DEVELOPMENT OF FLEXIBLE ANTENNA FOR BREAST CANCER APPLICATION

BY

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ABSTRACT

Breast cancer is the most diagnosed cancer among women all over the world after skin cancer. Meanwhile, microwave imaging has been a prominent detection technique for biomedical diagnosis in recent years and it has become very popular and widely accepted by the researchers and physicians for breast cancer detection (BCD) at an early stage. However, the microwave imaging is struggling with the spatial resolution that can be solved by an imaging technique based on the antenna with a wide operating bandwidth at the higher frequency range. In this thesis, a flexible Elliptical Ring Slotted Planar Monopole Antenna (ERSPMA) with a wide – 10 dB bandwidth of 7 GHz has been proposed for a breast cancer imaging application. This printable monopole antenna, after being design on flexible Polyimide substrate, operates from 7 GHz to 14 GHz which covers the entire X-band frequencies. The proposed antenna has achieved an average flat gain of 4 dBi with an average radiation efficiency of 92% for the entire – 10 dB bandwidth. Therefore, the – 20 dB bandwidth of the antenna covers the entire X-band (8 GHz – 12 GHz) with an average flat gain of 4 dBi and average radiation efficiency of 95%. Therefore, the minimum return loss of the antenna is as low as -58 dB. To justify the design stability, the proposed antenna has been realized on the other two different substrates, Paper and PET. With an average gain of around 4 dBi, the ERSPMA on Paper and PET substrates have achieved an average radiation efficiency of 92.5% and 85.5% respectively for the entire – 10 dB bandwidth of 7 GHz. Therefore, the average radiation efficiency of 97% and 90.5% have achieved with Paper and PET substrates respectively for the X-band frequencies. The average VSWR value for the proposed antenna has achieved around 1.5 and 1.1 for the whole –10 dB bandwidth and X-band frequencies respectively with a minimum value of 1 for all three substrates, which justifies a greater impedance matching between the radiator and the transmitter of the proposed antenna. The quasi-omnidirectional radiation pattern of the antenna offers the freedom of placing the antenna both at the front and back position on the body surface. Therefore, the average Specific Absorption Rate (SAR) of the proposed antenna is below than 0.5 W/kg for 1-gram mass that is within the specified standard by the FCC (≤1.6 W/Kg for 1-gram mass) for the public at microwave frequencies. For flexibility, the bending performance of the antenna has been presented for four different directions. The optimized antenna-prototype has a bandwidth of 5.4 GHz (8.6 – 14 GHz) with a minimum VSWR of 1. Due to the compact area of 13×13 mm^2, an average gain of 4.4 dBi and a peak gain of 6.33 dBi, the fabricated antenna is a suitable candidate for biomedical applications in X-band frequencies by utilizing a low-cost manufacturing process. Moreover, the optimized antenna-prototype of the proposed ERSPMA shows good performances with the in-Vivo test.

خلاصة البحث

أن سرطان الثدي هو أكثر أنواع السرطان تشخيصاً بين النساء في جميع أنحاء العالم بعد سرطان الجلد. وفي الوقت نفسه ،كان التصوير بالميكروويف تقنية اكتشاف بارزة للتشخيص الطبي الحيوي في السنوات الأخيرة ، وأصبح شائعًا جدًا ومقبولًا على نطاق واسع من قبل الباحثين والأطباء للكشف عن سرطان الثدي (BCD) في مرحلة مبكرة. ومع ذلك ، فإن التصوير بالموجات الدقيقة يفتقر الي الدقة الكافية التي يمكن حلها عن طريق تقنية التصوير القائمة على الهوائي مع عرض نطاق واسع للتشغيل في نطاق التردد العالي. في هذه الأطروحة ، تم اقتراح هوائي بيضاوي أحادي الحلقة ذي شق دائري (ERSPMA) له عرض نطاق يبلغ 10 ديسيبل يبلغ 7 جيجاهرتز لتطبيق تصوير سرطان الثدي. يعمل هذا الهوائي أحادي القطب القابل للطباعة ، بعد تصميمه على ركيزة بوليميد المرنة ، من 7 GHz إلى 14 GHz والذي يغطي كامل ترددات X–band . لقدحقق الهوائي المقترح متوسط ربح ثابت قدره 4 dBi بمتوسط كفاءة إشعاعية قدره 92٪ لكامل عرض النطاق – 10 .dB لذلك ، يغطي عرض النطاق الهوائي البالغ 20 ديسيبل النطاق X بأكمله (8 GHz – 12 GHz) بمتوسط اشعاعي ثابت قدره 4 dBi ومتوسط كفاءة الإشعاع بنسبة 95٪. لذلك ، يكون الحد الأدنى لخسارة الإرجاع للهوائي منخفضًا حتى –58 ديسيبل. لتبرير ثبات التصميم ، تم تحقيق الهوائي المقترح في الركيزتين الأخريين المختلفتين ، الورق و .PET مع كسب متوسط حوالي 4 ديسيبل ، حققت ERSPMA على ركائز الورق و PET كفاءة إشعاع متوسط 92.5 ٪ و 85.5 ٪ على التوالي لكامل النطاق الترددي – 10 ديسيبل من 7 غيغاهرتز. لذلك ، حقق متوسط كفاءة الإشعاع 97 ٪ و 90.5 ٪ مع ركائز الورق و PET على التوالي لترددات –X الفرقة. حقق متوسط قيمة VSWR للهوائي المقترح حوالي 1.5 و 1.1 لكامل عرض النطاق – 10 dBوترددات النطاق X على التوالي مع قيمة لا تقل عن 1 لكل الركائز الثلاثة ، مما يبرر وجود مقاومة أكبر للمطابقة بين المبرد والمرسل من الهوائي المقترح. يوفر مخطط الإشعاع شبه أحادي الاتجاه للهوائي حرية وضع الهوائي في الموضع الأمامي والخلفي على سطح الجسم. لذلك ، فإن متوسط معدل الامتصاص النوعي (SAR) للهوائي المقترح أقل من 0.5 واط / كجم للكتلة ذات الغرام الواحد والتي تكون ضمن المعيار المحدد من قِبل لجنة الاتصالات الفيدرالية (≤1.6 واط / كغ للكتلة ذات الغرام الواحد) للجمهور في ترددات الميكروويف. من أجل المرونة ، تم تقديم أداء ثني الهوائي لأربعة اتجاهات مختلفة. يحتوي النموذج الأولي للهوائي المحسّن على نطاق ترددي يبلغ 5.4 جيجاهرتز (8.6 – 14 جيجاهرتز) بحد أدنى من VSWR يبلغ 1. ونظرًا للمساحة المدمجة 13 × 13 مم 2 ، يبلغ متوسط الكسب 4.4 ديسيبل وكسب الذروة 6.33 ديسيبل ، هوائي ملفق هو مرشح مناسب للتطبيقات الطبية الحيوية في ترددات الفرقة X من خلال استخدام عملية تصنيع منخفضة التكلفة. علاوة على ذلك ، يُظهر النموذج الأولي للهوائي المحسَّن لنظام ERSPMAالمقترح أداءً جيدًا من خلال الاختبار داخل الجسم الحي.

APPROVAL PAGE

I certify that I have supervised and read this study and that in my opinion, it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a thesis for the degree of Master of Science (Communication Engineering).

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DECLARATION

I hereby declare that this thesis is the result of my own investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

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"In the name of Allah, the Entirely Merciful, the Especially Merciful.
[All] praise is [due] to Allah, Lord of the worlds-"

Surah Al-Fatihah, Ayat 1-2.

Firstly, I want to declare all the praise to Allah for everything. "Alhamdulillah for everything I have, Alhamdulillah for everything I had and Alhamdulillah for everything I will have". I convey my prayer to the beloved final Messenger of Allah, Prophet Muhammad (Peace be upon him).

It is my utmost pleasure to dedicate this work to my dear parents and my family. I am always grateful to Allah for blessing me with such a generous and understanding family. Hasina Begum, my mother; Md. Shahjahan Ali; my father; Md. Saiful Islam; my brother; Nahid Naznin Munni, my sister-in-law; Samia and Safia, my two beautiful Nieces… I am overwhelmed by their continuous love and belief in my ability to accomplish this goal: thank you very much for the support and patience. May Allah SWT bless them, guide them with the right path and give them the best reward in this world and in the hereafter.

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LIST OF SYMBOLS

λ_0	Wavelength in free space
t	Trace thickness
h	The dielectric thickness of the substrate
ε_r	Relative Permittivity of the substrate
ε_{eff}	Effective Permittivity
$\tan\delta$	Loss Tangent (Dielectric Loss)
f_r	Resonant Frequency
c	Speed of light
Z_0	Input Impedance
Γ	Reflection Coefficient
V_r	The amplitude of the Reflected wave
V_i	The amplitude of the Incident wave
e_{cd}	Radiation Efficiency
G	Antenna Gain
D	Antenna Directivity
θ	Elevation Angle
φ	Azimuth Angle
E	Electric Field
σ	Conductivity
ρ	Power Loss Density

LIST OF ABBREVIATIONS

BCD	Breast Cancer Detection
BCI	Breast Cancer Imaging
CAD	Computer-Aided Design
CPW	Coplanar Waveguide
CST MWS	Computer Simulation Technology Microwave Studio
EMI	Electromagnetic Imaging
ERS	Elliptical Ring Slot
ERSPMA	Elliptical Ring Slotted Planar Monopole Antenna
FCC	Federal Communication Commission
FDTD	Finite-Different-Time-Domain
FEM	Finite-Element Method
MPA	Microstrip Patch Antenna
MRI	Magnetic Resonance Imaging
MRPA	Microstrip Rectangular Patch Antenna
MWI	Microwave Imaging
PMA	Planar Monopole Antenna
RL	Return Loss
SAR	Specific Absorption Rate
UWB	Ultra-wideband
VNA	Vector Network Analyzer
VSWR	Voltage Standing Wave Ratio

CHAPTER ONE

INTRODUCTION

1.1 RESEARCH BACKGROUND

Breast cancer is the most diagnosed cancer among women all over the world after skin cancer. It impacts on 2.1 million women every year causing the highest cancer-related deaths around the world among women. In fact, only in 2018, around 627,000 women died of breast cancer that is 15% of the total cancer-related deaths (*WHO | Breast cancer*, 2018). Even though men can also be affected by breast cancer, but the probability rate among women is higher. To decrease the death rate, there is no other way but to detect cancer at an early stage. Meanwhile, it is important to know about the stages of breast cancer to determine its stage of detection. To determine, the TNM system is used for the breast cancer staging, where T (Tumor) describes the size of a tumor, N (Node) that describes about cancer spreading to the lymph node and M (Metastasis) that describes about spreading of cancer to the other part of the body (TNM staging for breast cancer | Cancer Research UK, 2018). As the target is to detect cancer at an early stage, the tumor size T plays the vital role that defines three breast cancer stages T1, T2 and T3. Understanding about breast cancer and its stages have been briefly discussed in chapter two with corresponding figure. Advanced early detection technique can only decrease the higher death rate among women for breast cancer which is Breast Cancer Imaging (BCI). In this case, the success rate has been increased in medical therapies due to the improvements in BCI techniques.

X-ray mammography is the most popular and standard medical imaging technique for Breast Cancer Detection (BCD). Unfortunately, it involves with the ionizing exposure and requires an uncomfortable compression. Other two conventional techniques are ultrasound echography and MRI (Magnetic Resonance Imaging), which can be substituted to X-ray mammography. However, these techniques mostly depend on the physician's ability with the requirement of very expensive tools and devices. As an alternative technique, Electromagnetic imaging at microwave frequencies has become popular and widely accepted by scientific researchers. The main advantages of using Microwave Imaging (MWI) is the use of non-ionizing radiation. Besides, the technique is without uncomfortable compression and with the accessibility of transmitters and receivers based on low-cost components (Nikolova, 2011).

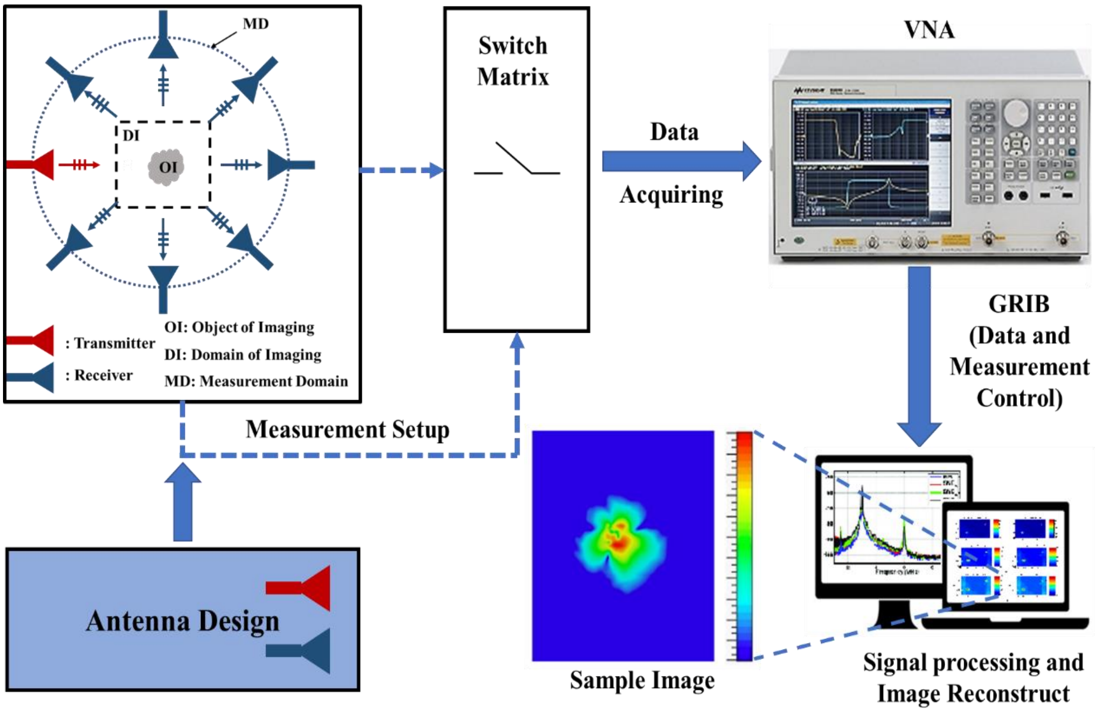

Figure 1. 1 Basic architecture of microwave breast cancer imaging technique

The MWI technique is based on the microwave signal transmission and reception by using antennas. Firstly, an electromagnetic signal has transmitted by an antenna and then the fractional backscattering signal by the discontinuities of biological tissues have been collected by the same antenna (or with other antennas). Therefore, the incident backscattering signal because of the different dielectric properties among malignant and normal tissues are the fundamentals of MWI technique. The backscattering signals have been collected through the Vector Network Analyzer (VNA) that is connected to the transmitting and receiving antennas. Furthermore, the acquired data (backscattering signal) are stored in a computer for further image processing. Therefore, by using an appropriate algorithm, the image of the desired object has been created from the collected backscattering signals. The basic architecture of radar-based MWI technique has been presented in Figure 1.1.

Antenna plays an important role in the MWI technique as it acts as an antenna sensor. The antenna sends the microwave signal to the desired domain and at the same time, it acquires the backscattering signal also. The proper design of antennas for MWI is a great challenge. Especially, when it comes near to the human body. Because the human body acts as a dielectric lossy material and antenna loses its performances. Also, because of the discontinuity of different dielectric properties of the human body, the antenna radiated power can be degraded or absorbed. While designing antennas that are working near to the human body for different applications, especially for MWI, these drawbacks have to be considered. To increase the antenna performances near to the human body, different initiatives have been utilized in (Das & Mitra, 2018; Magill et al., 2017; Shah & Yoo, 2018) with different design techniques. Therefore, most of the authors have also used flexible substrates to design antennas. The reason behind the use of a flexible substrate is to ensure the antenna flexibility and ease of using with the human body. As the human body structure is not flat or straight, the antenna designed on the flexible material substrate can only ensure the flexibility of antenna placement on the body surface.

Several numbers of research works related to MWI for BCD have been presented in recent years (Bahramiabarghouei et al., 2015; Mahmud et al., 2018; Porter et al., 2016; Rahman et al., 2016). However, the proposed MWI techniques are often with a low spatial resolution which prevents the detection of small lesions and eventually causes destructive references with required data for the physicians. As a result, this prevents the main focus of the early detection of breast cancer. Most of these proposed techniques work at lower range frequencies, within 2 - 10 GHz spectrum with a central frequency of few gigahertz. However, it is possible to increase image resolution by electromagnetic imaging at higher frequency ranges and with wide operating bandwidth. Therefore, some researchers have suggested breast cancer imaging at different frequencies, up to the THz and infrared spectrum (Erickson-Bhatt et al., 2015; Moscato et al., 2013).

Recently, a breast cancer imaging technique has been proposed at millimeter-wave (mm-wave) frequencies from 26.5 GHz to 40 GHz (Meo et al., 2017). In the work, authors have presented the feasibility of mm-wave imagine for BCD. Although, the mm-wave imaging can provide very good resolution, but with a cost of lower penetration depth. With a lower penetration depth, it can be less suitable for BCD because of the high density of breast tissue. Hence mm-wave imaging is suitable for other applications like skin cancer detection, cancer margins detection while surgical removal, corneal hydration sensing, dental diagnosis and treatment. However, with the lack of available facilities to perform the practical measurements of the system at mm-wave frequencies can be a challenging task also. Therefore, a little shift from the lower range frequencies towards the higher range frequencies like X-band (8-12 GHz) or Ku-band (12-18 GHz) spectrum can be a good substitute for the MWI technique for breast cancer. The main basic challenges to designing antennas that used near to the human body for MWI are good antenna efficiency, sufficient radiation power with minimum reflection coefficient, able to receive and transmit reference data and able to work at bending conditions to ensure its flexibility. Therefore, another challenging task is to design an antenna for MWI is to have wide operating bandwidth and ensure stable performances for the entire wide bandwidth.

1.2 PROBLEM STATEMENT

In MWI technique for BCD, antenna plays a very important role. The image resolution mostly depends on how preciously the transmitting microwave signal can be sent through the tissue and the backscattering signal can be received. And both the procedures performed by the antenna. Meanwhile, the antenna with better performances can ensure better image quality for the MWI technique.

The authors in (Bahramiabarghouei et al., 2015), have presented flexible16 antenna array (4×4 conformal array of four 1×4 linear arrays) for early BCD at microwave frequencies (2 – 4 GHz). In the paper, the authors have proposed two different Coplanar Waveguide (CPW)-fed antennas (spiral and monopole) designed and realized on a flexible Kapton polyimide substrate to ensure the flexibility of the antennas. The dimension of the single element antenna is 18×18 mm^2 for both the monopole and spiral antenna. By considering the same monopole antenna from the previous work, in (Porter et al., 2016), authors have proposed a prototype (medical wearable bra) of 16 antenna arrays (4×4 conformal array arranged with 1×3 linear arrays and 4 differently placed antennas) for BCD. In both cases, the electromagnetic performances of the antenna (S-parameter, gain, efficiency, radiation pattern) have not been reported.

In (Rahman et al., 2016), authors have stated both the previously mentioned works and have tried to overcome the limitations. They have proposed a flexible monopole antenna for BCD at a few higher range frequencies (4 to 6 GHz). The antenna has been designed on a new proposed flexible substrate for future implementation into a medical bra. Although, the antenna has achieved a good omnidirectional radiation pattern with good radiation efficiency while the average gain of the antenna for the entire bandwidth is only 1 dBi. For BCD with MWI, a new CPW-fed antenna has been proposed in (M. Z. Mahmud et al., 2018) with metamaterial 5×5 artificial magnetic conductor (AMC) array as a reflector. The proposed antenna has achieved a bandwidth of 2.9 GHz that works for 3.6 to 6.5 GHz. The antenna dimension is 76×44 mm^2 and has designed on hard 1.6 mm thick FR4 substrate. The antenna has achieved a good average gain of 5 dBi for the entire band with a minimum loss of around -20 dB. Therefore, the antenna is with lack of flexibility and larger in size.

Three are a few drawbacks, which are important for early BCD by using the MWI technique. The current works are depending on the particular frequency ranges and no one has tried to go a few ahead. Therefore, the antenna operating bandwidth is also a few gigahertz. To increase the operating bandwidth of the antenna for BCD, different antennas have been proposed in (Islam et al., 2017; Mahmud et al., 2016). In (M. Z. Mahmud et al., 2016), authors have proposed a Vivaldi antenna that designed on a 45×37 mm^2 Rogers substrate. The antenna has achieved an average gain of 4.8 dBi with wide 10 dB bandwidth of around 5 GHz. Therefore, good average radiation efficiency of 88% has been achieved. A side slotted Vivaldi antenna has been proposed in (M. T. Islam et al., 2017). The proposed antenna's 10 dB bandwidth is around 5.5

GHz with an average gain of 8.5 dBi. Although, the antenna has achieved wide bandwidth with good average gain and efficiency, therefore, it has been designed on 88×75 mm^2 Rogers substrate. It is noticed that to increased antenna bandwidth, gain and efficiency, most of the authors have proposed Vivaldi antenna. Even though this type of antennas gives good performance for ultra-wideband (UWB) and for MWI applications, however, the design procedure is complex and with larger dimensions.

Therefore, the currents works are lack of spatial resolution while reconstructing images. By proposing the MWI technique at higher range frequencies with wide operating bandwidth, the image resolution can be increased. Although the success rate of MWI for BCD has achieved significant improvements by enhancing the performances of antennas, but still have some limitations that lead the necessity of designing antennas with certain improvements that will help to increase image resolution for early BCD.

1.3 RESEARCH OBJECTIVES

The objective of this research is to develop an antenna designed on a flexible substrate for the application of early breast cancer imaging. The main goal of the research is to propose a flexible antenna with enhanced performances, which is suitable for BCD at a little higher microwave frequency range. To achieve the goal, the following adjectives have been considered:

1- To design a low-profile antenna on a flexible substrate for X-band frequency.

2- To validate the proposed design through performance analysis and measurement.

3- To validate the performance of the antenna with other research works.

1.4 RESEARCH METHODOLOGY

In EM technology while designing any of the components, it is necessary to tune or optimize the design several times to get desired performances. Therefore, at the beginning of the research, a simple microstrip patch antenna has been designed and furthermore, it has been optimized by using an existing method to achieve certain performances that are suitable for microwave BCD. At the early stage of the study, a literature review on the keywords of the topic has been done to understand the application and the design methodology. However, the main object of the research is to design and develop a flexible antenna with wide operating bandwidth and high efficiency for breast cancer imaging at X-band frequency. To achieve the specified objectives following steps have been taken:

1. Theoretical and mathematical approximation of designing microstrip patch antennas for X-band frequency.
2. Design and simulation of the antenna on Polyimide substrate (Kapton film) in Computer Simulation Technology Microwave Studio (CST MWS 2017).
3. Improvement of the antenna performances by utilizing new techniques.
4. Optimization of the simulated results to enhance the required performances.
5. Evaluation of the proposed design through performance analysis.
6. Validation of the design through measurement and benchmarking.

1.5 RESEARCH SCOPE

To propose an antenna for microwave BCI, the antenna must ensure a good electromagnetic performance for the application. Therefore, the emphasis has been given to design antenna in terms of efficiency, radiation pattern, reflection coefficient, bandwidth and gain. To ensure the using flexibility, the antenna has been designed and realized on flexible Kapton polyimide film substrate with compact size. Bidirectional