is malignant or benign in order to decide the medical management for a patient. Currently, there are various methods exist in detecting tumour, where different parts of the body need different type of imaging marker tests [9]. As specifically for the lungs, the most suitable methods available are low-dose spiral Computed Tomography (CT) scan, sputum cytology and chest x-ray. Recently, chest x-rays are considered outdated and no longer recommended for screening [10].

The cancerous tumour in the lung is diagnosed through the interpretation of the tissue or fluid of the lung resulted from the imaging processes by radiologists. However, even if cancerous tumour is suspected, the pathologists will further laboratorily investigate the result by testing specimens of live tissue from the patient through cytology like Fine Needle Aspiration Cytology (FNAC) or biopsy as needed as per case. Sometimes, a bronchoscopy will be done to further see the lungs condition to yield a more precise diagnosis. It will show the type; stage and condition of the illness, and this assist the oncologists to decide its suitable treatment and medical management [8,9].

But most of the screening methods suffer some shortcomings for example the diagnostic mammography x-ray for breast is not efficient enough to discover early-stage cancer tissues despite its high resolution images, yet, the results produced high false-alarm rate and its scanning procedure was considered uncomfortable by patients [11]. Above all, the main concern goes to the exposing patients to hazardous ionizing radiations and magnetic fields. Apart from it, the cost is exorbitant [12]. Contrary to that, UWB microwave imaging is a more viable alternative for cancer detection through Ultrasound or Magnetic Resonance Imaging (MRI) for example, due to the non-invasive nature, while also offering a lower cost speedy image generation, which detection results comparatively show higher level of sensitivity, specificity and accuracy [12].

Even so, UWB microware imaging has yet been widely used unlike other screening methods. Thus, this paper attempts to contribute another alternative technique in the list with the proposed method. Initially, the challenge is the field is still in the beginning, hence, is lacking of expected voluminous reference. It needs to tackle adequate knowledge on the biological dimension of the organ, the dielectric properties of the normal human tissue as well as establishing safe procedural microwave propagation into the lungs.

Moreover, there are many types of lung cancer in the medical classification. Each may need different procedural applications [13]. Medically termed, there are two main groups of classification involved in this specialization: Small Cell Lung Cancer (SCLC) and Non-Small Cell Lung Cancer (NSCLC) [14]. The SCLC cases rated at approximately 15-20% out of total [13]. Meanwhile, the NSCLC category consists of Squamous Carcinoma, Adenocarcinoma and Large Cell Carcinoma, and unclassified types with estimated incidence for each category: 35%, 27%, 10%, and 8% respectively. The highest rate goes to the Squamous Carcinoma, which typically developed over time due to smoking habits.

Usually microwave signal utilizes electromagnetic waves at frequency ranging from 300 MHz to 30 GHz to analyze the internal composition of an object [7]. So far, microwave imaging techniques are divided into three categories: active, passive and hybrid techniques [15]. For the active technique, a low power microwave signals are transmitted into the tissue using an array of antennas and then backscattered to form images through the transmitted signals of the imaged tissue. Examples of active imaging techniques are microwave tomography, holography and UWB pulsed radar imaging.

In the other method, the passive imaging uses the contrast of temperature between cancerous and normal tissues to form images. Characteristically, the cancerous tissues lose their thermoregulatory capacity and generate more heat than the normal host tissue. This approach is called radiometry and uses a radiometer [4,15]. When the microwaves heat up the tissues, pressure waves are generated due to the expansion of the heated tissues. An ultrasound transducer is used to detect these pressure waves and as there is more energy generated by tumour tissue, the pressure waves are significantly differentiated. The difference between the pressure waves can be used to construct an image [15]. Microwave-induced ultrasound imaging, thermo-acoustic tomography and microwave elastography are examples of hybrid microwave imaging techniques [4].

The dielectric properties of a biological tissue are a measure of the interaction of electromagnetic radiation with its constituents at the cellular and molecular level; and they are highly frequency and temperature dependent [16]. The water content of biological tissues plays a major role in their dielectric properties. Only organs with high water content are good conductors, in contrary to those with low water content tissues such as lungs, bones and fat are very poor conductors [17]. Theoretically, the tumour tissues have higher dielectric properties than the normal tissues. For instance, an experimental study [18] on the lungs has discovered that the relative permittivity of cancerous tissue is 1.2 to 3 greater than that of the normal tissue and the conductivity is approximately 1.6 to 2 greater.

Interestingly, the first attempts applying microwave propagation found in researches [3,19], where simulation was performed on a tumour infected lung into the thorax. The transmitted and reflected pulses are further analysed to detect the presence tumours or overrule it. The simulation uses a finite time domain technique and it involves radiating plane waves of different frequencies between 1 to 30 GHz on a section of human thorax and reading the transmitted and reflected signals on a screen. Values obtained for the signal detected were observed for these signals at frequencies less than 6 GHz. The results suggested using 3 GHz as the optimum frequency for lung related simulations using microwaves.

2. UWB MICROWAVE IMAGING METHOD

A conventional circular microstrip UWB antenna was used in this research as shown in Fig. 1. Its geometrical parameters are listed in Table 1. The substrate material used is FR-4 lossy with 1.6 mm thickness and dielectric constant of 4.4. While the copper used for both the patch and ground parts are 0.017 mm thick respectively. The range of frequency used is the all-inclusive UWB frequency (i.e. less than 6 GHz) in order to get more exhaustive perspectives of the results. Whereby, the standard accounted range of optimum frequency is at 3 - 4 GHz for the lung related simulations [18].

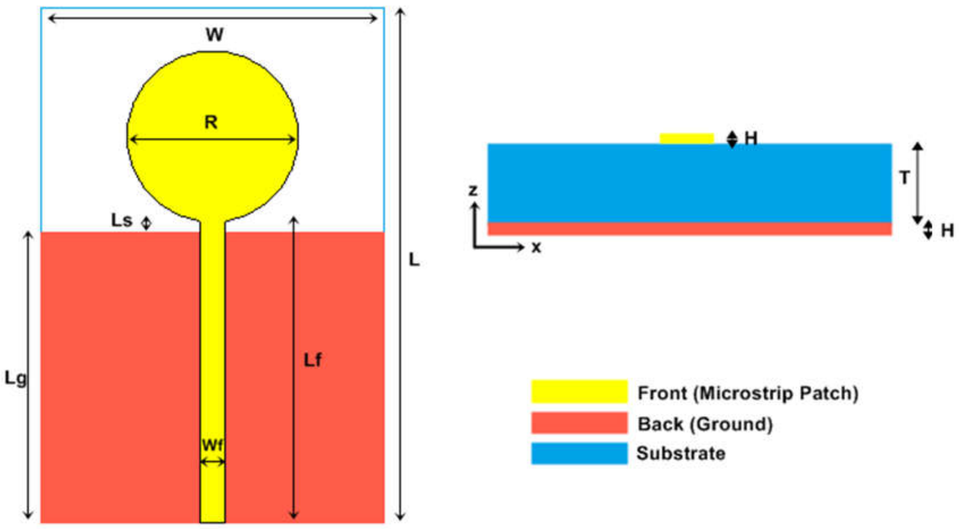

Fig.1. Structure of the conventional circular microstrip UWB antenna

A sliced section of the thoracic wall covering dimensions 60 mm by 60 mm is cubically illustrated in Fig. 2 to represent the human thorax model. The thickness of every tissue layer displayed there was originated from the work of Cavagnaro et al [5]. The heart part was excluded in in the simulation to simplify illustration.

Table 1. UWB antenna parameters

Parameter	Dimension (mm)
H	0.002
T	1.513
W	40
L	60
Wf	3
Lf	35
Lg	34
Ls	1
R	10

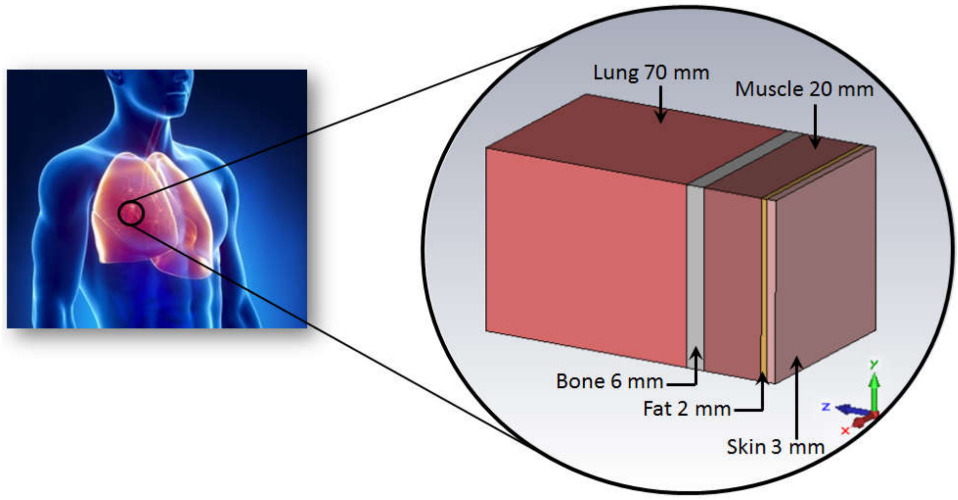

Fig.2. Multilayers of thoracic tissues [5]

Additionally, a tumour model was incorporated as a spherical shape into the lung tissue model. Referring to the dielectric properties comparison done in [18], the results concluded that the ratios of dielectric properties between cancerous tissues and normal lung tissues are approximately at 3:1 for permittivity and 2:1 for conductivity along the frequency band of microwaves. However, the simulation also taken into account the properties of muscle tissue to represent the tumour because tumour tissue would appear to have blood and muscle related tissue as mentioned in [18] to avoid discrepancy or fallacy of the results. The first part of the simulation process is done on determining the optimum distance between the antenna and the human thorax section. A 10 mm radius tumour was placed at (0, 0, 10) mm respectively into the virtual mass of the lung tissue. The antenna was initially placed 20 mm away from the human thorax section and gradually decreased from 15 mm to 10 mm and 5 mm. The *d* label in Fig. 3 represents parameter of antenna distance in the measurement setup.

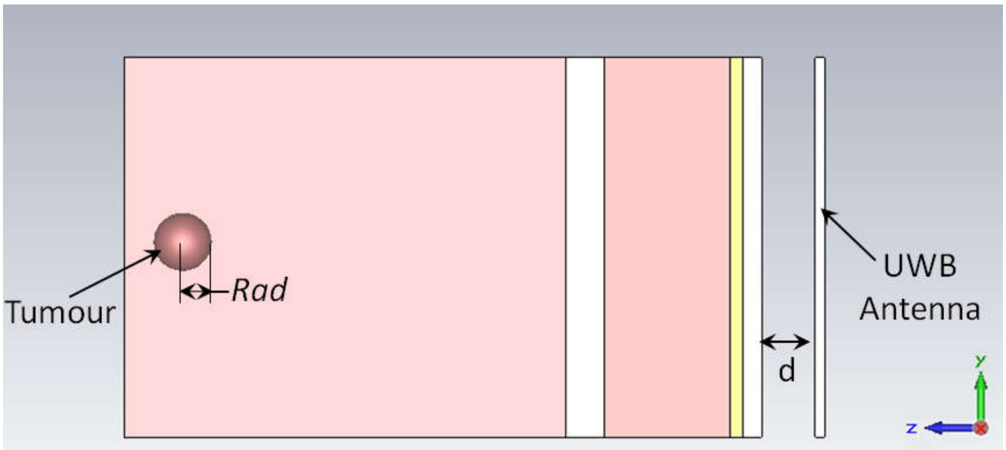

Fig.3. Measurement setup

Later, the second part is simulated for size of tumor variations labeled as *Rad* in Fig. 3. According to Seki et al [20] and Mayo Clinic research group [10] the approximate tumour size of early-stage lung cancer detected using CT scanning is typically 15 mm in diameter or less. Subsequently justified, four radius sizes of 10 mm, 8 mm, 5 mm and 3 mm each were simulated. The final part of the simulation is detecting the tumour position variation. There were nine (9) probable positions located at 60 mm along the z-plane inside the lung tissue visualization as illustrated in Fig. 4 were assessed. The simulated antenna is tried onto each fictional position of the tumour at the coordinates (A-I) and the reflected waves are recorded as reflection coefficient of return loss values.

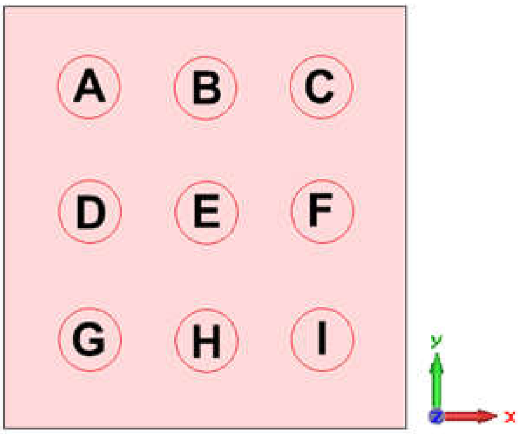

Fig.4. Tumour coordination inside the lung tissue

3. RESULTS AND DISCUSSION

Overall, the proposed UWB microwave imaging method used to detect the lung tumour went through required simulation experiments to validate its effectiveness in terms of the principle of work, results and demonstrate its advantages over the existing methods. A tumour of 10 mm radius is inserted for this process. As the Fig. 5 demonstrates, the resonance frequencies of all four of the distances have reflection coefficients below -10 dB. This indicates that all of the considered distances can be used to perform the imaging at the lungs to detect tumour. However, it is found that the lowest return loss that the reflection coefficient represents is achieved by distance d = 10 mm. Also, Fig. 5 illustrates the results yielded from the variation of antenna distance “d” at 2.5 to 7 GHz. The figure also shows that the difference in losses of 10 mm compared to other distances are more significant as listed in Table 2. Accordingly, the antenna works best at a distance of 10 mm, on the resonance frequency of 3.67 GHz which matched the research result in [2], [3] that stated as the optimum frequency for lung related simulations is within the range of 3 to 6 GHz.

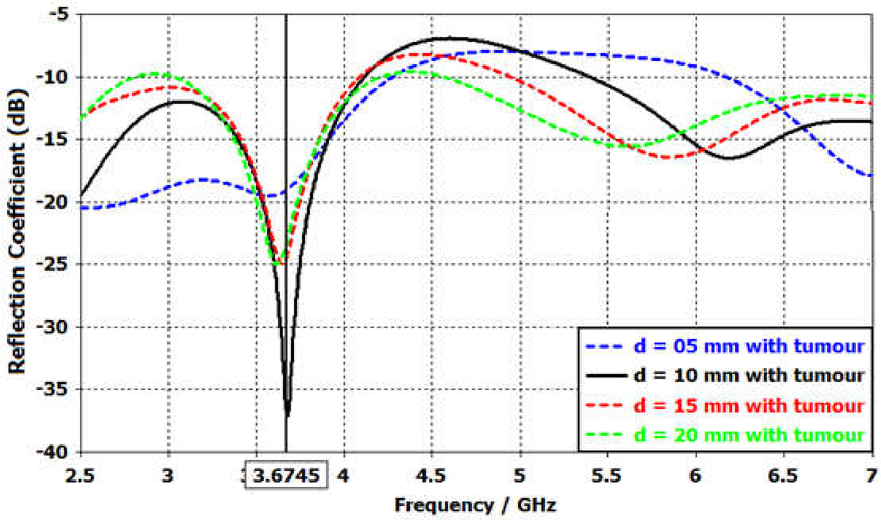

Fig.5. Simulated return loss with different values of *d*

Table 2. Reflection coefficient at different antenna distance

Antenna distance, *d* (mm)	Reflection Coefficient (dB)
5	-20.45
10	-37.21
15	-24.99
20	-24.93

Fig. 6 depicts the result of the tumour size variation at several points of frequencies form 2.5 to 7 GHz. Antenna is located at a fixed distance of 10 mm away from the thorax tissue as it is the best distance according to the results obtained from the analysis of previous simulation results. The simulated results are analyzed by comparing frequency shift of the simulation with different values of Rad (radius) to the frequency of simulation with the absence of tumour represented by Rad = 00 mm. From Fig. 7, the detection can be successfully deduced with tumour of 4 mm radius size showing the most significant shift in frequency. Meanwhile, the results also mean that tumour of radius 5 mm, 8 mm and 10 mm have the same value of frequency shift from Rad = 00 mm, which indicate that they are detectable. From the figure also, reflection coefficient values are lower in the presence of tumour than in the absence of tumour. This gives the indication that the tumour contributed to the changes in reflection coefficient. However, simulation results of radius 2 mm and 3 mm sized tumour interpreted that there are no frequency shift occurring. This can be deduced that the simulation is ineffective to detect tumour radius size from 3 mm and below.

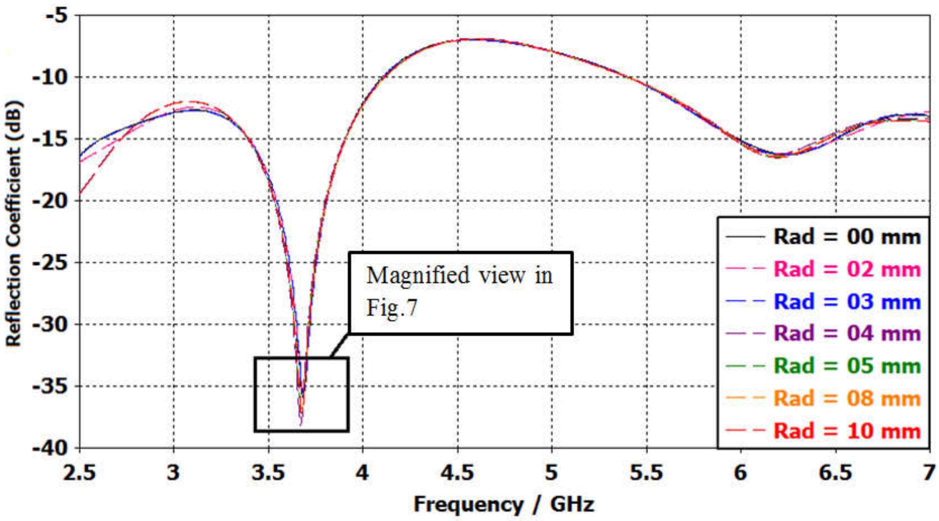

Fig.6. Simulated return loss with different values of *Rad*

By applying the results of previous analyses; 4 mm tumour radius and antenna distance 10 mm away from human thorax section are used to perform this experiment by simulating a tumour positioned at 9 coordinates (A to I) and the results are illustrated in Fig. 8. As the simulated results in Fig. 9 demonstrate, it can be excitingly inferred that the techniques successfully detected the presence of tumour at different locations. However, those at the locations: A, B and C are more noticeably identified. From observation, it is implied that the antenna can significantly detect any presence of tumour at the upper side of the lung tissue section. Furthermore, it can be seen from the figure, "tumours" located at D, E, F and H are also detectable. Unlike in the Fig. 9 also, where it can be understood that tumour located at G and I, respectively had not shown any frequency shift compared to the simulation result with absent tumour in the black solid line. Hovering the antenna around the human thorax can be helpful to detect the presence of tumour at different locations.

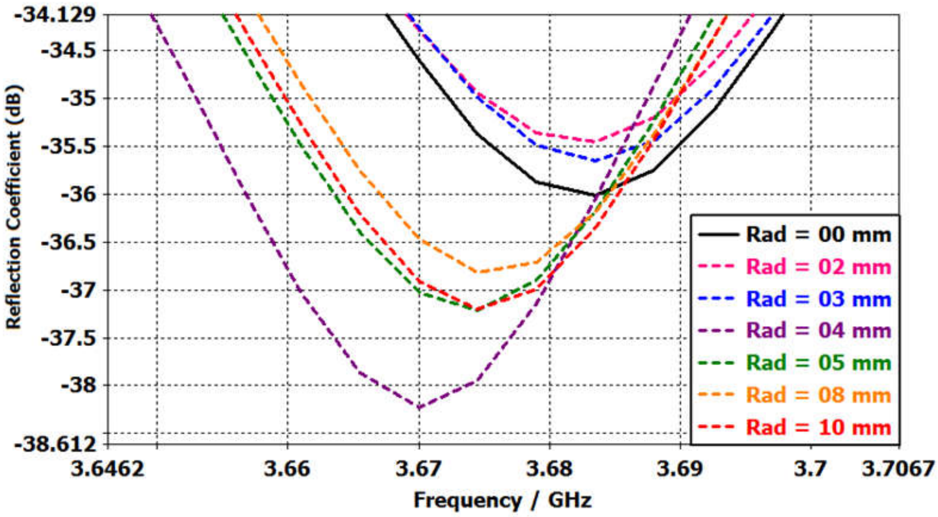

Fig.7. Magnified view of simulated return loss with different values of *Rad*

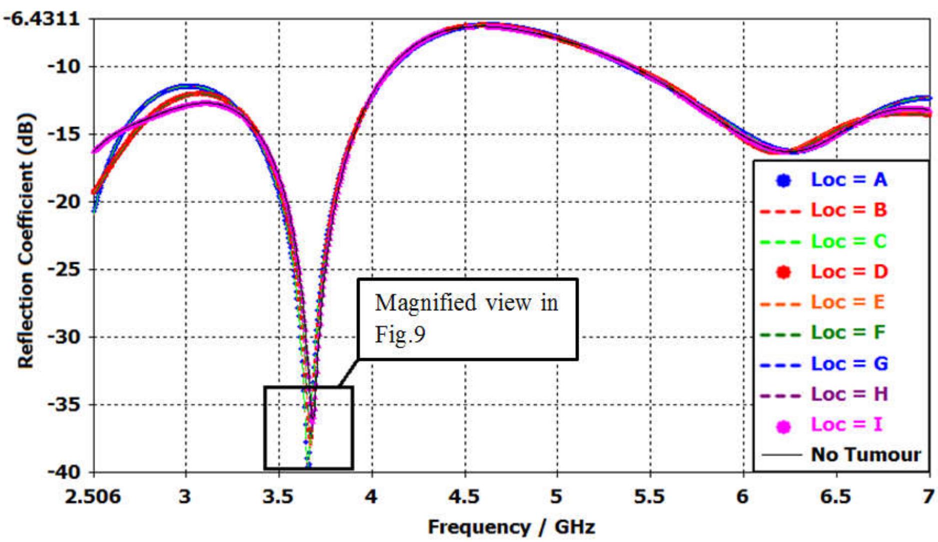

Fig.8. Simulated return loss with different values of tumour locations (*Loc*)

In general, it can be observed that UWB microwave imaging technique can detect lung tumour. Only it requires the discoveries of dielectric properties of any biological normal living tissues versus the cancerous ones. The measure of electromagnetic radiation interaction with its constituent at the cellular and molecular level is important to differentiate between the two types. The normal lung tissue has significantly low dielectric properties compared to the cancerous tissue. When designing the human thorax model in the software, the dispersion data of body tissues for the thorax model such as lung, bone, muscle, fat and skin are provided by the simulation. However, with the unavailability of dispersion data for cancerous tissue, the spherical tumour model was incorporated with muscle and blood properties. This is meant in order to get more precise results by removing as much erroneous factors as possible. For instance, the blood and muscle properties have significantly high permittivity and conductivity compared to lung properties, so, they need to be adjusted well for valid measurement.

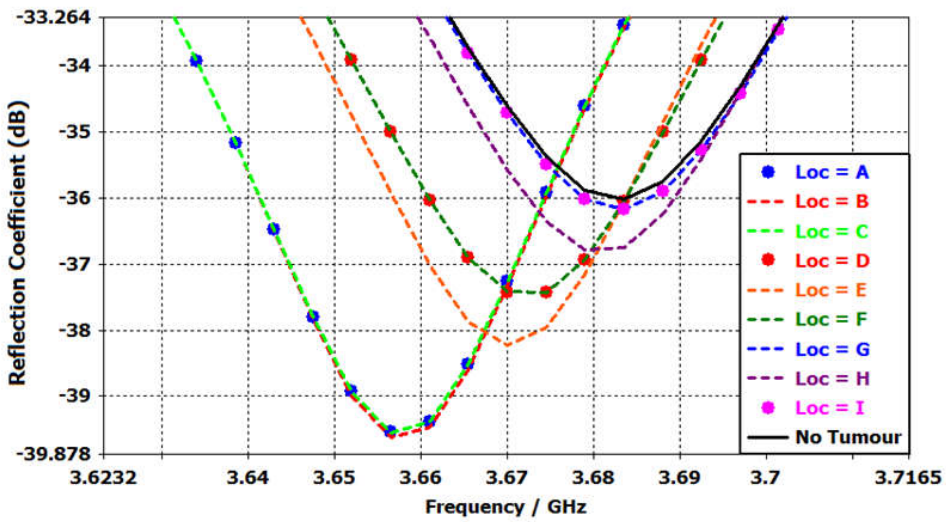

Fig.9. Magnified view of simulated return loss with different values of tumour locations (*Loc*)

4. CONCLUSION

This project presents a promising detector of lung tumour, even if situated at multiple locations, in spite of its simple UWB microwave imaging technique. It is also capable to differentiate between cancerous and benign ones. Based on the analysis of the measured experimental results, the best distance for the UWB antenna to perform the imaging is at 10 mm away from the body and it works best at the resonance frequency of 3.67 GHz. It is a better economical alternative among non-invasive methods in order to avoid exposures to any harmful radiation.

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