A Review of Frequency Selection and Antenna Arrangement System for Microwave Imaging in Early Breast Cancer Detection

Hadi Jumaat1*, Mohd Tarmizi Ali1, Kismet Hong Ping2, Najwa Mohd Faudzi1, Nurfarahin Miswadi1, Hamizan Yon1

1Faculty of Electrical Engineering, Universiti Teknologi MARA, Malaysia.
2Department of Electrical & Electronic Engineering, Faculty of Electrical Engineering, Universiti Malaysia Sarawak, Sarawak, Malaysia

*jumaathadi@gmail.com

Abstract. Microwave imaging technique is one of the developing techniques that having attention by researcher around the world in early breast cancer monitoring due to non-ionizing and the potential for cost saving and simpler system as compared to the current imaging techniques. The frequency selection is crucial in this application due to no bandwidth proven best. However, the amount of antenna is said affected the image resolution. This paper is an attempt to review the frequency selection and the antenna arrangement system in the past decades works for future antenna development in early breast cancer detection.

1. Introduction

According to the breast cancer mortality statistic [1], it is in the stressing situation to the world and moves toward becoming test to the specialists in exploring the fix, particularly in early breast cancer detection method. As result, in the past two decades the techniques in early malignant growth discovery have evolve; mammography, tomography, thermography, ultrasound and microwave imaging [2]–[6]. Microwave imaging is potential to become alternative technique besides X-ray mammography and magnetic resonance imaging (MRI) in early breast cancer detection due to the non-ionizing radiation, safer, potential for cost saving and simpler system [7].

The microwave imaging adopted the techniques on dielectric contrast by reconstructed the data obtained from transmitter and receiver whereby object is located between the transceiver. Then, the reconstructed data produce the contrast of malignant tumour and benign tissue. The tissues identified clearly since water density in malignant tumour is more than the normal breast tissue. At present, no bandwidth proven best for microwave imaging [7]. The frequency selection is crucial in antenna design since all equations involve in antenna shaping is depending on the operating frequencies. Thus, literature on frequency selection has been held with considering the works by signal processing field to justify the suitable frequency range for next work on designing antenna for microwave imaging on early breast cancer detection application. Some of the works basically using a point radiator representing antennas suggested at 1 GHz to 3 GHz in detecting the malignant tumour [8]. Besides that, a few researchers in antenna design field in [9]–[12] have been highlighted the potential of UWB frequency range in microwave imaging for breast cancer monitoring range from 1.3 GHz up to 20 GHz. Furthermore, a work highlighted in [7] is using 3.2 GHz to 5.7 GHz operating frequency with consideration of details.
tissue parameters. Overall from the previous researches, numerous frequency range have been suggested to cover the tissues.

In microwave imaging a single pair of antennas is insufficient for effective classification of tumour as per mentioned in [13]. More antenna will have better image resolution. Image resolution in microwave imaging is important to display better image of scanning object. Anyhow, not much literature presented to date regarding the arrangement of antenna for breast cancer monitoring. The optimization work on arrangement of antenna elements (antenna arrangement system) need to be done to have the best fundamental theory towards the arrangement system. Since the antenna arrangement system should be at the circumference of human breast, this limitation will lead to limited space between antenna. Without compromising the necessity of having much antenna in producing better image resolution, miniaturization of antenna should be proposed so it can be arranged with the maximum number of antennas on a level. However, miniaturizing antennas in contact with biological tissues is challenging due to having different propagation behaviour and return loss compared to those in free space [15].

The importance of frequency selection and good antenna arrangement system for microwave imaging in monitoring breast cancer has been highlighted. As per mentioned, in microwave imaging, multiple identical single antenna design is arranged around the object. Thus, the works by previous researchers is investigated including the size of the single antenna design involve in the multiple antenna arrangement system. These will help in precise frequency range selection in developing antenna arrangement system for microwave imaging in early breast cancer detection application in future. In this work, the reviews are focusing on the frequency range, number of antennas adopted, and the level in the antenna arrangement.

2. Antenna Arrangement for Microwave Imaging Breast Cancer Detection

The antenna arrangement in microwave imaging is developed at the area of around the human breast. However, the arrangement could be on one level, two level or more as at the height of the human breast. This is depending on the overall size of the single antenna to fit in the arrangement system without performance degradation. In this section, the review works is classified into two categories of antenna arrangement; one level and multiple level.

2.1. One Level Antenna Arrangement

An annular antenna system for microwave imaging for breast cancer detection has been developed by Amit S. Narkhede [14] in 2016. A circular patch antenna in conjunction with circular slot as shown in Figure 1 (a) is fabricated on FR4 substrate ($\varepsilon_r = 4.4$) with the thickness of 1.6 mm. The overall single antenna size is 47mm x 37 mm (L x W). The antenna design operates from 2.2 GHz to 12 GHz with gain of 6 dBi and having an omnidirectional radiation pattern. Next, the antenna arrangement has been simulated by using HFSS simulation tool whereby 12 identical antennas are assembled in one level arrangement as depicted in Figure 1 (b) along a cylinder circumference with radius of 200 mm to form an antenna system.

![Figure 1. The annular antenna system for microwave imaging for breast cancer detection. (a) The geometry of the single antenna and (b) simulated one level antenna arrangement. [14]](image-url)
Another simulation work on one-layer antenna array arrangement have been proposed in 2016 by using 8-element microstrip patch antenna array [36]. The antenna has been designed purposely for microwave imaging application, but the measurement of the antenna system is using representative method such as plexiglass and ethanol samples to be detected instead of breast phantom. The authors develop the antenna system to be operated at 3 GHz to detect the representative object. The microstrip patch antenna is designed on FR4 substrate (\(\varepsilon_r = 4.3, \tan\delta = 0.025\)) with 8 antennas are assembled in octagon shape around the object with the overall system footprint exhibit 136 mm x 136 mm (L x W) as shown in Figure 2.

![Figure 2. Microwave imaging using 8-element microstrip patch antenna array on one level arrangement. [15]](image)

An experimental work on early breast cancer detection using circular antenna array have been reported by S. S Tiang in [16]. The overall work including antenna development and image reconstruction. At first, a p-shaped wide slot antenna configuration has been proposed by the author with 16 mm x 16 mm (L x W) overall size of the single antenna to be placed later in circular antenna arrangement circumference the breast phantom. The antenna is designed to operates from 4.5 GHz to 10.9 GHz on Rogers RT6010 microstrip substrate with dielectric constant of 10.2. The author proposed using 88 mm diameter phantom with contain of fat, skin, glandular and tumour layers. The distance between two opposite antennas is set to 90 mm. Next, 16 identical single antennas are arranged on one layer with circular arrangement as depicted in Figure 3.

![Figure 3. Development of compact wide-slot antenna for early stage breast cancer detection with (a) circular antenna arrangement and (b) experiment set up.[16]](image)

2.2. Multiple Level Antenna Arrangement
In 2016, a work done by Yunpeng Li [13] classified in the comparison of microwave breast cancer detection results with breast phantom data and clinical trial data by varying the number of antennas. The experimented data has been collected and illustrates the microwave imaging technique (using breast phantom experiment) contribute to easier task as compared to clinical trial data collection. It is also summarized in this work the insufficient for effective classification of tumor by using a single
antenna pair. The variations of the point antenna arrangement are from 2, 4, 8 and 16 have been investigated. The simulation is working on points radiating element representing as antennas instead of using real antenna structure as exhibit in Figure 4 simulated between 2 GHz to 4 GHz. This experiment shows that at least four antennas are needed for good classification performance, and the performance becomes more reliable as the increasing to 8 or 16 points of radiating elements. Hence, this condition showing that the numbers of antenna will enhance the image output by producing more data towards the object. Furthermore, in this research work do mention the importance in adopting reliable breast phantom specification to get more robust result of the breast tumor detection.

Figure 4. The simulation of 1 to 16 points of antenna arrangement. [13]

In 2017, an assembly conformal antenna array for wearable microwave breast imaging application has been conducted by F. Wang [17] in simulation using CST Studio Suite. The author designing a single UWB antenna with triangle shape of fractal slot to reduce the overall size of the antenna with the final footprint is 32.7 mm x 26 mm (L x W) in size as shown in Figure 5 (a). The designated antenna operating frequency is from 3.2 GHz to 5.7 GHz with 2.5 GHz of bandwidth on DuPont Kapton polyimide substrate ($\varepsilon_r = 3.1$) and 0.075 um thickness. Next, simulation works is done for two-level antenna array mounting with 16 reassemble antennas involve on realistic Voxel-based breast model as depicted in Figure 5 (b). The proposed work could provide the estimate location and size of breast tumor less than 2.5 mm radium.

Figure 5. The assembly conformal antenna array for wearable microwave breast imaging application. (a) The geometry of UWB antenna and (b) Two-level antenna array mounting on breast model. [17]

Another interesting work by Hadi Bahramiabarghouei [18] developing a flexible 16 antenna array for microwave breast cancer detection. Two antenna designs with arrangement system produced by the author. A single and dual polarization antenna has been investigated and fabricated on Kapton polyimide ($\varepsilon_r = 3.5$) with 0.05 mm thickness. The geometry of the antennas is shown in Figure 6 (a). The simulated result analyzed in this work is using HFSS simulation tool. The antennas have been designed to be
operated from 2 GHz to 4 GHz. The single polarized antenna design adopted the patch tapping technique to resonate from the lowest to higher desired frequency. On the other hand, the dual polarized antenna design adopted spiral shape to produce dual-polarization and attaining the desired frequency. In addition, the dual-polarization is supposed by the author due to it may add information to the collected signal by enabling recording of backscattered signal of two polarizations. Both antenna design achieved 20 mm x 20 mm (L x W) size. Moreover, the antennas were arranged by using 4 x 4 array arrangement system as exhibited in Figure 6 (b) that creates 4 levels of antenna arrangement.

![Figure 6](image)

**Figure 6.** The flexible 16 antenna array for microwave breast cancer detection. (a) The single antenna geometry for single and dual-polarization and (b) 16 antenna array assembly system. [18]

### 3. Conclusion and Future Research

A several works related to the development of antenna arrangement system for microwave imaging in early breast cancer detection has been done. In this work, several arrangement techniques that researchers have undertaken within this decade have been reported and tabulated in Table 1 for guidance and enhancement of future antenna arrangement. Frequency selection has been observed and found the wideband frequency suitable for use in this application. The reviews on antenna arrangement system has been presented on one level and multiple level. The arrangement of a single antenna at each stage is aimed at achieving the maximum number of antennas which will be benefited in the array system to be used. This is due to the theory that the number of antennas will affect the imaging resolution. In addition, the breast phantom model adopted in the investigated work were also identified and tabulated for consideration in future related to design work on breast phantom model. In summary, the measurement result of each investigated work shows agreement with their hypothesis by exhibited imaging result. However, improvement of antenna arrangement in the system probably will enhance the data to be reconstructed to produce better image resolution.

| Name of antenna arrangement system | Frequency (GHz) | Level | No. of antenna | Breast phantom model |
|-----------------------------------|----------------|-------|----------------|---------------------|
| The annular antenna system [14]   | 2.2 - 12       | One   | 12             | No phantom          |
| 8-element microstrip patch antenna array [15] | 3             | One   | 8            | Plexiglass and ethanol samples |
| Wide-slot antenna for early stage breast cancer detection with circular antenna arrangement [16] | 4.5 – 10.9 | One  | 16            | Chemical-based heterogeneous phantom (oil-gelatin mixture) |
| Assembly conformal antenna array [17] | 3.2 - 5.7     | Two   | 16            | Voxel-based breast model |
| 1 to 16 points of antenna arrangement [13] | 2 - 4          | Four  | 16            | Heterogeneous phantom (mimic dielectric properties) |
| The flexible 16 antenna array [18] | 2 - 4          | Four  | 16            | Three layers homogeneous medium |
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