BASIC EVALUATION OF ANTENNAS USED IN MICROWAVE IMAGING FOR BREAST CANCER DETECTION

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ABSTRACT

Microwave imaging is one of the most promising techniques in diagnosis and screening of breast cancer and in the medical field that currently under development. It is nonionizing, noninvasive, sensitive to tumors, specific to cancers, and low-cost. Microwave measurements can be carried out either in frequency domain or in time domain. In order to develop a clinically viable medical imaging system, it is important to understand the characteristics of the microwave antenna. In this paper we investigate some antenna characteristics and discuss limitations of existing and proposed systems.

KEYWORDS

Microwave imaging, breast cancer, UWB antenna

1. INTRODUCTION

Breast cancer is being one of the most frequent form of cancer that leading cause of cancer deaths in women worldwide. Around 50% of breast cancer cases death because the detection of the cancer is typically late. The early detection of tumor could save a lot of lives. Around 7% of women with breast cancer are diagnosed before the age of 40 years. Survival rates are worse when compared to those in older women [1,2].

Thus the role of cancer screening has become increasingly important leading to a demand in effective diagnostic measures; in particular non-invasive cancer diagnoses.
X-ray mammography is the most frequently used tool for breast cancer requires medical expertise to accurately diagnose the presence of tumor. The number of cancers found with mammography alone is very much less than that found with both mammography and physical examination. Other limitations include having high false negative and false positive rates [3].

Such large false negative which can be as large as 30% and false positive: on average, 75% of breast biopsies prompted by a "suspicious" mammographic abnormality prove benign which lead

David C. Wyld et al. (Eds) : CSEN, SIPR, NCWC - 2016
pp. 55–63, 2016. © CS & IT-CSCP 2016 DOI : 10.5121/csit.2016.61005

to increased healthcare cost, unnecessary medical procedures and the distress and anxiety on the part of the patient [4]. Other important concerns ,is that screening mammography is less sensitive in women with radio-graphically dense breast tissue prevalent in younger women, where it has been shown that X-ray mammography has failed to detect up to 30% of cancers greater than 5 mm in diameter [5], due to its relatively poor soft-tissue contrast.

The other drawbacks include variability in radiological interpretation, and a slight risk of inducing cancer due to the ionizing radiation exposure. Frequent monitoring is difficult because of health concerns related to exposure to ionizing radiation.

2. ELECTRICAL PROPERTIES OF THE TISSUES

A large scale studies determine the dielectric properties of a variety of normal, malignant and benign breast tissues, measured at the microwave range has been conducted in the USA [6]. The potential for using microwaves for detecting breast tumors is based on the concept of tissue-dependent microwave scattering and absorption in the breast to exploit the contrast in the dielectric properties of malignant and normal breast tissues.

It has been widely assumed that normal breast tissue is largely transparent to microwaves because they are featured with a low relative permittivity and conductivity at the microwave frequency bands, whereas lesions, which contain more water and blood are characterized by a high relative permittivity and conductivity at the microwave frequencies and hence they cause a significant backscatter [7]. Microwave breast cancer detection is based on the difference in the dielectric properties between healthy (ϵr=9 and σ=0.4 S/M) and malignant (ϵr=50 and σ=7 S/M) for example [8].

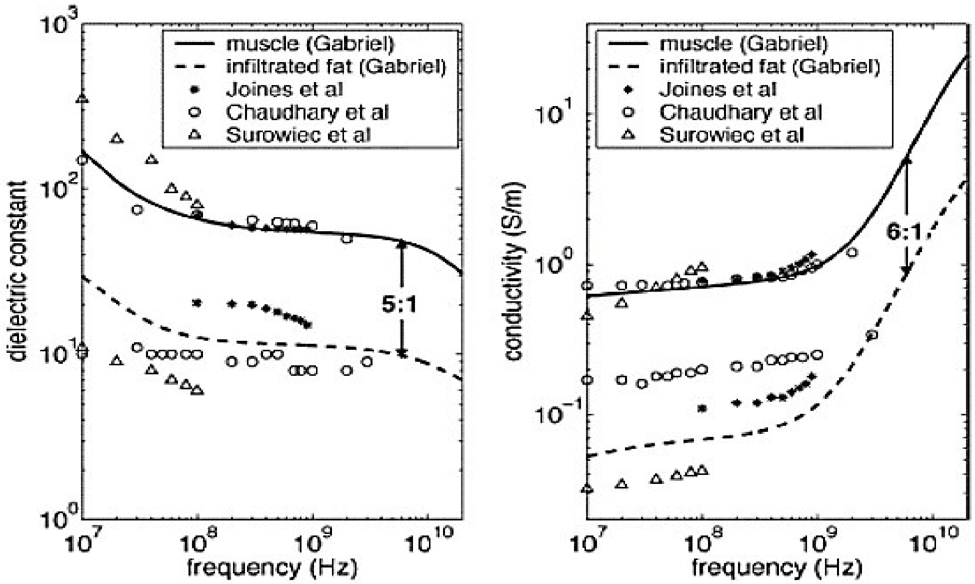

Figure 1: Electrical behavior of normal and malignant tissues at different microwave frequencies acquired by applying four-term Cole-Cole parametric dispersions models [9].

3. MICROWAVE IMAGING TECHNIQUES

There are three different methods in microwave imaging for breast cancer detection, passive, hybrid, and active.

3.1 Passive Microwave Imaging

In passive microwave imaging based on the fact that microwave pulses causes the cells temperature inside the breast increases, and due to different characteristics different tissues have different temperature. The produced image in this method shows measured temperature. In this method, the tumor is detected as points with higher temperature due to its characteristics [10–11].

3.2 Hybrid Method Microwave

In hybrid method, microwave and acoustic are combined together. Because tumors absorb higher energy compare with normal tissue they expand more. This expansion causes pressure waves. Using a focused ultrasound transducer these waves can be detected [12].

3.3 Active Microwave Imaging

In active microwave imaging, breast is illuminated by a microwave transmitter and the scattered waves are received. There are two approaches for image making, tomography and radar-based microwave imaging. In tomography, by analyzing the received scattered waves, we try to reconstruct the permittivity distribution of the breast tissues.

The higher permittivity shows tumor compare with low permittivity as normal tissue. In radar-based microwave imaging based on the strong scattered waves, tumor is detected. There are several researches using this method for breast cancer detection [13–15]. Based on the design, patient lies on supine or prone position and an antenna array locates on the breast. An UWB pulse is transmitted sequentially from each antenna. The scattered signal received and analyzed, and using these signals and space time beam forming method an image is created. Because tumors have a stronger backscattering compare with normal breast tissues, locations related to malignant tumors have higher energy level in the image.

4. MICROWAVE ANTENNAS EMPLOYED IN IMAGING

Antenna is the key element of the microwave imaging system that radiates and receives signals to or from nearby scattered objects. Many medical antennas have been designed and realized over the years. Some are patented, some are successful while others have never had the spread that was intended. Antenna technology for medical applications is a major research field.

The primary requirement for the UWB imaging antennas to be used in the 3D time domain non-linear super resolution inverse scattering microwave imaging techniques is low dispersive behavior (linear phase) over the operating bandwidth of 1-4 GHz.

There are many challenges for designing UWB antenna includes the ultra-wideband performance of the impedance matching, (i.e. good impedance matching “S11< -10 dB” in the band of 3.1 to 10.6 GHz), small size, minimum distortion, stable radiation pattern, and stable gain. Currently, there are many antenna designs that can achieve broad bandwidth to be used in UWB systems.

Various microwave antennas are used across the world by different microwave medical Imaging groups. This section details four such antennas which are either used in medical imaging applications or are identified as potential solutions to be used. In what follows, a discussion on each of these antennas will be made.

4.1 Dipole and Monopole Antenna

The dipole antenna is reasonably compact and lightweight, however, its bandwidth is not very large and, when excited by an impulse, the reflections of the impulse from the ends of the dipole are evident as a long, ringing, impulse response which, as discussed above, is undesirable.

The end-reflection problem can be eased by placing lossy material at the dipole ends in order to reduce the reflected wave (and hence the Q of the antenna), or by placing resistors at a quarter-wavelength distance from the ends of the antenna. The latter technique was used as far back as the early 1960s to create a travelling-wave antenna, although the varying electrical distance from the resistors to the ends of the dipole arms makes this a rather bandwidth-limited approach and it also requires the length of the dipole to be greater than a half-wavelength [16].

A resistively loaded monopole constructed by soldering together chains of 32 resistors has also been presented, with a quoted efficiency of 25% and very good impulse-radiation characteristics. In general, as the electrical size of the antenna reduces, the amount of resistive loading must be increased to maintain bandwidth, and efficiency reduces.

By using monopole antennas the entire imaging region can be illuminated by placing them close to the target, whereas in other antennas the distance has to be greater in order to provide sufficient illumination coverage. Space advantage offered by the monopole transmitters can prove to be very useful for systems using multiple transmit/receive channels. In a medium such as air or deionized water this type of antenna is notorious for producing exciting currents [17]. Demonstrate that the isotropic radiation pattern of the monopole does not serve to degrade imaging performance in the near field context, rather it actually increases the image quality obtained.

In order to realize a clinically viable system a fixed array data acquisition design may be desired. Planar monopole antennas are considered as promising candidates for microwave imaging. Many modern designs try to add more enhancements in terms of side lobe level (SLL) and the size.

4.2 Bow-Tie Antenna

The design of an efficient wideband coplanar strip line fed bow-tie antenna with improved bandwidth, low cross polarization and reduced back radiation [18]. The new antenna is constructed by structurally modifying the conventional micro strip bowtie antenna design; this is achieved by attaching an image plane. The antenna is designed as a patch on a single layered substrate with $\varepsilon r = 4.28$ and thickness of 1.6mm.

The coplanar strip line is designed to have an input impedance of 50Ω in order to couple the antenna effectively with the measurement system. The parameters, such as the distance to the image plane, flare angle of the bow, and dimensions of the antenna, are found to affect the bandwidth. These parameters are optimized to enhance the performance. The antenna exhibits unidirectional radiation pattern with enhanced bandwidth reduced back radiation and low cross polarization in the operational band and thus making it suitable for Confocal Microwave Imaging (CMI). A typical wideband bow-tie antenna with coplanar strip line feed for CMI is shown in Figure 2. CMI employs back scattering to locate breast cancer tumors, so the antenna employed is required to focus the microwave signal towards the target and collect the back scattered energy . A 2:1 Standing Wave Ratio (SWR) bandwidth of 45.9% is obtained for the designed 4x4cm bow-tie antenna in air, which has a flare angle of 90°. The antenna operates in the band of 1850MHz - 3425 MHz with a return loss of -53dB. It is reported that in corn syrup the bandwidth is enhanced to 91% in the range of 1215 MHz – 3810 MHz with resonant frequency of 2855MHz and return loss of -41dB[19].

4.3 Vivaldi Antenna

The Vivaldi antenna that satisfies the requirements for imaging systems in terms of bandwidth, gain and impulse response, albeit at the expense of significant volumetric size. In addition to the bandwidth requirement, the antenna supports the sub nanosecond pulse transmission with negligible distortion to achieve precision imaging without ghost targets. Later in 2006 designed a Vivaldi antenna that reduced its physical dimensions such that it can be incorporated in a compact microwave imaging detection system whilst maintaining its ditortionless performance [20]. A typical Ultrawideband Antipodal Vivaldi antenna operates over an Ultrawideband (UWB) from 3.1GHz to 10.6GHz with a peak gain of 10.2dBi at 8GHz. These characteristics show that the Antipodal Vivaldi antenna has the potential to be used in medical imaging applications. The antenna is capable of radiating an impulse with little distortion, and their Superior directionality results in useful gain. This type of antenna is commonly used in commercial systems.

4.4 Pyramidal Horn Antenna

Horn Antennas are capable of radiating an impulse with little distortion, and their directionality results in useful gain. This type of antenna is commonly used in commercial systems, including those produced by Geophysical Survey Systems, The antennas are known for their higher aperture efficiencies but are constrained to certain applications due to their limited bandwidths. However, the bandwidth of the horn antennas can be increased significantly by adding metallic ridges to the waveguide and flared sections. Numerical and experimental investigations of pyramidal horn antennas with double ridges have been reported [21]. A designed a modified version of the ridged horn antenna in which the waveguide section is eliminated and one of the two ridges is replaced by a curve metallic plane terminated by resistors. Later in 2003 Susan C. Hagness and her team presented a complete numerical and experimental study of a specific realization of this design, wherein the antenna is customized to centimeter scale dimensions for operation in the microwave frequency range 1 to 11 GHz [22]. The pyramidal horn is connected to the outer conductor of the coaxial feed and serves as the ground plane, providing a current return path. Because of the coaxial feed, the ground plane configuration eliminated the need for a UWB Balun. The dimensions of the horn antenna are chosen according to the physical size required and operating frequency range.

This antenna yields VSWR of less than 1.5 over the frequency range and fidelity of approximately 0.96 in both the simulation and experiment [22]. The antenna has been tested under low loss immersion medium and achieved similar VSWR and fidelity. Overall it is evident that this type of antenna can be useful for biological sensing and imaging application.

4.5 Stacked-patch Antennas

While stacked-patch antennas are well known to have good operating bandwidths, the bandwidths achieved are usually of the order of 30 % [23]. The stacked patch antenna developed at the University of Bristol was designed from the outset to radiate directly into breast tissues, and furthermore achieves a bandwidth of approximately 77 %. It achieves this without resistive loading, and, in fact, FDTD models demonstrate that even if the losses in the surrounding tissues are removed, the bandwidth is practically unchanged.

4.6 Log periodic and spiral antennas

Although both log periodic and spiral antennas can operate in the UWB frequency band (3.1-10.6 GHz), they are not suitable for imaging applications because they have large physical dimensions as well as their dispersive characteristics and severe ringing effect [23].

5. SELECTED EXPERIMENTAL MICROWAVE IMAGING SYSTEMS

Investigated operational systems with the characteristics are described in Table 1.

Origin	Antenna configuration	Targets
Dartmouth College	2-8 antennas mechanical scanning, laser camera system	500+patients
University of Bristol	60 antennas ceramic fitting cups	95 patients
University of Calgary	1 Antenna mechanical scanning	Pilot clinical experiments 9 patients
McGill University	16 antennas two perpendicular arcs	13 healthy patients
ETRI, Korea	16 antennas Dartmouth inspired	Dogs Suitable for humans
Carolinas Medical	24 antennas 2-D dynamic phenomena	Anesthetised pig
University of Michigan	36 bow ties, 3 circular arrays	Acrylic spheres or hyperthermia
Supélec	2 large horns w. retinas	Tube with water in cylinder w. Triton X-100 mixture
University of Manitoba	1 Vivaldi antenna	Misc. dielectric cylinders

Politecnico	8 monopole antennas	Metal cylinder in glycerin/ water
Technical Univ. of Catalonia	1 fixed, 1 on linear positioner	Misc. rods and cylinders Clay balls in paraffin

6. CONCLUSION

The role of cancer screening and detection has become increasingly important leading to a demand in effective diagnostic measures; in particular non-invasive and non-ionizing cancer diagnostics. Microwaves, along with other methods, are actively pursued as an alternative to existing imaging modalities, which may help reduce the number of false• positive and false-negatives, especially in challenging cases radiographically dense breast tissue.

Microwave imaging is based on the significant dielectric contrast between normal and cancerous breast tissues at microwave frequencies. The technique is considered particularly promising due to the relatively short required penetration depth and the accessibility from different angles. Nevertheless, there are challenges associated with this modality. In terms of experimental implementation, the challenges include the design and fabrication of UWB antenna elements and arrays, the management of the aperture size and scan time, etc. Recent research suggests the use of microwaves for breast tumor detection, in particular the ultra-wideband (UWB) frequency region, offering a promising trade-off between imaging resolution and tissue penetration depth.

ACKNOWLEDGEMENTS

I would like to acknowledge Eng. Maged Eldaheebi for his advice and assistance. Many thanks to all reviewers for their time and effort.

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