Optimized Microstrip Slot UWB Patch Antenna for Medical Imaging

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Abstract

This research work presents the development of an Ultra-Wideband (UWB) microstrip patch antenna (MPA) with the specific purpose of tissue characterization. The antenna was carefully designed and simulated to operate within a frequency range of 4.8 to 6.9 GHz, optimized for its intended application. To ensure the best performance, a series of simulations and comparisons were conducted using CST Microwave Studio. Various antenna shapes were tested and evaluated to determine the most effective design. The results of these simulations were highly promising, as they revealed a simulated return loss (S_{11}) of -33dB. This indicates excellent performance and demonstrates the suitability and acceptability of the proposed antenna for medical imaging such as breast imaging, tumor detection, or monitoring physiological changes.

Keywords: Microstrip antenna, medical imaging, UWB, CST

1. Introduction

In recent years, the use of microstrip antennas in medical imaging has attracted significant attention. These antennas have demonstrated immense potential in delivering high-resolution images and precise measurements in various medical imaging techniques like magnetic resonance imaging and positron emission tomography. According to Shimu et al., microstrip patch antennas have found wide-ranging applications in the medical field, as well as in other industries [1]. Microstrip antennas offer several advantages that make them well-suited for medical imaging applications. Firstly, microstrip antennas have a small size and low profile, which makes them ideal for integration into medical devices and equipment. Their lightweight nature allows for easy customization to meet specific requirements. Additionally, microstrip antennas can be designed with wide bandwidths, enabling the transmission and reception of diverse frequencies. Microstrip patch antennas also provide high gain and low return loss, ensuring efficient signal transmission and reception [1, 2]. Another advantage of microstrip patch antennas in medical imaging lies in their robust design and fabrication. These antennas are known for their durability and reliability, which are crucial factors in medical imaging where accuracy and consistency are of paramount importance. Furthermore, microstrip antennas exhibit excellent radiation characteristics, including low cross-polarization and high directivity. These characteristics are particularly valuable in medical imaging, as they contribute to clearer and more accurate imaging results. With these advantages, microstrip antennas have the potential to revolutionize medical imaging by providing high-quality images with improved resolution and accuracy. However, it is important to address the limitations associated with microstrip antennas in order to fully harness their potential in medical imaging.

One limitation of microstrip antennas is their narrow bandwidth, which restricts the range of frequencies that can be transmitted or received. Researchers are actively exploring different techniques, such as adding additional resonant elements or using multiband designs, to increase the bandwidth of microstrip antennas. Additionally, microstrip antennas often have relatively low gain compared to other types of antennas [3]. To address this, researchers are investigating techniques such as designing stacked or array configurations to enhance the gain of microstrip antennas. Impedance matching is another issue that microstrip antennas face, leading to signal degradation. Researchers are focusing on improving the manufacturing process and developing advanced impedance-matching techniques, such as using matching networks or adding dielectric layers, to optimize impedance matching and improve overall performance. Furthermore, efforts are being made to enhance the polarization characteristics of microstrip antennas, as certain imaging techniques require specific polarization orientations for optimal image quality. Researchers are exploring various polarization techniques, such as circularly polarized microstrip antennas or the use of metasurfaces, to control the polarization of the antenna [4]. The study in [1] presents the design, fabrication, and analysis of a compact microstrip patch antenna operating in the Industrial, Scientific, and Medical (ISM) frequency range of 2.4-2.5 GHz for medical applications. To investigate the performance of this antenna structure through simulations, the high-frequency structure simulator (ANSYS HFSS) and Advanced Design System (ADS) has been used. Moreover, to measure the level of electromagnetic waves absorbed by the human head model the specific absorption rate (SAR) is simulated at different positions. A 2.45 GHz Rectangular Patch Microstrip Antenna (RMSA) was designed and analyzed for breast cancer detection in [5], using an insect feed technique for impedance matching. Simulations showed the RMSA had a VSWR<2 bandwidth of 70 MHz (2.8% of operating frequency), resonating at 2.45 GHz. Results indicate the RMSA outperforms existing designs, making it a promising option for improved breast tumor detection. While in [7, 8] a low-cost microstrip patch antenna was developed specifically for microwave imaging (MWI) applications across a wideband frequency range. The antenna design incorporates an artificial magnetic conductor (AMC) to enhance its performance. Computer simulations using CST demonstrated that the presence of the AMC significantly improved the frequency selectivity at 8.6 GHz, resulting in a peak realized gain of 9.90443 dBi (simulated) and 10.61 dBi (measured). To validate the simulation results, the proposed microstrip antenna was fabricated and experimentally tested.

2. Antenna Structure

In this paper, we introduce a newly proposed Ultra-Wideband microstrip antenna and provide an overview of its structure. The decision to utilize an FR-4 substrate is driven by its cost-effectiveness and wide accessibility in the market. The simplicity and convenience of implementing FR-4 as a substrate make it an ideal choice for the design of our antenna. In the upcoming sections, we will delve into the fabrication process and design specifics of the microstrip antenna, emphasizing its potential for Ultra-Wideband applications.

As depicted in Fig. 1, the antenna is mounted on the FR-4 substrate including the main and sub-fluidline for the impedance matching purpose. The detailed dimensions of the design can be found in Table 1.

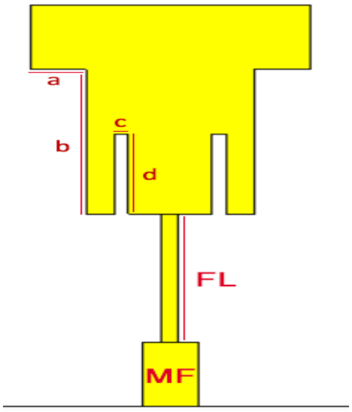

Fig.1 Front View of the Proposed Antenna

Table 1. Antenna Dimensions

Area	Parameter	Dimensions (mm)
PATCH (copper)	Width	10
	Length	13
	a	2
	b	9
	c	0.5
	d	5
	Thickness	0.035
FEED LINE (FL) (copper)	Width	0.6
	Length	8
	Thickness	0.035
MAIN LINE (ML) (copper)	Width	2
	Length	4
	Thickness	0.035
SUBSTRATE (FR-4)	Width	28
	Length	29
	Thickness	1.6
GROUND (copper)	Width	28
	Length	10.5
	Thickness	0.035

3. Results and Discussion

3.1. *Accuracy of numerical integration*

As defined in [4], the UWB has a bandwidth of greater than 500MHz and an operating frequency of between 3.1GHz and 10.6GHz. The return loss threshold of -10dB has been defined in [5]. A simulation of return loss S_{11} is shown in Fig. 2.

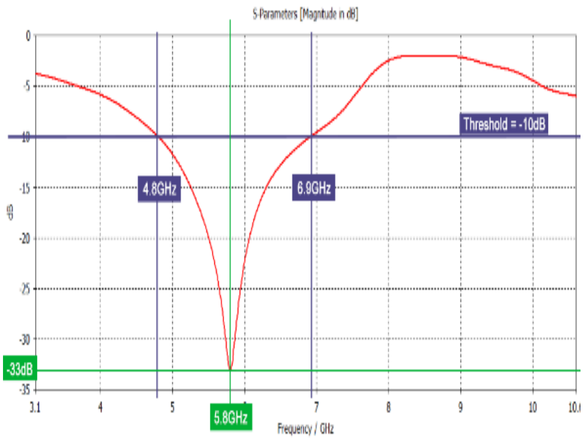

Fig.2 Return Loss of the Proposed Antenna

The simulation and expected results match well. The threshold is pointed at -10dB, so the bandwidth is 2.1GHz, in agreement with the 500MHz minimum required by UWB. Furthermore, the resonance frequency is 5.8GHz. This one is great, the signal propagation characteristics at 5.8GHz in free space are similar in rainy conditions. This issue is important to consider in tropical climates such as Malaysia [6]. The radiation pattern of the proposed antenna is illustrated in Fig. 3.

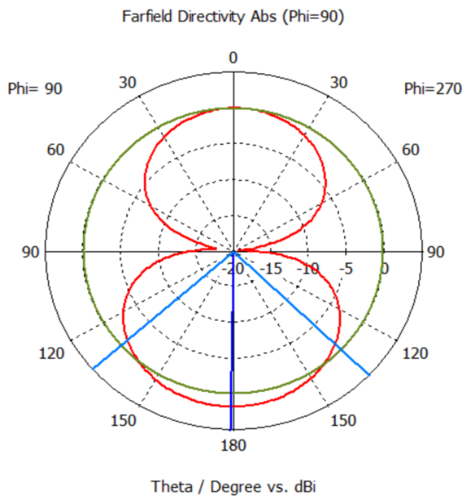

Fig. 3 Antenna's radiation pattern

As shown in Fig. 3, the main lobe magnitude is 1.68 dBi and the main lobe direction of 179 deg has been obtained. The Angular width (3dB) of 94.8 degrees and the side lobe level of-1.7 dB has been obtained. Finally, the results of the VSWR simulation are given in Fig. 4.

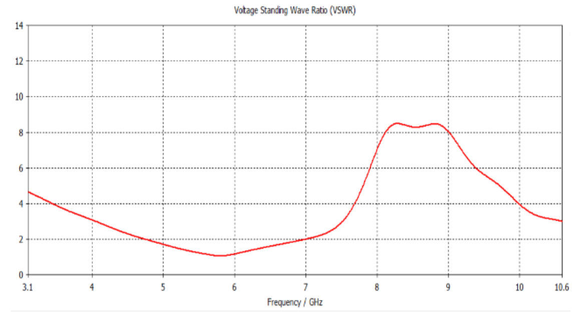

Fig. 4. Simulation of VSWR

The acceptable range of Voltage Standing Wave Radio (VSWR) is under 2V. So the acceptable frequency of between 4.7 and 7 GHz are the acceptable range which matches well with the previous results obtained in the operating frequency from 4.8 to 6.9 GHz.

4. Conclusion

In conclusion, this project successfully proposed an Ultra-wideband (UWB) microstrip patch antenna (MPA) using an FR-4 substrate. The achieved return loss of -33dB at a resonance frequency of 5.8GHz demonstrates the effectiveness of the antenna design. With dimensions of 29×28mm, this antenna offers a cost-effective, user-friendly, and portable solution for various applications, particularly in breast cancer detection. Through meticulous design and simulation using CST Microwave Studio, the antenna was optimized to operate within the desired frequency range of 4.8 to 6.9 GHz. The extensive simulations and comparisons performed confirmed the superior performance of the proposed design. The obtained results, including the impressive return loss of -33dB, highlight the antenna's suitability for medical imaging, such as breast imaging, tumor detection, or monitoring physiological changes.

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Authors Introduction

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She has received her PhD from Wireless Communication Centre Faculty of Electrical Engineering in University Technology Malaysia (UTM) in 2014. She has also obtained her master's degree from the faculty of engineering in 2009 from the University Technology Malaysia. She is a member of Board of Engineers Malaysia (BEM) since 2017, She has been working in UCSI University, Malaysia, since 2015 in which she currently serves as an Assistant Professor in the Faculty of Engineering and Built Environment (FETBE). Her research interests include: Wireless communications, spectrum sharing method, spectrum management, cellular communication systems and Antenna design. To date, he has been awarded with the qualifications of a Chartered Engineer (C.Eng.) from U.K. Engineering Council.

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