7th Bangladesh Conference on Industrial Engineering and Operations Management
December 21-22, 2024
Publisher: IEOM Society International, USA DOI: 10.46254/BA07.20240099
Published: December 21, 2024

MWCNT-Based Antenna for Biomedical Application

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Abstract

This paper represents the design of an on-body patch antenna for biotelemetry made of multi-wall carbon nanotubes. The primary goal of this research is to use a new antenna and monitor changes in the S1,1 parameter to diagnose lung tumors. The substrate of the antenna is composed of FR-4, the ground is made of copper and the patch is built of MWCNT. The antenna is 1.08 mm thick overall, with the patch being 0.010 mm thick, the substrate being 1.06 mm thick, and the ground being 0.010 mm thick. The overall dimension of this antenna is 60 mm by 60 mm by 1.08 mm (3888 mm3). The antenna's performance was evaluated utilizing the lung tumor phantom model's two sizes and placements. The suggested antenna's resonance frequency was determined to be 7.529 GHz. Furthermore, in unoccupied space, we observed a VSWR of 1.2 and -20.75 dB S1,1. S_{11} is -23.42 dB at 7.452 GHz in the normal lung and -20.77 dB in the tumor-affected lung. This antenna operates at frequencies ranging from 3 to 10 GHz. The proposed antenna has a SAR of 1.425 W/kg in 10 g of tissue.

Keywords
MWCNT, Lung tumor, Microstrip Patch Antenna, Ultra-wideband, Biomedical

1. Introduction

A lung tumor occurs when cells in the lung or airways divide at an abnormal rate or die in an unusual manner. Actually, "tumor" is simply an abnormal development of tissue that happens when cell division or cell death is abnormally slow or excessive. Any tumor that develops in the lung tissue or the airways leading to the lungs is referred to as a lung tumor. There are mainly two types: benign and cancerous (Cleveland 2022).

The most common type of cancer in the world is lung cancer. The four main histological classes of human lung malignancies are adenocarcinoma, squamous cell carcinoma, big cell carcinoma, and small cell carcinoma Adenocarcinoma is currently the most prevalent kind of lung cancer, and its incidence is rising (Jackson et al. 2001).

Multi-walled carbon nanotubes (MWCNTs) are formed by placing several single-walled carbon nanotubes inside each other, forming a special kind of carbon nanotube (Ossila 2022). In order to aid in the early identification of lung tumors, a new rectangular patch antenna using multiwall carbon nanotubes has been designed. Multi-walled carbon nanotube (MWCNT) fabrication has become increasingly simple and straightforward in recent years, making them an essential component for designing nanoelectronics systems like interconnects, antennas, integrated circuits, wireless sensors, transparent, flexible conductors, and transparent conductors (Thampy et al. 2016; Hasan et al. 2022).Microstrip patch antennas are becoming increasingly popular due to their versatility and wide range of applications. In addition to biomedical uses, these antennas are employed in various fields such as aerospace, 6G communication, and body-wearable health monitoring systems. They are also utilized in THz applications, showcasing their adaptability across advanced technological domains (Moni et al. 2024; Roy et al. 2024; Saiful et al. 2023).

Multi-walled carbon nanotubes are highly conductible and have a high aspect ratio. In comparison to typical solutions, such as carbon black or metal particles, the required level of conductivity can be achieved with far lower loadings (Eshan et al 2024)[9]. From the results, it can be shown that the return loss, bandwidth, and operating frequency are shifted by detecting lung tumors from the normal lung phantom. Therefore, the proposed techniques could help detect lung tumors in various locations. This research is based on upper-level tumor and lower-level tumor detection. CST microwave studio is used to design this proposed antenna. MWCNT has been proposed for detecting lung tumors and it operates in the ultra-wideband frequency range (3.1 GHz - 10.6 GHz).

2. Structure and Design

In this paper, it is described how to build a microstrip patch antenna that is 60 mm long and 60 mm in width. This antenna is made up of three parts: the patch, the substrate, and the ground. The substrate is FR-4, the patch is made with MWCNT, and the ground is made of copper. CST Microwave Studio was used while designing the antenna. This antenna's overall thickness is 60 mm, 0.010 mm for the patch's thickness, 1.06 mm for the substrate, and 0.010 mm for the ground's thickness. The lungs of humans in the CST phantom model and a phantom with lung tumor model were developed for the purposes of studying and testing an antenna on a human lung. This designed antenna is an on-body antenna shown in Figure 1. A 1 mm thick air gap layer has been produced as a result. Then, in the CST Microwave Studio, four uniform layers of skin, fat, muscle, and lung formed.

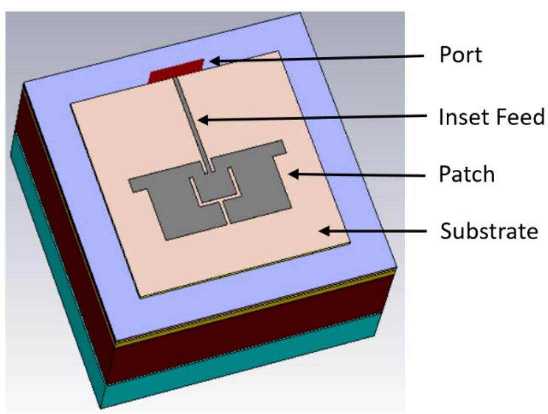


Figure 1. Different parts of the designed antenna.

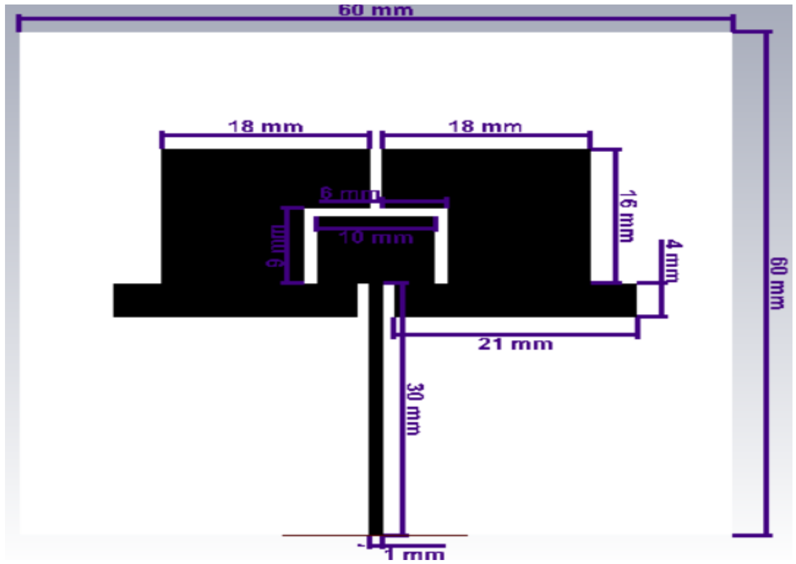


Figure 2. Dimension of designed antenna.

Table 1. Antenna Size Parameter

Parameter	Dimensions (mm)
Ground Width, *Wg*	60
Ground Length, *Lg*	60
Patch Width, *Wp*	44
Patch Height, *Hp*	20
Patch Thickness, *Tp*	0.010
Ground Thickness, *Tg*	0.010
Substrate Thickness, *Ts*	1.06
Feedline Width, *Wf*	1.2
Feedline Insertion, *If*	4
Feedline Length, *Lf*	30

2.1 Equations for designing Microstrip Patch Antenna

This equation is used to calculate different parameters for designing the antenna.

Width,

$$W = \frac{c}{2f_0\sqrt{\frac{\epsilon_R + 1}{2}}}$$

$$L = \frac{c}{2f_0\sqrt{\epsilon_{eff}}} - 0.824h\left(\frac{\left(\epsilon_{eff} + 0.3\right)\left(\frac{W}{h} + 0.264\right)}{\left(\epsilon_{eff} - 0.258\right)\left(\frac{W}{h} + 0.8\right)}\right)$$

Here,

W = $width\ of\ the\ antenna$

L = $length\ of\ antenna$

$\epsilon_R = dielectric\ constant$

$$\epsilon_{eff} = \frac{\epsilon_R + 1}{2} + \frac{\epsilon_R - 1}{2}\left[\frac{1}{\sqrt{1 + 12\left(\frac{h}{W}\right)}}\right]$$

2.2 Methodology

The needed parameters and their values are shown in the table below. The CST software was used to design and simulate the lung phantom. In this table II, all the parameters of lung phantom are shown below using references (Ossila 2022; Al-Nahiun et al. 2021). Figure 3 shows the designed lung phantom model.

Table 2. The parameters of the phantom model

	Skin	**Fat**	**Muscle**	**Lung**	**Tumor**
Permittivity	12.29	3.44	19.07	7.44	1
Conductivity [s/m]	31.04	2.14	41.82	14.839	4
Density [kg/m^3]	1100	910	1041	1020	1058
Thermal Conductance [W/K/KG]	0.50	0.24	0.56	0.48	-
Heat capacity [Kj/K/Kg]	3.5	2.5	3.7	3.8	-
Diffusivity [m^2/s]	7.6e-08	8.8e-08	1.4e-07	1.7e-07	-
Blood flow [W/K/m^3]	9100	1700	2700	9500	-
Metabolic rate [W/m^3]	1620	300	480	1700	-
Size[mm]	1	3	25	15	3 and 6

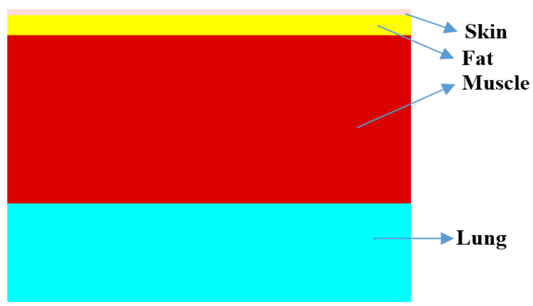
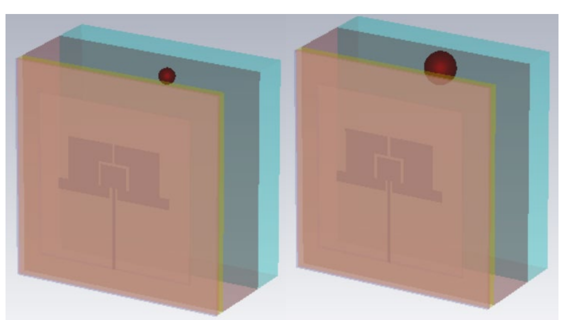


Figure 3. Human normal skin phantom model

Figure 3 depicts the development of the four homogenous layers—skin, fat, muscle, and lung—with thicknesses of 1 mm, 3 mm, 25 mm, and 15 mm, respectively. Two tumors with radii of 3 and 6 mm later affected the models that were created, as figure 4 illustrates. Moreover, two locations were created for tumors of three and six millimeters in diameter.



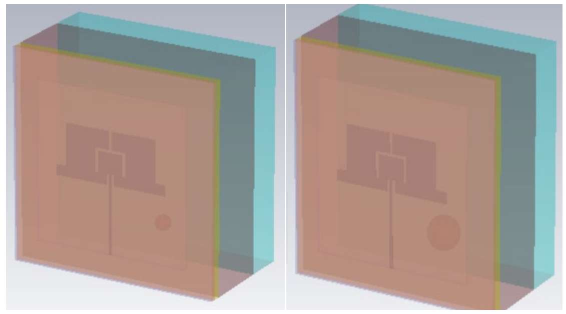


Figure 4. Different positions and sizes of tumor-affected model.

3. Analysis of Antenna Characteristics

The antenna is simulated in free space, as well as in normal lung, two sizes upper position lung tumor, and two sizes lower position lung tumor phantom model. Below are the necessary results for evaluation.

A. S-parameter.

The suggested antenna uses a frequency of 7.529 GHz, as shown in Figure 5, and works in free space with a return loss of -20.75 dB. The antenna has a bandwidth of 0.2388 GHz. The return loss indicates the maximum radiation of the antenna, which enhances performance and permits utilization at its operating frequency (IT IS 2022). A return loss of less than -10 dB is advised for optimal outcomes. Return loss, also known as the S_{11} parameter (also called the reflection coefficient) controls the amount of power that an antenna transmits or reflects (Islam et al 2018; Hasan et al 2023).

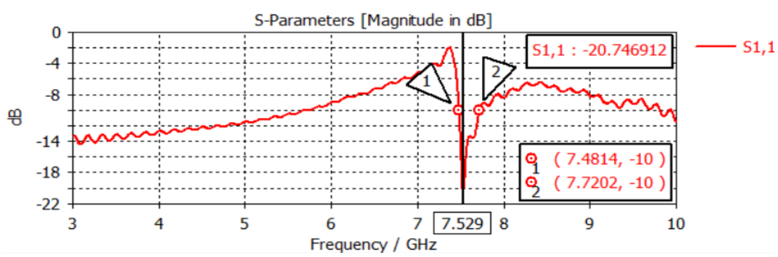


Figure 5. Return loss -20.75 dB in 7.529 GHz frequency in free space

Figure 5 shows the frequency in GHz on the X-axis and the return loss in dB on the Y-axis.

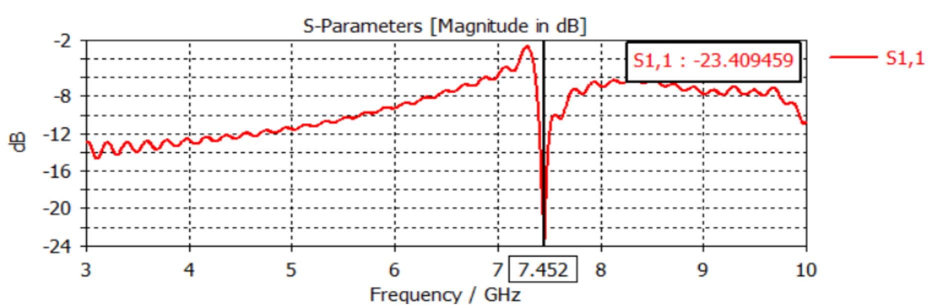


Figure 6. S_{11} -23.41 dB in 7.452 GHz frequency in normal lung model.

The conventional lung model's S_{11} parameter, which is -23.41 dB at a frequency of 7.452 GHz, is shown in Figure 6. The S_{11} parameter for the model with a lung tumor at position 1 is displayed in Figure 7, where the tumor has a 3 mm radius and a 6 mm radius. The S_{11} value was -22.27 dB for the tumor with a 3 mm radius at a resonant frequency of 7.445 GHz, and -21.64 dB for the tumor with a 6 mm radius at a resonant frequency of 7.452 GHz.

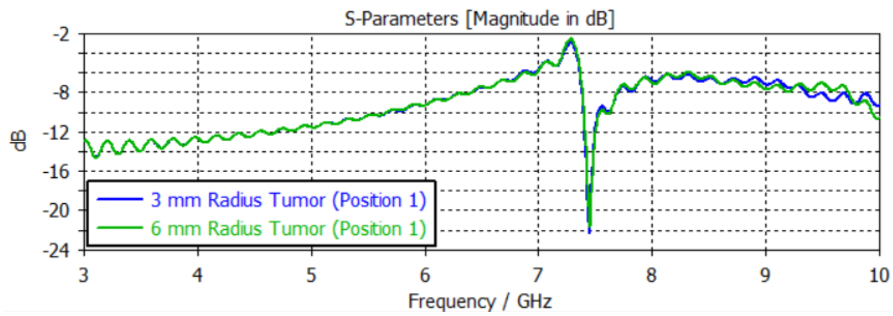


Figure 7. Return loss for position 1, 3 mm radius tumor -22.27 dB in 7.445 GHz frequency and for 6 mm radius tumor -21.64 dB in 7.452.

The lung tumor-affected model's S_{11} parameter is shown in Figure 8 at position 2, where a 3 mm and a 6 mm radius tumor are both visible. The S_{11} value was -20.77 dB for the tumor with a 3 mm radius at a resonant frequency of 7.445 GHz, and -23.02 dB for the tumor with a 6 mm radius at a resonant frequency of 7.452 GHz.

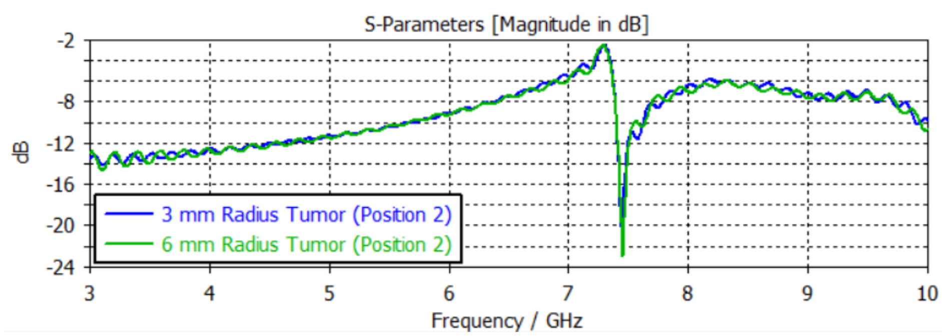


Figure 8. Return loss for position 2, 3 mm radius tumor -20.77 dB in 7.445 GHz frequency and for 6 mm radius tumor -23.02 dB in 7.452 GHz.

B. Far-field Radiation Pattern

The far-field region, or the area farthest distant from an antenna, determines its emission pattern. In this location, distance has little impact on the shape of the radiation pattern. The radiated fields are dominating, with the electric (E) and magnetic (H) fields perpendicular to each other, and the wave propagates in a plane (Moni et al 2024). Figure 9 shows a three-dimensional picture of the antenna's directivity. The directivity is determined using a resonance frequency of 13.08 dBi in normal lung and 12.56 dBi in free space. The radiation efficiency of empty space and normal lung is -4.970 dBi and -6.502 dBi, respectively.

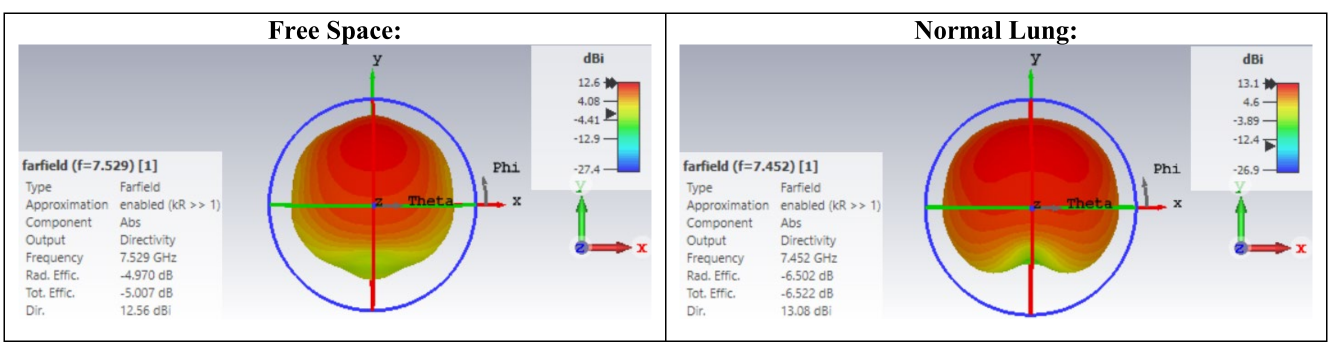


Figure 9. Far-field radiation pattern (3D) of the proposed antenna on free space and normal lung model.

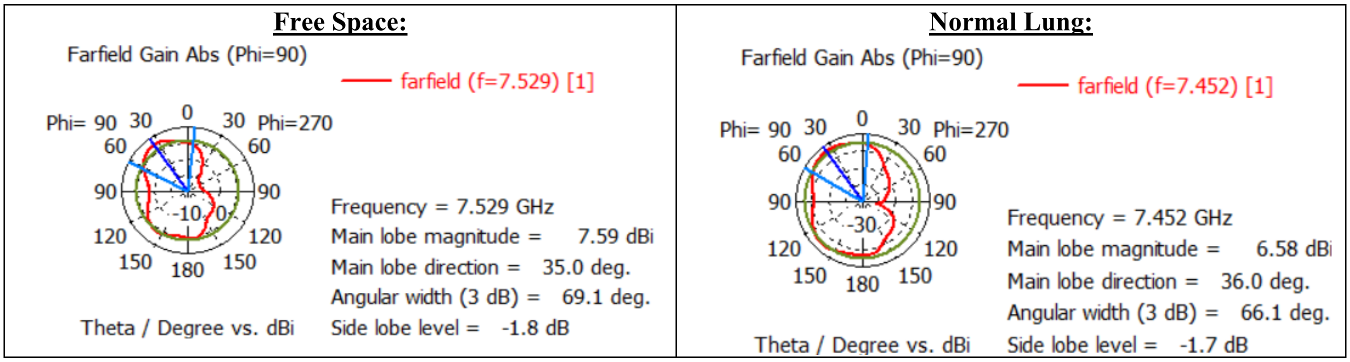


Figure 10. Far-field gain (2D) of the proposed antenna on free space and normal lung.

Figure 10 shows the two-dimensional gain for open space and normal lung. The primary lobe is revealed to have a 35-degree free space direction with a magnitude of 7.59 dBi in the resonant frequency 7.529 GHz. A normal lung has principal lobes at 46 degrees and 6.5 dBi in the resonant frequency of 7.452 GHz. Here the angular width 69.1 degree for free space and 66.1 degree for normal lung model.

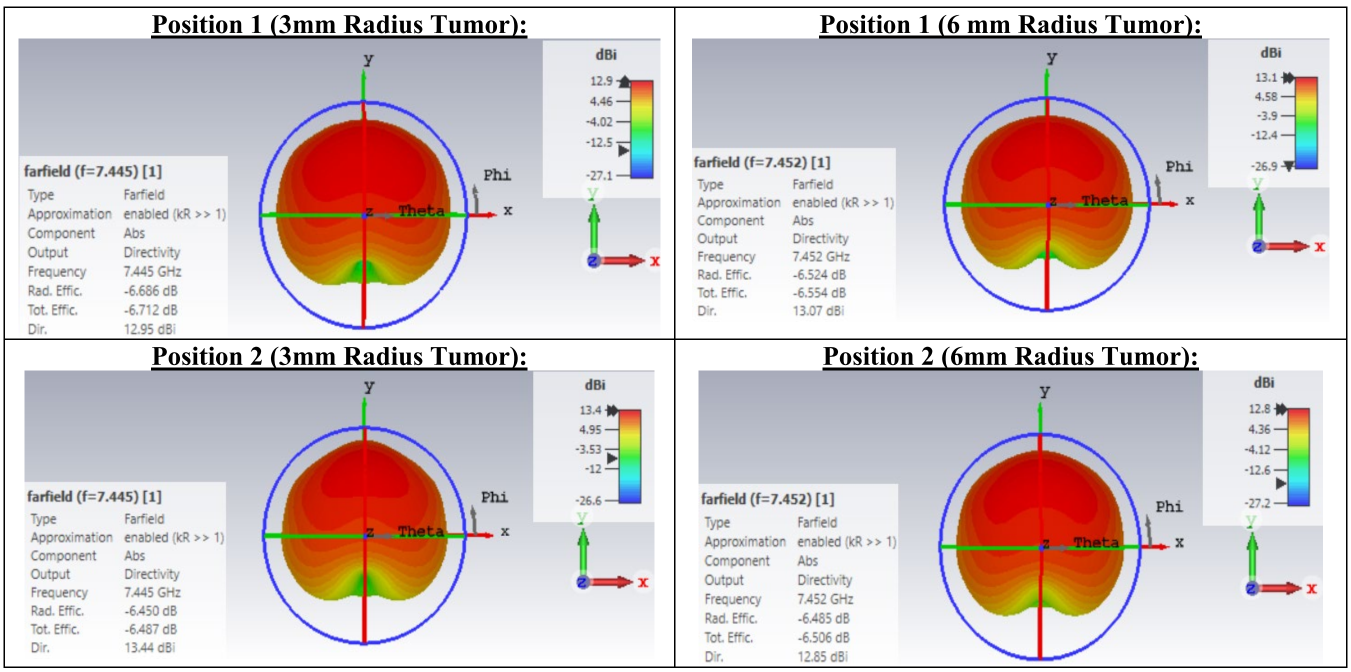


Figure 11. Far-field radiation pattern (3D) of the proposed antenna in two positions and sizes tumor.

Figure 11 indicates the directivity of the antenna in three dimensions. The results show that the directivity is 12.95 dBi for position 1, 3 mm tumor; 13.07 dBi for position 1, 6 mm tumor; 13.33 dBi for position 2, 3 mm tumor; and 12.85 dBi for position 2, 6 mm tumor. The radiation efficiency values are -6.686 dB, -6.524 dB, -6.450 dB, and -6.485 dB, respectively. The total efficiency values are -6.712 dB, -6.544 dB, -6.487 dB, and -6.506 dB respectively.

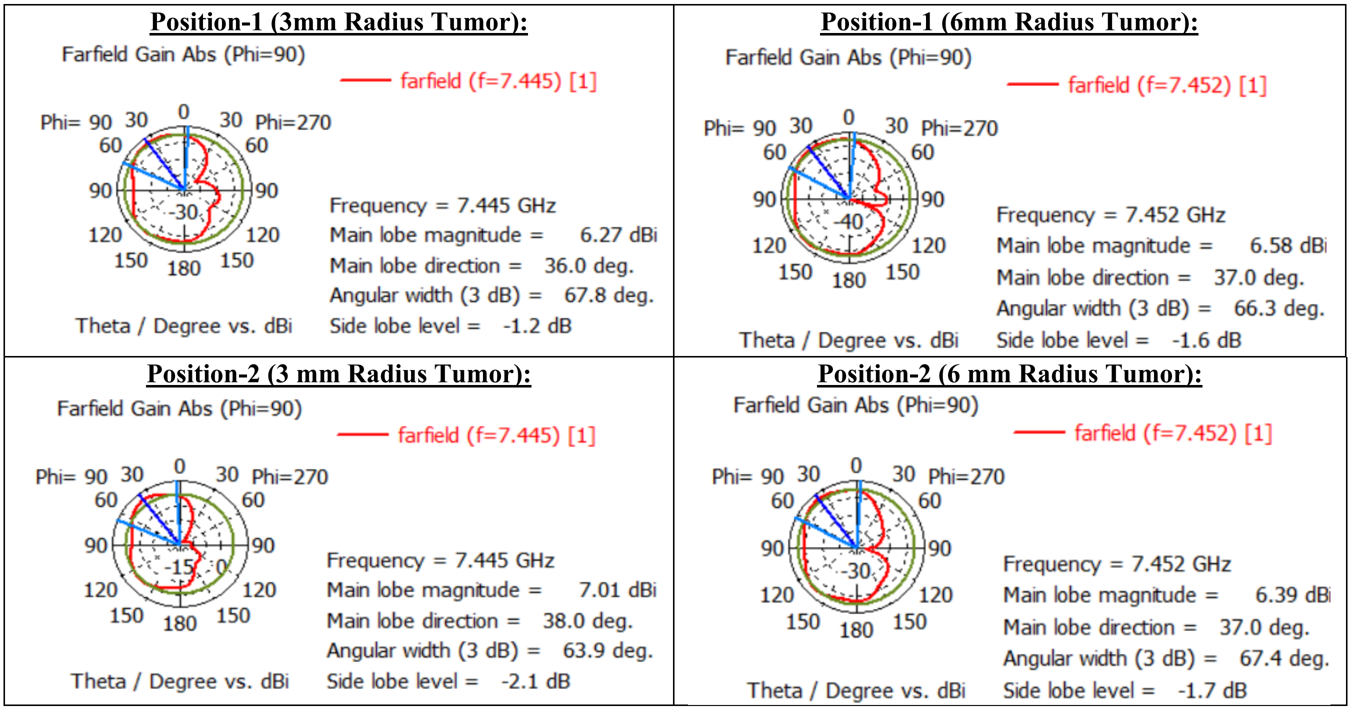


Figure 12. Far-field gain (2D) of the proposed antenna in two positions and sizes tumor.

The 2D gain is measured for two tumor positions and sizes. For a 3 mm tumor at position 1, the primary lobe magnitude is 6.27 dBi with a direction of 36 degrees, while for a 6 mm tumor at the same position, it is 6.58 dBi with a direction of 37 degrees. At position 2, the magnitude is 7.01 dBi in the 38-degree direction for a 3 mm tumor and 6.39 dBi in the 37-degree direction for a 6 mm tumor.

C. **VSWR Calculation**

An antenna's Voltage Standing Wave Ratio indicates how well its impedance matches that of the transmission line it is linked to (Hasnat et al 2022). The VSWR of a biocompatible antenna must be less than 2. The proposed antenna has a VSWR of 1.2 in free space. Figure 13 shows the VSWR for normal lung tissue as 1.14, for position 1 at 3 mm as 1.16, for position 1 at 6 mm as 1.18, for position 2 at 3 mm as 1.2, and for position 2 at 6 mm as 1.15.

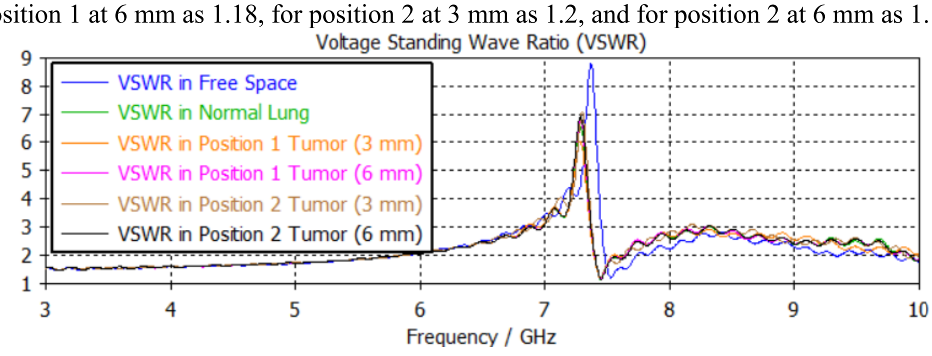


Figure 13. VSWR of the proposed antenna for all environments.

D. Specific Absorption Rate

The specific absorption ratio, or SAR, is one method for calculating the amount of radiation that the surrounding tissue is able to detect. SAR is an essential safety measure. The FCC states that SAR for 10gm tissue should be less than 2W/Kg to provide increased safety (Eshan et al 2023; Eshan et al 2023). As seen in Fig. 14, the maximum SAR of the proposed antenna at resonance frequency for a 10 g tissue sample is 1.425 W/kg.

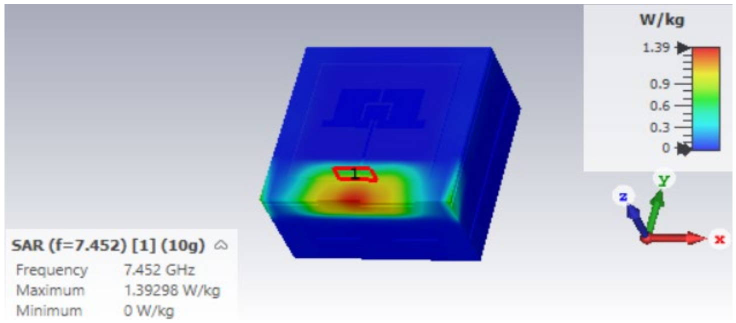


Figure 14. SAR plot for lung phantom model.

4. Results Comparison in Different Environment

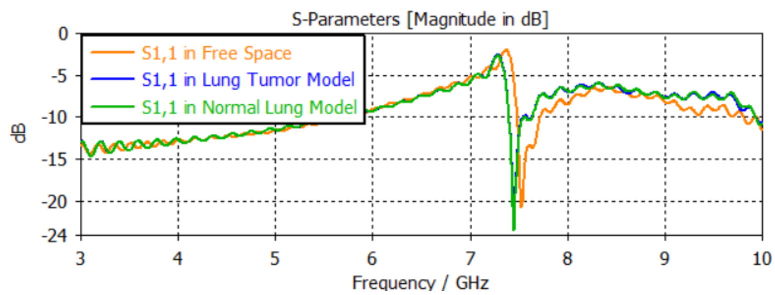


Figure 15. Different environment antenna performance analysis. In free space return loss is -20.75 dB, in normal lung -23.42 dB, in lung tumor -20.77 dB.

The information acquired from various antenna analysis settings is shown in Table 3 and Figure. 15. While the resonance frequency is constant, the return loss changes depending on the surroundings. Variations in outcomes across various configurations offer optimal antenna performance, including tumor detection capabilities.

Table 3. Performance of antenna in different environment

	Resonant Frequency	S_{11} **(dB)**	**VSWR**
Free Space	7.529	-20.75	1.2
Normal Lung	7.452	-23.42	1.14
Lung Tumor (Position 1, 3 mm)	7.445	-22.27	1.16
Lung Tumor (Position 1, 6 mm)	7.452	-21.64	1.18
Lung Tumor (Position 2, 3 mm)	7.445	-20.77	1.2
Lung Tumor (Position 2, 6 mm)	7.452	-23.02	1.15

5. Comparative Study

The majority of previous research projects have been in-depth investigated and compared with the current works as part of the comparative study. Resonance frequency, tumor size, return loss (S_{11}), and other variables are compared to previous research. After a simple comparison, it is visible that the antenna model proposed in this research work is considerably more beneficial and suitable, including its capacity to precisely identify low and big-sized tumors. Table IV shows a quick comparison between the suggested antenna model and earlier studies. Because of its optimized geometry, which reduces reflection loss and improves impedance matching, as well as the use of low-loss dielectric materials, which lessen signal attenuation, the developed antenna model performs better at higher frequencies. These developments lead to increased bandwidth and gain, surpassing previous models in crucial parameters like return loss and VSWR.

Table 4. Comparison analysis of previous work

Return Loss (S$_{11}$), dB	***Resonance Frequency (GHz)***	***Tumor Size (in mm)***	***Reference***
-18.2	0.9501	10	(Singh et al 2019)
-9.15	0.4610	35	(Elkorany et al 2019)
-12.73	2.876	-	(Aziz et al 2019)
-20.75	7.529	3	Designed Model

5. Conclusion

A patch antenna has been made from MWCNTs that can effectively detect lung tumors in different positions. Basically, in this research two positions and sizes of the tumor have been analyzed, one is the upper position, and another one is the lower position in the lung. Using a phantom model, we found that the developed antenna performs better than the reference antenna in a number of respects, including resonant frequency, return loss, and voltage standing wave ratio (VSWR). The higher performance of the suggested antenna operates in the Ultra-Wideband (UWB) frequency range of 3.1-10.6 GHz. The proposed antenna operates at 7.529 GHz suggesting its potential utility for other medical applications. The proposed antenna is intended to be used as an on-body device for the early detection of lung tumors after all the studies and comparisons of these parameter values are completed.

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Biographies

Lamia Mannan is a driven professional who has successfully completed a Bachelor of Science degree in Electrical and Electronic Engineering from the esteemed American International University-Bangladesh (AIUB). With a solid academic background, she brings a wealth of knowledge in various aspects of electrical and electronic engineering. Her research interests span a diverse range of subjects. She is particularly intrigued by microwave engineering, antenna design, electronics, sensors, and nanomaterials. These areas not only fuel her academic pursuits but also inspire her to explore the boundless possibilities within the field of electrical and electronic engineering. she has demonstrated her commitment to contributing to the academic community as a co-author of three conference papers, showcasing her expertise and dedication to advancing knowledge in her chosen field. She can be contacted at email: lamia.12mannan@gmail.com

Md. Farukuzzaman is a dedicated and aspiring electrical and electronic engineer currently pursuing his Bachelor of Science in Electrical and Electronic Engineering (EEE) at the American International University-Bangladesh (AIUB). With a strong foundation built during his SSC from Kolaroa G. K. M. K. Govt Model High School in 2018 and HSC from Simanta Ideal College in 2020, Farukuzzaman has consistently demonstrated academic excellence and a passion for innovation. His technical expertise spans advanced tools like MATLAB and CST Microwave Studio, alongside proficiency in electrical circuit analysis. He has contributed to several impactful projects, including the design of antennas for 6G applications, power system analysis, and ongoing MATLAB-based simulations. His practical skills extend to Arduino programming, showcased through the development of an all-terrain vehicle, where he played a vital role in both hardware implementation and software coding. Farukuzzaman’s academic journey is marked by discipline, effective time management, and a relentless pursuit of knowledge. He is deeply passionate about emerging technologies in antenna design, power systems, and automation, seeking to explore their potential for real-world applications. As an aspiring innovator, Farukuzzaman aims to leverage his technical skills and creative mindset to contribute to groundbreaking advancements in the field of electrical and electronic engineering. He can be contacted at email: faruktumi6@gmail.com

Mahfuzur Rahman Ruhit earned his B.Sc. degree in Electrical & Electronic Engineering from the American International University-Bangladesh (AIUB) in 2023. He completed his Higher Secondary School Certification from Notre Dame College, Mymensingh (NDCM). Currently, he is working as an Assistant Engineer at MRM & Era Construction. His primary research interests include antenna design and electrical power systems, reflecting his dedication to advancing these fields. He can be reached at ruhitrahman084@gmail.com

Abedul Hadi received B.Sc. in Electrical & Electronic Engineering from American International University Bangladesh (AIUB), Dhaka, Bangladesh in 2009. He received his MBA and M.Sc. degree from Dhaka University in 2011 and 2018 respectively. He has been an Assistant Professor, Department of EEE & ECE with University of Information Technology and Science. He is interested in research Renewable Energy, Green Building, Solar Efficiency, Solar optimization Methods, Industrial Electronics, Economic Power Generation, Electrical Power Transmission and Distribution, Electrical Power Protection. He can be contacted at email: abedul.hadi@uits.edu.bd

Mehrab Hossain Shihab received his B.Sc. degree in Electrical & Electronic Engineering from the American International University-Bangladesh (AIUB) in 2022. Recently, he completed a Master's in Electrical & Electronic Engineering from the same university. He obtained his Higher Secondary School Certificate in 2018 from Dhaka City College and his Secondary School Certificate in 2016 from A.K. High School. In 2019, he volunteered with the IEEE AIUB Student Branch and later became the Treasurer of the IEEE Microwave Theory and Technology Society AIUB SB Chapter in 2022. He has been an active member of the Institute of Electrical and Electronics Engineers (IEEE). He is also a member of the Institution of Engineers, Bangladesh (IEB). His research interests include antenna design, robotics, biomedical engineering, and electrical power systems. He can be contacted at mehrabhossain86@gmail.com.

Rapsan Amin Anonto received his B.Sc. degree in Electrical & Electronic Engineering from the American International University-Bangladesh (AIUB). With a strong academic foundation, he has developed extensive knowledge across various domains of electrical and electronic engineering. His research interests include antenna design, quantum sensing, integrated photonics, and FDTD simulations, showcasing his passion for exploring cutting-edge advancements in technology. Rapsan is dedicated to contributing to the academic and professional community through impactful research and collaborations. He can be contacted at rapsanaminanonto@gmail.com.

Md. Arifuzzaman is graduated from the Department of Electrical and Electronic Engineering (EEE) at Daffodil International University. With a strong foundation in engineering principles, he is driven by a passion for research and innovation. His research interests span across biomedical engineering, antenna design, and materials science, where he aims to contribute to advancements in technology that address real-world challenges. Md. Arifuzzaman is committed to exploring the intersection of cutting-edge technologies and their applications, striving to make a meaningful impact in his field. He can be contacted at mdarif826664@gmail.com

Sayed Mainul Hassan received his B.Sc. degree in Electrical & Electronic Engineering from the American International University-Bangladesh (AIUB). With a strong academic foundation, he has developed extensive knowledge across various domains of electrical and electronic engineering. Currently, he serves as a Plant Manager at Global Oil Company Limited, where he oversees plant operations and ensures optimal performance across various projects. Sayed's extensive knowledge and leadership skills contribute significantly to the company's operational excellence. With a background in electrical engineering and experience in managing complex processes, he is dedicated to driving innovation and operational efficiency.