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RESEARCH ARTICLE

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An Extensive Survey on Metamaterial Based Antenna Design for Breast Cancer Detection

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ABSTRACT

The Threats To Human Life Due To Cancer Is Growing Faster And Early Detection And Easy Diagnostic Methods Are In Demand. This Paper Provides A Detailed Survey On Metamaterials And Analysis Of Various Antenna Structures To Detect Breast Cancer At The Earliest. The Cancer In The Breast Can Be Effectively Diagnosed And Screened Using Microwave Imaging Technique. This Can Be Achieved By Designing A Medical Imaging System Using Microwave Antenna. Metamaterial Antennas Improve The Performance Of Miniaturized Antenna Systems With Efficient Power And Acceptable Bandwidth. One Among The Most Widely Investigated Detection Mechanism Is Using Microwave Imaging In The Field Of Medicine.

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KEYWORDS

Metamaterial, Bandwidth, Microwave Imaging, Tumour, Antenna

INTRODUCTION

One of the major public health troubles is cancer. Breast cancer is caused by the abnormal growth of breast tissues. Among Hispanic women, the most common death causer is breast cancer and the second most common cause among Pacific Islander women, Asian women, Black women and White women according to the Centers for Disease Control and Prevention (CDC). Several factors affect the treatment of breast cancer namely time of detection, number of tumours, tumour size, depth of tumour spread in the lymph nodes or nearby parts. A huge group of diseases that can begin in almost any tissue or organ of the body due to the growth of abnormal tissues uncontrollably beyond the usual boundaries, invading the nearby body parts and spreading to other organs is termed as cancer.

According to survey, among the world wide cancers, the breast cancer plays a serious role in women and it accounts to 25% of all cases. Around 6,27,000 deaths and 2 million new cases occurred in the year 2018. It is 100 times more common in women compared to men especially in the developed nations. Scaly or a red patch in skin, a newly-inverted nipple, a change in breast shape, fluid coming from the nipple, dimpling of the skin, and a lump in the breast are some common signs of breast cancer.

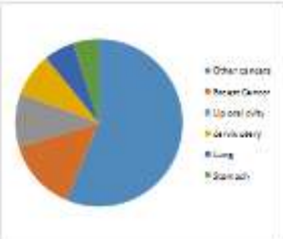

Fig 1. Cancer Statistics

Scientists across the world used several techniques for early diagnosis of breast cancer. Diagnostic techniques based on imaging such as contrast-enhanced digital mammography [1], (MRI) Magnetic resonance imaging [2], and Positron Emission tomography [3] and Breast mammograms [4] provide limited image resolution but are

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expensive techniques. For obtaining information regarding the type and stage of cancer, a single marker is insufficient and techniques based on biomarkers are still in research [5]. Identification of benign tissue and cancerous tissues are made possible by biopsy based techniques [6], however, these methods often require trained people and suffer from high cost factors [7]. Hence microwave imaging technique is an recent and emerging alternative methods that is reliable, nonionozing, cost effective, portable, side effect minimization nature compared to other existing solutions and comfortable for breast screening.

Fig 2 .Early Signs of Breast Cancer

MICROWAVE IMAGING TECHNIQUE

In this technique, detection of tumour tissues is performed using the variations in the electrical properties of malignant and healthy cells.

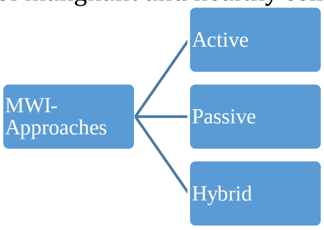

Fig 3. Approaches in microwave imaging technique

Active microwave imaging technique uses microwave energy for illuminating the breast. The breast tissues attenuate and reflect the microwaves traveling through the breast. Lesser reflection and attenuation are created from normal tissues when compared to the tumour tissues. Due to increased vascularization, the temperature of a tumour is said to be larger than that of the healthy breast tissue which forms the principle assumption of passive microwave imaging for tumour detection. Usage of Microwaves by the hybrid microwave-acoustic imaging technique for illumination of breast and the signals are measured using ultrasound transducers. Microwave energy is absorbed more by the tumour cells due to their dielectric properties [8]. When microwave and acoustics are combined together the tumour cells expand more as they absorb higher energy compared to normal tissues. The pressure waves produced by this expansion is detected using a focused ultrasound transducer [9].

Microwave imaging produces reasonably precise breast tumour detection along with considerations of shape, size, and boundary irregularities [10].Two main classifications of microwave imaging techniques are tomography based and radar based microwave imaging.

A. Tomography Based

In order to identify tumours, quantitative information is provided on dielectric properties of breast tissues by microwave tomography [11] An ill-possessed and non-linear output is obtained from an inverse scattering problem[12].

B. Radar Based

In this method the internal structure is mapped with the dielectric property of the breast tissue. An assuring tool for early diagnosis is radar based microwave imaging It offers advantages of specificity, high sensitivity, safely and cost-effectiveness. When compared to microwave tomography, this technique is safer and more comfortable. The radar-based microwave imaging approaches can be demonstrated using several experimental measurement systems [13] [14] such as the holographic microwave imaging (HMI) [19] [20], microwave imaging via space time (MIST) [17] [18] and confocal microwave imaging (CMI) [15] [16] were developed. To obtain relatively high contrast, the fat tissue in the breast is to be considered as it makes the tumour a significant scatterer. Hence from the survey it is observed that the radar based technique can be effectively utilised to locate the tumour [15, 22, 23, and 24– 30].The outcomes of this method includes repeatability, size reduction, wider impedance bandwidth and cost effective fabrication [31] [32]. The dielectric property differs for different tissues as their have dielectric properties are characterized by relative permittivity and conductivity.

METAMATERIALS IN ANTENNA DESIGN

Metamaterials are the new materials that are formed by the organization of metal structures on the dielectric substrate. Hence, rather than the component that makes them, the structures of metamaterials are more important than their physical properties. Negative permeability and permittivity are the features of these materials. Negative permeability is offered by one of the metamaterial particles termed as a split-ring resonator (SRR). Negative permittivity is introduced by the interaction of duality of SRR and electric field by the complementary split-ring resonator (CSRR) [33], which are most commonly used in biomedical sensors.

C. Understandings of Electromagnetic Metamaterials

The arrangement of homogeneous metal structures with unusual properties lead to the creation of artificial materials called the electromagnetic metamaterials (MTMs). On the surface of dielectric substrates, metal structures are arranged to form new materials called MTMs. Different types and applications of metamaterials are generated based on different structures. Based on the permeability created and the material permittivity, they are further classified [34].

- In order to to form a unit cell of metamaterials, the guided wavelength should be greater than the homogeneous structure [35].
- Arrangement of cells made from dielectric, nonelectrical or electrical materials or atoms lead to the generation of metamaterials.
- Creation of the desired macro characteristics for the metamaterial can be done by the arrangement of atoms in a chaotic or orderly manner.

D. **Metamaterials and their Properties**

Maxwell's equations can be used for describing the electromagnetic property. For highlighting the properties of metamaterials, we use the transformation of this equation. The following set of equations represent the same:

$$\nabla \times \bar{E} = -j\omega\mu\bar{H}$$

$$\nabla \times \bar{H} = j\omega\varepsilon\bar{E}$$

$\bar{E}$ is the vector of electric field, $\bar{H}$ is the vector of magnetic field and the material permittivity and permeability are represented by ε and μ respectively. The angular frequency is ω and the imaginary number $j = \sqrt{-1}$. The electric and magnetic fields in plane wave propagation are:

$$E = E_0 e^{(-jkr+j\omega t)} \quad (3)$$

$$H = H_0 e^{(-jkr+j\omega t)} \quad (4)$$

For evaluation of the properties of materials, Poynting power density vector $\bar{S}$ offers a general definition which is subdivided into the space $e^{-j\omega t}$ and the time $e^{+j\omega t}$ components. The energy flow of the Poynting vector $\bar{S}$ is

$$\bar{S} = \frac{1}{2}\,\bar{E} \times \bar{H}^* \quad (5)$$

The plane waves of electric field $\bar{E}$ and magnetic field $\bar{H}$ are given by

$$\bar{K} \times \bar{E} = \omega\mu\bar{H} \quad (6)$$

$$\bar{K} \times \bar{H} = -\omega\varepsilon\bar{E} \quad (7)$$

The ε and μ values are positive for homogeneous and isotropic medium. In this medium, are the right circulate triad of orthogonal vectors depends on the propagation vector $\bar{K}$, the electric field $\bar{E}$ and magnetic field $\bar{H}$. The electromagnetic waves propagate in the right-handed medium, the $\bar{S}$, $\bar{K}$ have the same directions (8). Then the values of μ and ε are simultaneously negative, so the above equations can be rewritten as,

$$\bar{K} \times \bar{E} = -\omega\lfloor\mu\rfloor\bar{H} \quad (8)$$

$$\bar{K} \times \bar{H} = \omega\lfloor\varepsilon\rfloor\bar{E} \quad (9)$$

A triad of orthogonal vectors are circulated by the propagation vector $\bar{K}$, magnetic field $\bar{H}$ and the electric field $\bar{E}$ form the left hand. The Poynting vector $\bar{S}$ in this medium and the propagation vector $\bar{K}$ are opposite to each other, so that the wave fronts and the energy travel in opposite directions and it can support backward waves.

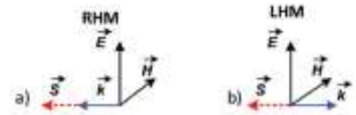

Fig 4. The Vectors for Right and Left Handed Media

E. **Antenna Design and the role of Metamaterials**

One of the prominent applications in designing antennas includes application of metamaterials to the design [36] [37]. In such antennas, the antenna performance is improved by adding many number of metamaterial layers in addition to the configuration of antenna paramteters [38–40]. Certain crucial parameters can be improved by the radiated power by the application of Metamaterials in the antenna design.

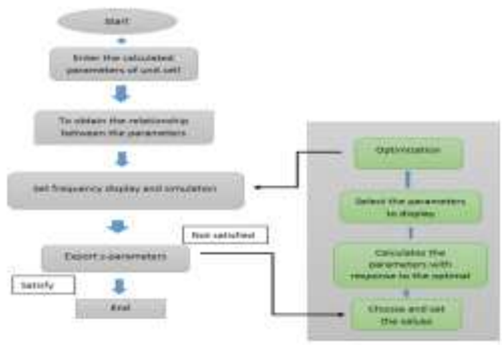

Fig 5. Unit cell of Metamaterial

Additionally the antenna size, design and purpose can be effectively reduced according to the application based on the Metamaterial used.

MICROWAVE IMAGING WITH ANTENNA

In microwave imaging systems, antennas form the building blocks for transmission and reception of signals to and from the scattered objects nearby. Biomedical applications make use of several antenna structures. Few such structures are listed below.

F. Microwave Breast Imaging Sensing Arrays using UWB Active Antenn

Farzad Foroutan et.al [40] developed and validated an UWB miniature active printed slot antenna by measuring two prototypes (with an external bias and an on-board bias-tree by means of coaxial connectors). In a frequency band of 3 GHz to 8 GHz, this article achieved a signal gain of about 20 dB, which is similar to the LNA integrated on the antenna panel. Comparable results were obtained from two types of Antenna

Fig 6. Fabricated element types: (a) Active antenna with the bias circuit on the same board, (b) LNA chip and inductor L1 only on the board (c) Third element type of a passive antenna for comparison

Fig 7:(a) Top layer facing the tissue phantom. (b)Bottom shielding

The prominent features of this proposed active antenna elements are: full shielding at the back, easy to fabricate planar design, small element size with center-to-center spacing of 12 mm, impedance bandwidth from 3 GHz to 8 GHz, and 20 dB gain enhancement. Yet they note that the back shield has a negative impact on the impedance match close to the 3 GHz end of the bandwidth.

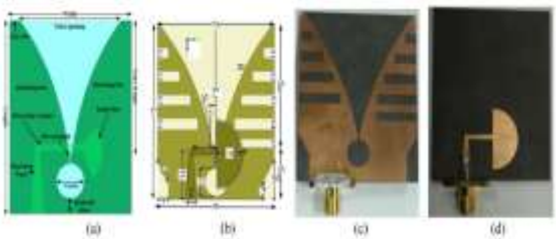

Fig 8. (a) Exponentially narrowed slot (b) proposed modified antenna (c) fabricated prototype-front view (d) fabricated prototype- back view

G. Low Cost and Portable Microwave Imaging System with UWB Directional Antenna array for Breast Tumor Detection

Mohammad Tariqul Islam.et.al [41] designed an antenna system based on UWB directional Vivaldi antenna. The high peak value for pulse envelope and tapered slot design provides this antenna with a high gain. It also provides stable group delay.

H. Design of Wide Band and Rectangular Microstrip Patch Antenna for Detection of Breast Tumor

S. Maria Glammi et.al [42] proposed a design having matching liquid at the frequency range of 2.4 GHz to 7GHz with wideband slot antenna. The optimized emulsion for matching liquid is obtained in a mixture of 80% sunflower oil and 20% distilled water. They analysed directivity, power radiated gain and return loss.

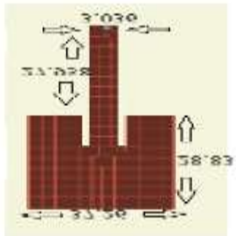

Fig 9. Rectangular microstrip patch antenna design

I. CPW-fed Microstrip Antenna based on Uniplanar AMC for Detection of breast tumor using Microwave Imaging

M D. Zulfiker Mahmud et.al [43] proposed that the directivity and gain can be enhanced by means of MTM AMC structure. Using this method, the gain is increased by 5dB for CPW-fed Microstrip antenna and the directivity is increased by 4.5 dB with lower interference to adjacent microwave elements.

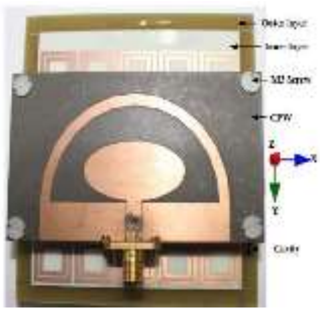

Fig 10.. The CPW-fed antenna prototype

Based on analysis, it is evident that the variation of dielectric properties of the phantom leads to variation of scattering signal. Low cost, easy installation and portability are the key elements for this design. The system has many advantages e.g. easy installation, low cost, portability, compact design.

J. Improved Modified Microwave Imaging Antenna Sensor with a Homogeneous Breast Phantom Measurement System

Mohammad Tariqul Islam.et.al [44] developed a system with a BSAVA sensor .Vivaldi antenna sensors are used with a fractional bandwidth of 114% from 3.01 to 11 GHz forming directional radiation pattern, higher gain, and efficiency. For enhancing the bandwidth, gain, directional radiation pattern and higher efficiency the different antenna sensor parameters are optimized including slots on both patch and ground.

Fig 11. Front and back view of the fabricated prototype

It was observed that the unwanted cells inside the human breast can be located using the scattered signal as the key point and this system can localise tumour cells from healthy cells using this concept.

K. Microwave Imaging System using Highly Directional Microstrip Ultra Wide Band Antenna

Vanaja Selvaraj.et.al [45] presented a staircase UWB directional antenna with the impedance bandwidth between 1.43GHz and 8.92GHz and maximum proposed gain is 6.06dB. The recommended antenna works good for imaging in the aspect of radiation pattern, surface current and VSWR.

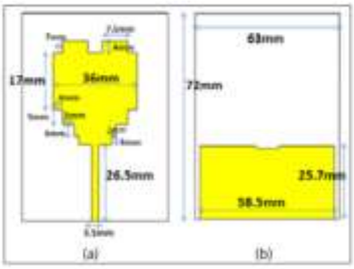

Fig 12. Fabricated prototype : Top view and bottom view

The result concludes that the UWB microwave imaging system is a favourable tool for obtaining the radiation pattern, surface current, and VSWR.

L. Perfromance enhancement of Miniaturized UWB Antenna using a A Negative Index Metamaterial for Microwave Imaging Applications

The ground plane and the radiating patch are laid with two layers of left-handed metamaterial array from the metamaterial micro strip antenna developed by Md. Zulfiker Mahmud et.al[46] with 3.1 GHz to10.71 GHz of impedance bandwidth is achieved by the antenna, covering the full UWB band with a gain more than 3dB and an increased efficiency of 10–20%.

Fig 13. Front and back view of the fabricated prototype

The antenna suitability for MIS applications is proved by the near field directivity factor, radiation efficiency with the breast model and its coupling efficiency.

M. Breast-Cancer Detection using A Microwave Imaging System based on COTS

Mario R. Casu.et.al [47] proposed a low-cost system for breast cancer detection using microwave imaging with the theory of I-MUSIC confining that at ideal condition point-like scatterers can be detected.

Fig 14.: Front view and back view of the fabricated prototype

N. for Microwave Breast Cancer Detection using a Flexible Sixteen Antenna Array

H. Bahrami.et.al [48] presented a technique for breast cancer detection by the design of wearable single-and dual-polarization antennas on a flexible substrate operating on frequency bands of over 2-4GHz.

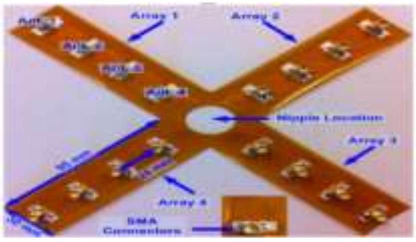

Fig 15. View of the individual antenna-element with the resonator

It also stated that significant improvement can be attained in the penetration of the propagated electromagnetic waves by using a reflector for the arrays.

TABLE I. COMPARISON OF VARIOUS ANTENNA DESIGNS

Antenna Used	Features		
	Frequency	*Substrate*	*Tool*
Slot Antenna	3GHz-8GHz	Rogers RT/Duroid 6010LM	CST Microwave Studio
Vivaldi Antenna	3.1GHz-10.71 GHZ	-	MATLAB
Microstrip Antenna	3GHz-10GHz	FR4	HFSS Simulator
Microstrip Antenna	3GHz-10GHz	FR4	HFSS Simulator
UWB Patch Antenna	3.1GHz-10.71 GHZ	FR4	CST Microwave Studio
Vivaldi Antenna	3.1GHz-10.71 GHZ	-	MATLAB
Patch Antenna	1.4GHz-8.92 GHz	FR4	CST Microwave Studio
Monopole and Spiral Antenna	2GHz-4 GHz	Kapton Polymide	HFSS Simulator

Conclusion

From the survey it is clear that the early detection of the tumour cells is the only possibility to diagnose breast cancer at the early stage. Microwave imaging technique paves way for this approach and this technique provides accurate and efficient diagnosis results. Various antenna structures are identified for improvisation of output parameters so that the ease of usage can be increased for this application.

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