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L-Shaped Multiband Co-Planar Dipole Antenna for Breast Imaging System

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ABSTRACT

Microwave imaging (MI) has recently gained popularity in breast imaging due to its non-ionizing and low-complexity technique. Over the microwave frequency range, the conductivity and permittivity of normal and malignant human tissues differ. A wideband operation starting at a lower frequency is preferable for the detection of potentially cancerous tissues. This paper presents a 47mm×12mm (L×W) L-shaped multiband co-planar dipole antenna that is simple, compact, cost-effective, and suitable for inverse scattering techniques in time-domain with Finite-Difference Time-Domain (FDTD) grid size of 1mm. The proposed antenna operates at multiband resonant frequencies ranging from 2 to 7 GHz, with the entire reflection coefficient curve falling below -10dB over the desired bandwidth. Comparisons between simulation and experimental results were conducted to evaluate the performance of the proposed antenna. The results demonstrated a satisfactory correlation. This antenna is designed for breast imaging systems.

Keywords:
Multiband antenna; Dipole antenna; Electromagnetic scattering; Microwave imaging; Breast cancer detection

1. Introduction

Breast screening system is an important tool in the early detection of any abnormality within the breast. The non-ionizing, cost-effective, portable, and less complex technology of microwave imaging (MI) as a tool for current clinical approaches has attracted the interest of researchers in recent years, particularly in breast imaging taken from previous research [1-8]. Since microwaves are non-ionizing and changes in the tissue dielectric properties may be linked to their physiological condition, employing microwaves for imaging enables non-destructive evaluation of biological tissues.

Microwaves are known in the electromagnetic (EM) spectrum between frequencies of 300MHz and 30 GHz. Based on a review by Jumaat *et al.*, [9], the MI system with a broad frequency is the optimum option. The wider bandwidth can generate further details regarding the medium within the human body. Human tissues are complex and have been categorized according to their dielectric

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density. Normal and malignant human tissues have varying conductivity and permittivity in the microwave frequency range as mentioned by Jalil *et al.*, [18]. Therefore, it is preferable to generate a multiband operation with a lower, mid, and high frequency for detecting any possible malignant tissues, notably in the breast imaging system. Therefore, the optimal performance of the MI system is greatly dependent on the antenna's design stated by Misilmani *et al.,* [10]. Significant amount of work is placed on developing antennas which able to meet the demands of these imaging systems. Short pulses are transmitted to the breast area, and by determining the contrast in dielectric properties between cancerous and healthy cells, one can obtain and use the differentiated scattering to generate images and locate the tumours. The ability to exhibit broadband behaviour is vital in the antenna element. The antenna needs to generate pulses with high fidelity and a fair gain across a broad spectrum of frequencies as stated by Cicchetti *et al.,* [11]. However, the crucial part of designing antenna is the size. The size of antenna tends to contribute larger size when it involves lower frequency.

Various designs of multiband antenna have been introduced by researchers for breast imaging systems are taken from previous studies [13-16,24,25]. However, their research indicates that multiband dipole antenna is not often used in breast imaging systems from the previous studies [17-19]. In addition, a dipole antenna is usually operated at a single frequency only for current breast imaging applications and was conducted by Shea *et al.,* [13]. In microwave breast imaging, tumours are detected through the disparity in dielectric properties between normal and malignant tissues, which are exploited from the tissue-dependent microwave scattering and absorption in the breast discussed by Porter *et al.,* [19]. Normal breast tissue is widely assumed to be transparent to microwave due to its low relative conductivity and permittivity at microwave frequencies band as mentioned in previous research [20,21]. Malignant tissue, on the other hand, contains more blood and water, and has a high relative conductivity and permittivity explained by Porter *et al.,* [19]. This paper proposes a simple, small multiband co-planar dipole antenna operating in $2 - 7$ GHz range for the 3D breast imaging system that utilizing an inverse scattering technique in time-domain with Finite-Difference Time-Domain (FDTD) grid size of 1mm.

The proposed antenna design can operate multiband desired resonant frequencies to detect the various size of the breast tumours. Therefore, this paper will discuss the performance characteristics of the multiband co-planar dipole antenna that satisfy a multiband operation to detect the various size of tumours within a specific frequency range. In addition, the antenna also requires a compact size to fill a compact area of the breast's overall surface area. Thus, a comparison of physical size and performance in both simulated and experimental settings between (a) straight arm and (b) L-shaped multiband co-planar dipole antenna are presented in this paper.

In this paper, Section 2 provides the dimensions of both the conventional and the proposed antenna designs. In Section 3, simulations of both antenna designs are performed using Computer Simulation Technology (CST) Microwave Studio for design optimization, parametric investigation, and performance analysis of the antennas. Section 4 demonstrates the fabrication and measurement of the proposed antenna to validate its performance.

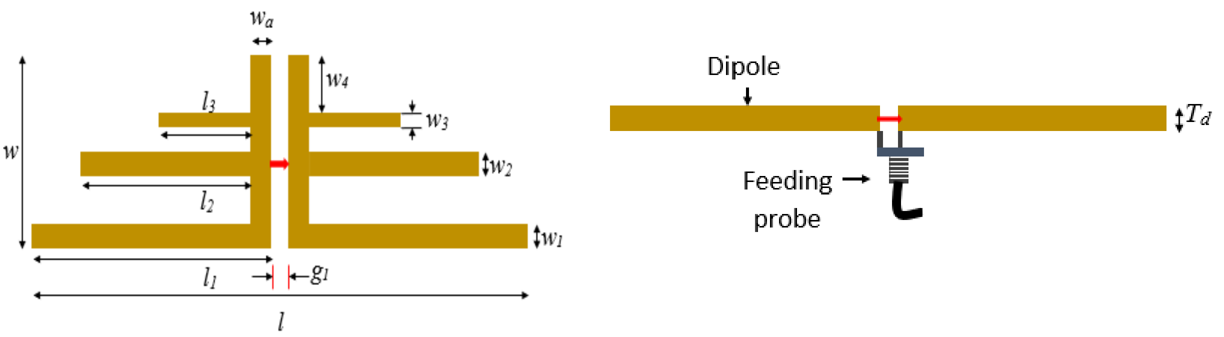
2. Multiband Dipole Antenna Design

This work aims to develop a small, wideband antenna. To achieve this, we designed:

i. conventional multiband co-planar dipole antenna
ii. modified multiband co-planar with L-shaped arms dipole antenna.

2.1 Conventional Multiband Co-Planar Dipole Antenna

Firstly, the conventional design of a multiband co-planar dipole antenna with the size of $59mm \times 10mm$ $(l \times w)$ is shown in Figure 1. Figure 1(a) and Figure 1(b) show the front view and the side view, respectively. The multiband antenna has three straight dipole arms, which allow the antenna to operate at three different desired frequencies. The length of the dipole arms is dependent on the desired resonant frequencies. The initial antenna is designed using a copper plate with a thickness of $T_d = 1.0mm$ as shown in Figure 1(b). Referring to Figure 1, it is shown that the conventional antenna tends to be larger in size. In this work, antenna size is very crucial when it comes to antenna design. A wideband operation antenna is significant in breast imaging where the antenna needs to generate from a lower frequency to specific frequency range. Consequently, the size of antenna tends to be larger when dealt with low frequency. Hence, it is crucial to overcome this limitation in antenna design.



(a) (b)

Fig. 1. Conventional design of multiband dipole antenna (a) Front View (b) Side View

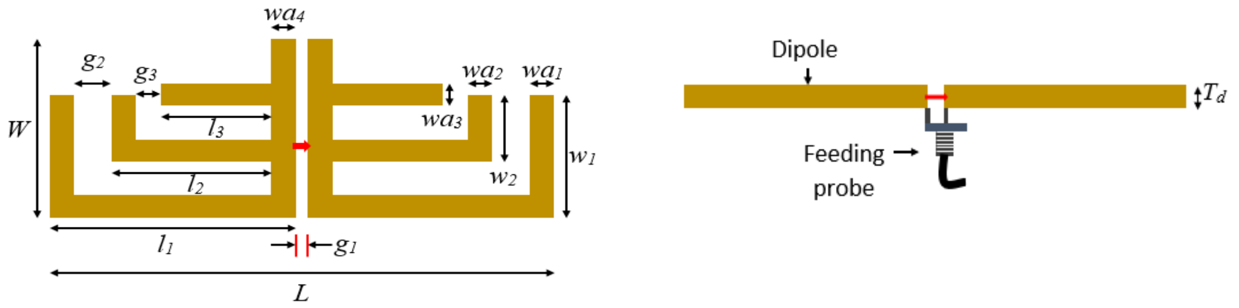
Table 1
Dimension and parameter of conventional multiband dipole antenna

Parameters	Dimension (mm)	Parameters	Dimension (mm)
l	59.0	w_2	2.0
w	10.0	w_3	1.0
l_1	29.0	w_4	2.0
l_2	18.0	wa	2.0
l_3	12.0	g_1	1.0
w_1	2.0	-	-

2.2 Modified Multiband Co-Planar with L-Shaped Arms Dipole Antenna

The proposed multiband co-planar with L-shaped arms dipole antenna shown in Figure 2 is a modification from the conventional design in Figure 1. Figure 2(a) and Figure 2(b) depict the front view and the side view, respectively. In this work, a multiband dipole antenna is designed to provide a wideband operation for the detection of various tumour sizes. In addition, the dipole antenna also includes the co-planar feeding technique and L-shaped arms to reduce the antenna size so that it can fit on the breast's entire surface area. Referring to Figure 1 and Figure 2, it is shown that the proposed antenna size is reduced by 20% from the conventional antenna size. The new size of proposed dipole antenna is $47mm \times 12mm$ $(L \times W)$. Each length of the dipole arms is modified according to the desired resonant frequencies; $l_1 = 23mm$, $l_2 = 16mm$ and $l_3 = 11mm$. The dipole arms, l_1 and l_2

are bent for the purpose of reducing the antenna size. Meanwhile, the excitation gap, g_1 is set at $1.0mm$ to achieve a 50 Ω impedance matching the source. The Finite Difference Time Domain (FDTD) grid size used in the numerical simulations is $1.0mm \times 1.0mm$, hence the thickness of the antenna is set to $T_d = 1.0mm$ to satisfy the FDTD grid size [22-23]. This will be done by using copper plate with the thickness of $1.0mm$.



(a) (b)

Fig. 2. Multiband co-planar with L-shaped arms dipole antenna (a) Front View (b) Side View

Table 2 provides the design requirements for the proposed antenna. The L and W indicate the length and width of the antenna, respectively. The length of bend arms is labelled as w_1 and w_2. The g_2 and g_3 are imply to the gap between the dipole arms. The width of each arm is illustrated as wa_1, wa_2, wa_{a3} and wa_{a4}. The proposed multiband co-planar dipole antenna operates at frequencies 2.4 GHz, 4 GHz, and 6 GHz. The length of the dipole's arm, L is determined by:

$$L = 0.5\left(\frac{c}{f}\right) \tag{1}$$

where c is speed of light and f is the desired operating frequency.

Table 2
Dimension and parameter of multiband co-planar with L-shaped arms dipole antenna

Parameters	Dimension (mm)	Parameters	Dimension (mm)
L	47.0	wa_1	2.0
W	12.0	wa_2	2.0
l_1	23.0	wa_3	2.0
l_2	16.0	wa_4	2.0
l_3	11.0	g_1	1.0
w_1	9.0	g_2	2.0
w_2	5.0	g_3	2.0

3. Simulation and Parametric Studies on Size Reduction

Simulations were run to examine the reflection coefficient of both the conventional antenna design and the multiband L-shaped arms dipole antenna as illustrated in Figure 3. The solid black line illustrates the S_{11} result for conventional multiband dipole antenna, while the dashed red line shows the result for the proposed multiband co-planar with L-shaped arms dipole antenna. Simulation results have demonstrated the efficacy of the antenna design that has been proposed. The dimension of the L-shaped antenna has reduced with the size of $47mm \times 12mm$ $(L \times W)$ and the operating frequencies are at 2.4 GHz, 4.0 GHz and 6 GHz. The results demonstrate that the S_{11} for the L-shaped antenna improves at frequency 2.4 GHz and 4.0 GHz, where all the values are lower than -20dB. Although the S_{11} at 6 GHz showed a depth degradation, the L-shaped antenna surpasses the conventional design in terms of bandwidth.

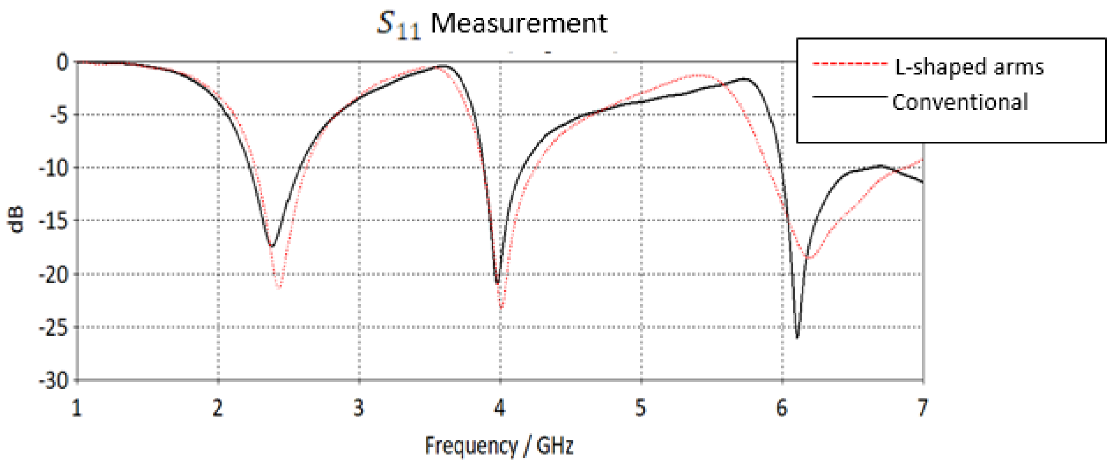


Fig. 3. S_{11} Result of conventional multiband dipole antenna design and proposed multiband co-planar with L-shaped arms dipole antenna

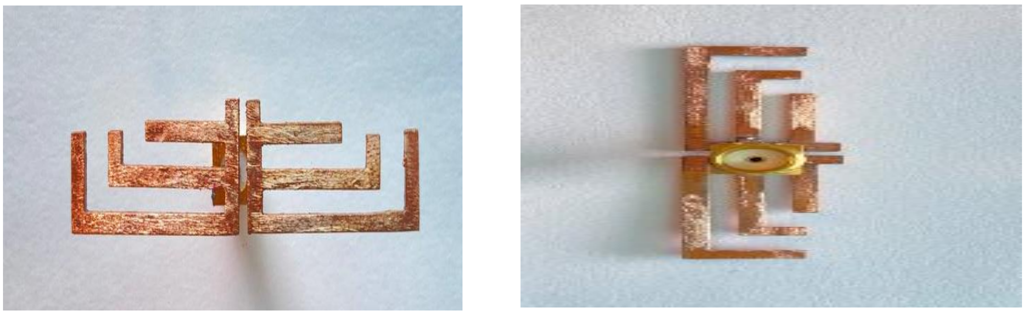
Besides, the bandwidth of the proposed antenna is slightly wider as compared to the conventional design as shown in Table 3. Therefore, to validate its performance, the L-shaped arms antenna is fabricated. The simulated and measured findings are discussed in Section 4.

Table 3
Comparison between conventional and L-shaped arms antenna

Antenna	Size	Operating frequency (GHz)	Bandwidth (%)	Peak Gain (dBi)
Conventional	$59mm \times 10mm\ (l \times w)$	2.37 GHz, 3.9 GHz, 6.1 GHz	14.6, 6.9, 11.2	2.17, 2.93, 2.68
L-shaped Arms	$47mm \times 12mm\ (L \times W)$	2.4 GHz, 4.0 GHz, 6.2 GHz	14.8, 9.1, 15.5	2.10, 2.68, 2.70

4. Fabrication and Measurement

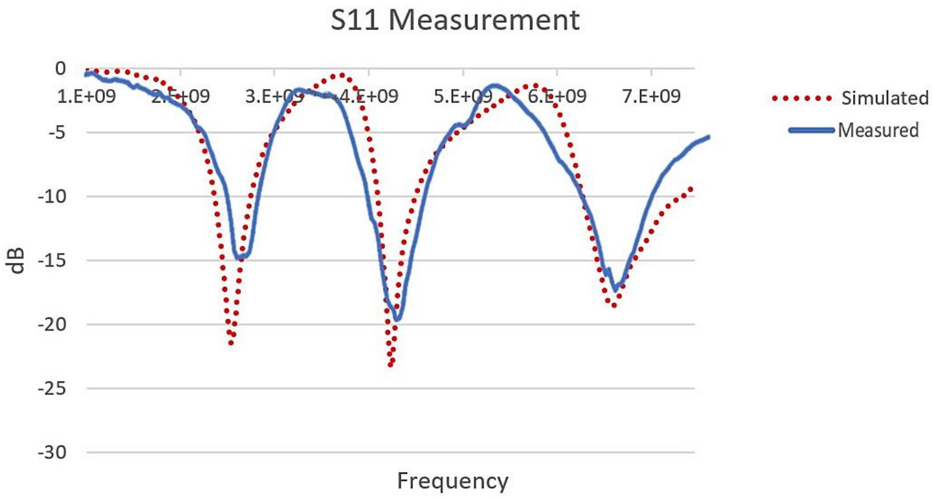
The multiband L-shaped arms dipole antenna is fabricated to verify the effectiveness of the proposed antenna. The fabricated antenna is shown in Figure 4 from two different perspectives: (a) the front view and (b) the bottom view. The antenna is made from copper plate with a thickness of $T_d = 1.0\ mm$ to make sure the antenna is compatible with the algorithm that will be applied in the breast imaging system. The antenna is crafted using a metal laser cutting system. The antenna is connected to the 50Ω SMA feed in the centre. The fabricated antenna is experimentally validated in terms of its radiation pattern and reflection coefficient. The performance of S_{11} and the radiation pattern were measured and compared to simulation results.



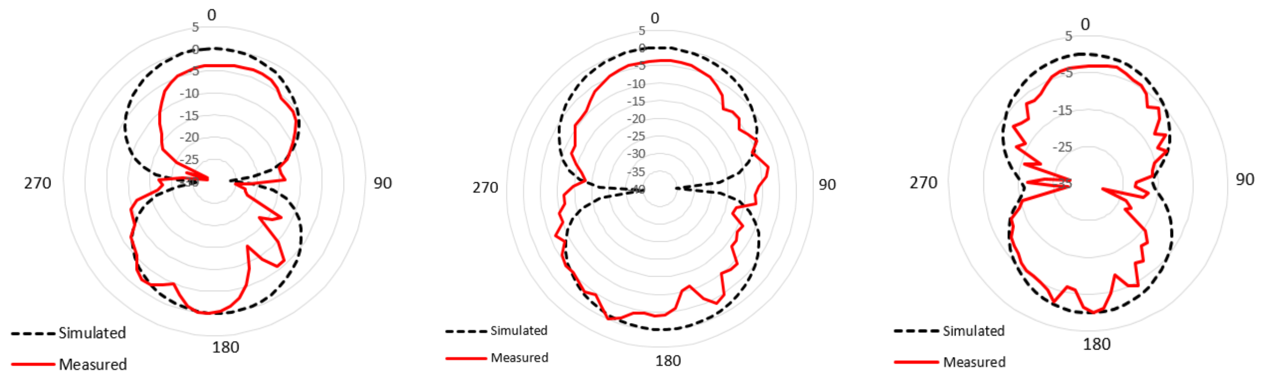
(a) (b)

Fig. 4. Fabricated antenna (a) Front View (b) Bottom View

Figure 5(a) depicts the simulated and measured S_{11} of the proposed antenna, with the red dashed line representing the simulated result and the blue solid line representing the measured result. Based on the S_{11} result, the lower and high frequency operation in measured result has slightly shifted to 2.5 GHz and 6.5 GHz respectively. It has been found that there is an acceptable correlation between the results of the simulation and the measurements. The simulated radiation pattern of E and H-plane at three frequencies of the antenna is shown in Figure 5(b) to observe the characteristic of the L-shaped antenna radiation. Note that, the L-shaped antenna is located along the X-Y plane. The antenna behaved as omnidirectional and radiates along z-axis.

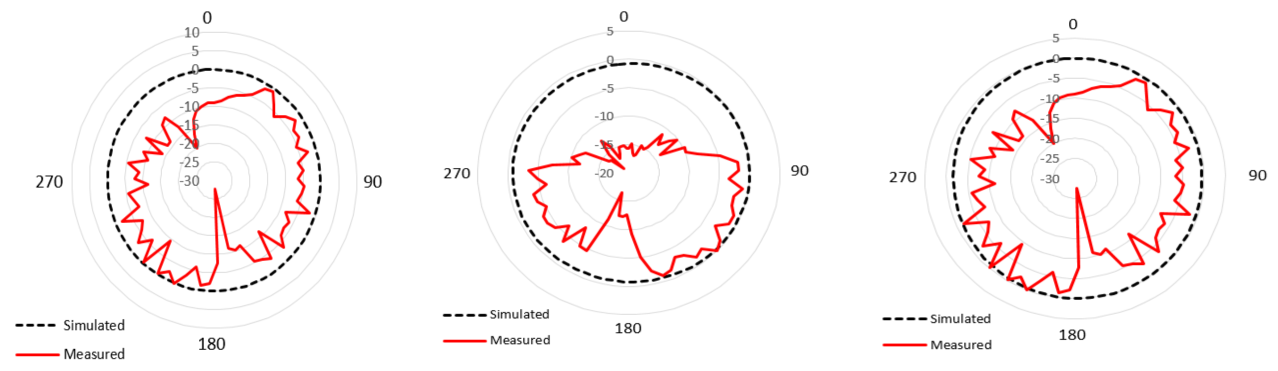


(a)



2.4 GHz 4.0 GHz 6.0 GHz

(b) E-Plane



2.45 GHz 4.0 GHz 6.0 GHz

(b) H-Plane

Fig. 5. (a) Comparison of simulated and measured reflection coefficient, S_{11}. (b) Radiation Pattern of E and H-Plane at three frequencies; 2.4 GHz, 4 GHz, 6 GHz

The disparity between simulated and measured values for $S_{11}$and gain is due to fabrication and material tolerances, in addition to the uncertainty initiated by the SMA connector. For instance, copper plates are prone to oxidation when exposed to air, which could affect the measurement result. In addition, despite the use of laser cutting, it is challenging to cut the copper plate because the antenna is too small, which might result in a minor crack. Additionally, poor SMA connector soldering might impact antenna impedance matching. Moreover, utilizing more exact fabrication methods or instruments could improve the measurement outcomes.

5. Conclusions

A multiband co-planar with L-shaped arms dipole antenna is presented in this paper. The modification of the L-shaped arm of the antenna results the reduction of size by 20% from the conventional multiband antenna design with the new size is $47mm \times 12mm$ $(L \times W)$. Furthermore, it is shown that the proposed antenna can operate on frequencies at 2.4 GHz, 4 GHz and 6 GHz. Due to its small size and compatibility with inverse scattering in the time domain [22,23], the proposed antenna is considered acceptable for implementation in a breast imaging system. As for future work, a 3D imaging algorithm will be integrated into the breast imaging system.

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