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Feasibility of the Detection of Breast Cancer Using Ultra-Wide Band (UWB) Technology in Comparison with Other Screening Techniques

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Additional information is available at the end of the chapter

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Abstract

Breast cancer is considered a leading cause of deaths among women. Researches state that women around the world still face this problem, and because of its unawareness, it is many times left unattended in the budding stages. If correctly screened and detected early, then with proper treatment, this could stop the metastasis and reduce the pains and difficulties of the later stages. Screening methods such as x-ray-based mammography, ultrasound, PET scan, and magnetic resonance imaging (MRI) clinically exist for breast tumor investigation. It is very important that screening procedures should have high specificity and sensitivity for the detection of tumors. Additionally, these methods also have to placate concerns such as ease of the patient during imaging, high-resolution images for added precise elucidation, cost effectiveness, and the capacity to detect the malignant-leading tumors in the early stage. Existing imaging techniques do not meet all of these conditions concurrently. In this scenario, ultra-wide band (UWB) technology has come into play the role of a useful alternative for screening and detection of breast tumors. This chapter discusses firstly probabilistic qualitative metrics which are used in measuring the quality of testing procedures, and then later UWB testing methods are discussed in brief.

Keywords: cancer, breast cancer, x-rays, MRI, ultrasound, UWB, microwave tomography, radars

1. Introduction

Cancer is a syndrome characterized by an uncontrolled anomalous growth of cells, originating anywhere in the human body and spreading to other nearby tissues and organs as a chain

reaction and at an exponentially fast pace. The mass formed by these cells is called tumor. These can be malignant or benign. A malignant tumor can grow uncontrollably to other parts of the body. Comparatively, a benign tumor can grow but does not spread. Cancers that are defined by the existence of tumors are carcinomas and sarcomas. The spreading of cancer cells, which also characterize them as malignant, is called metastasis. New metastatic tumor in some other organ or tissue is of the same type from where it was originated. For example, if breast cancer spreads into the lungs, the cancer cells in the lungs are designated as breast cancer cells. Hence, it is quite apparent that early detection of the presence of cancer cells is a very important stage to cure it. This early detection is called screening. The whole objective of screening is to stop the metastasis stage as early as possible.

Scientists and researchers are always in the continuum to develop the methods which could help in the finding of cancer cells well before the symptoms appear or impact of cancerous cells could be observed/felt with as convenience as possible to the patients. Modeling new cancer screening methods is an area of active research in medicine and biomedical engineering.

Screening methods available or in use at present and clinically accepted include x-ray mammography, ultrasound, and magnetic resonance imaging (MRI) [1–3]. Another screening method which is still under experimental research is ultra-wide band (UWB) technology. In this chapter we shall discuss about the feasibility of UWB technology for early detection of breast cancer.

2. Breast cancer screening techniques

2.1. X-ray mammography

X-rays are electromagnetic waves having wavelengths varying from 0.01 to 10 nanometers, belonging to frequencies in the range 30 petahertz to 30 exahertz (3×10^{16} – 3×10^{19} Hz) and having energies from 100 eV to 100 keV. Their wavelength is shorter than UV rays and longer than gamma rays. X-ray mammography employs controlled dose of these radiations for producing images (radiographs) to early detect breast cancer before the symptoms become visible. X-ray radiography is noninvasive if used controllably, i.e., in small dose. Exhausting a standard measure of radiation dose, millisievert (mSv), the total dose for a screening mammogram with two views of each breast (four images total) is approximately 0.4 mSv [4, 5]. The radiation which a woman receives with a screening mammogram is about equal to the dose received over 7 weeks from natural surroundings or background radiation. The radiation dose from a mammogram is little more than from a chest x-ray. Interestingly, if the radiation dose from x-rays is not controlled, then they themselves can become a high risk of producing breast cancer. This effect is because of the ionizing nature of high-energy x-rays at high frequencies. Hence, using x-rays for mammography requires ensuing precise guidelines and conducting regular equipment inspections to guarantee that the equipment is safe and uses the lowest radiation dose possible for producing high-quality, investigative images. The frequency of x-rays and their energy with duration of emission (dose) set the quality of x-rays which are difficult to trade off for each other.

Penetration of x-rays is directly proportional to the wavelength. So, high-frequency x-rays have low power to penetrate than low-frequency x-rays. In comparison, energy of the transmitting x-rays varies inversely with the wavelength and directly with the frequency of transmission. Thus, high-frequency x-rays lead to high-energy photons and also produce better resolution of the mammogram. But, at the same time, the higher the penetrating power is of the x-rays, the more is their ionizing effect.

So, although x-ray mammography is a conventional method for breast cancer screening, it is not easy to trade off between low-frequency x-rays (for higher penetration), low-energy x-rays for less ionization, and simultaneously high-energy x-rays for better resolution of the mammogram. Also, as reported in [6, 7], the rate of failure in detecting the tumor using x-ray mammography is significantly considerable and therefore cannot be neglected. This includes false-positive and false-negative probabilities.

2.2. Magnetic resonance imaging (MRI)

An alternative to x-ray mammography is magnetic resonance imaging or MRI for detecting breast tumors or other cancer tumors. MRI offers better sensitivity as compared to X-rays, but besides the cost of the examination, the specificity is very little and can lead to erroneous diagnosis [8]. MRI does not involve x-rays and other ionizing radiations. The frequencies used are in 60 MHz range [8]. This is quite low as compared to x-rays. The human body mostly comprises water and chemically water molecules (H_2O) contain hydrogen nuclei (which are protons). They become aligned in a magnetic field. An MRI scanner produces such a strong magnetic field (about 0.2–3 tesla), which aligns the proton “spins.” The scanner also produces a current that creates a varying magnetic field of approximately 60 MHz. The protons absorb the energy from the magnetic field and flip their spins. When the field is removed, the protons gradually return to their normal spin (precession). The return process produces a radio signal that can be measured by the receivers in the scanner and converted into an image. Protons in different body tissues return to their normal spins at diverse rates, so the scanner can differentiate among various types of tissues. The scanner settings can be adjusted to produce contrasts between the body tissues. Surplus magnetic fields are used to produce three-dimensional images that may be viewed from different angles. There are many forms of MRI, but diffusion MRI and functional MRI (fMRI) are two of the most commonly used forms in biomedical imaging. Diffusion MRI measures the way water molecules diffuse through body tissues. Certain disease processes—especially tumor—can hamper this diffusion, thus helping to diagnose them. In addition to structural imaging, functional MRI can also be used to visualize functional activities. Functional MRI, or fMRI, is used to measure changes in blood flow to different parts of the tissues or organ.

2.3. Ultrasound waves

This is another alternative for detecting and screening the presence of tumors and specifically breast tumors. In this testing procedure, high-frequency sound waves are transmitted to the effected tissue, and without involving radiations, the received signals are converted into images. Ultrasound cannot replace the effectiveness of mammogram or MRI. It is only

used to see if the breast lump is filled with cyst or if it is solid. Ultrasound can also be used to characterize the type of tumor. They are considered a good extension of physical palpations which use touching the breasts to detect the presence of any tumors. But they are limited to penetration because of lower frequency as compared to MRI and x-ray mammograms. Ultrasound waves have frequencies above about 20 kHz [9, 10].

3. Quality of diagnostic testing procedure

It should be understood that testing the presence of breast tumor (just like any other tumor) is a random experiment with probabilities associated with the outcomes. Therefore, the quality of diagnostic tests can be measured using the probabilities associated with them. A test can be positive (detect tumor) when the tumor is actually present (true positive), and a test can also be positive (detect tumor) when there is no tumor at all (false positive). Likewise, a test can be negative (does not detect tumor) when the tumor is not present (true negative), and a test can also be negative (does not detect tumor) when the tumor is actually present (false negative). Out of these four different probabilities, the two which are normally used to qualitatively access the diagnostic procedure accuracy are *sensitivity* which is the true-positive rate probability and *specificity* which is the true-negative rate probability. If T^+ indicates the test is positive, T^- indicates the test is negative, C^+ indicates existence of cancer, and C^- indicates the absence of cancer, then the conditional probabilities stated above are shown in **Table 1**.

Sensitivity, specificity, and other probabilities which are used in the test’s qualitative measure can be easily calculated using Bayes’ theorem. If “a,” “c,” “b,” and “d” indicate the test positive and cancer-carrying persons, test positive and cancer-not-carrying persons, test negative and cancer-carrying persons, and test negative and cancer-not-carrying persons, respectively, then using **Table 2**, the probabilities in **Table 1** and other percentages can be calculated in **Table 3** at any confidence interval (CI).

The statistics of the cancer-detecting modalities in **Table 4** suggests that despite their recognized ability to detect tumors they still have their lackings. False-positive rate and false-negative rate are not negligible. False-positive rates lead to a number of needless surplus investigations which could produce ionization. In the context of false-negative rate, if a fraction of the tumors are not detected at an early stage, then this could lead to malignancy and

Probability name	Conditional probability
True positive	$P(T^+/C^+)$
False positive	$P(T^+/C^-)$
False negative	$P(T^-/C^+)$
True negative	$P(T^-/C^-)$

Table 1. Conditional probabilities associated with cancer diagnostic tests.

Test	Cancer tumor		
	Present	Absent	Total
Positive	a	c	a + c
Negative	b	d	b + d
Total	a + b	c + d	a + b + c + d

Table 2. Cross tabulation table of conditional probabilities.

S. no	Test statistics	Computation method	Definition/interpretation
1.	Sensitivity	$a/(a + b)$	It is the true-positive rate. This shows the probability that a test result will be positive when the cancer tumor is present
2.	False-negative rate	$1 - \text{Sensitivity} = b/(a + b)$	This shows the probability of a negative test result given that the cancer tumor is present
3.	Specificity	$d/(c + d)$	It is the true-negative rate. This shows the probability that a test result will be negative when the cancer tumor is absent
4.	False-positive rate	$1 - \text{Specificity} = c/(c + d)$	This shows the probability of a positive test result given that the disease is not present
5.	Positive likelihood ratio	$\text{Sensitivity}/(1 - \text{specificity})$	It is the ratio of the true-positive rate to the false-positive rate.
6.	Negative likelihood ratio	$1 - \text{Sensitivity}/(\text{specificity})$	It is the ratio of the false-negative rate to the true-negative rate
7.	Cancer prevalence	$(a + b)/(a + b + c + d)$	This shows total probability of the presence of cancer tumor
8.	Cancer absence	$(c + d)/(a + b + c + d)$	This shows total probability of the absence of cancer tumor
9.	Positive predictive value	$a/(a + c)$	This shows the probability that the cancer tumor is present given the test is positive
10.	Negative predictive value	$d/(b + d)$	This shows the probability that the cancer tumor is absent given the test is negative
11.	Accuracy	$(a + d)/(a + b + c + d)$	This shows the probability that he patient will be correctly classified

Authors in [11] surveyed these test statistics of different breast cancer screening tests, and their results are tabulated in **Table 4**.

Table 3. Calculation methods of test statistics as quality metrics of diagnostic tests for 95% confidence intervals (CI).

ultimately to metastasis. An important reason for the limitations using the techniques is that the contrast between the tumor and the surrounding tissue sometimes can be as low as a few percent and therefore it adds to the error of diagnostic procedure.

These and other relevant issues motivated the researchers to seek for an alternative technology which could provide better statistics and also not be harmful at the same time. This alternative technology and methodology is the use of ultra-wide band (UWB) emission and imaging system.

Diagnostic procedure	Sensitivity	Specificity	PPV	Accuracy
Mammography	67.8%	75%	85.7%	70.2%
Mammography and clinical examination	77.4%	72%	58.6%	75.6%
Clinical examination	50.3%	92%	94%	63.6%
Ultrasound	83%	34%	73.5%	67.8%
Mammography and ultrasound	91.5%	23%	72.3%	70.2%
Mammography, clinical examination, and ultrasound	93.2%	22%	72.4%	70.9%
MRI	94.4%	26%	73.6%	72.9%
Mammography, clinical examination, and MRI	99.4%	7%	70.1%	70.5%

Table 4. Contrast among different breast cancer detection modalities [11].

4. Positron emission tomography (PET)

PET is an imaging procedure that identifies the presence of cancer by using an injection mixture of radioactive materials with sugar and observes how cells react to it. The cancer cells having the characteristics to grow faster than normal cells consume nutrients. When this happens, positrons are emitted. PET makes an image by detecting these positrons. Unlike X-ray, CT, and MRI, PET can detect cancer in the very early stages. However, it has low resolution. PET scanning is combined with other techniques, e.g., PET and CT scan, for further evaluation. Therefore, PET scans cannot be used to detect small-sized tumors in the breast (in the budding stages). But they can be used for identifying the presence of metastasis, spreading to other body parts or spreading to lymph nodes.

5. Breast cancer screening using ultra-wide band (UWB)

In the last decade, the alternative technology which has been in focus of research is breast cancer detection using ultra-wide band (UWB) electromagnetic radiations, i.e., at microwave range. Microwaves provide higher and stronger contrast between healthy tissue and tumors, which supports in better tumor detection without the hazard of ionization effects. UWB microwave imaging can be done, either using microwave tomography or microwave radar imaging. The latter uses power distribution of scattered waves to distinguish between healthy and tumor-containing tissues.

Ultra-wide band (UWB) radio is no more an emergent technology, but rather the past two decades are full of experimentations with UWB for various research applications in wireless communications, radar, and medical fields.

Before the present millennia, UWB was confined totally in military applications. But, since 2002, Federal Communications Commission (FCC) has increasingly allowed the commercialization of UWB bandwidths. Federal Communications Commission (FCC) has standardized

that the frequency for the UWB technique is from 3.1 to 10.6 GHz in America. However, in Europe, the frequencies include two parts: from 3.4 to 4.8 GHz and from 6 to 8.5 GHz. Applications of UWB radar in health and medicine include human body monitoring, remote sensing, and imaging. Unlike with x-ray imaging, UWB radar uses non-ionizing electromagnetic waves which have been proved to be harmless to the human body. Additionally, the UWB radar has a very low-average power level, power efficiency, and robustness against noise. Thus, UWB is a cost-effective way of real-time human body imaging. Categorically, some other features of UWB are enumerated as follows.

Penetrating through obstacles. UWB uses RF pulses with high gain. Therefore, UWB can penetrate through walls. This makes UWB practicable for wide area presentations where obstacles are sure to be met. This uniqueness of UWB makes it feasible to image organs of the human body.

High precision ranging at the centimeter level. UWB provides an effectively precise ranging to the centimeter level because of highly short-pulse characteristics. The short UWB pulse has a very strong temporal and space-resolving capability, which is appropriate for the localization and detection in the medical diagnostic applications of tumors.

Low electromagnetic radiation. UWB also features low electromagnetic radiation because of low radiation power of the emitted pulse. According to the standards, these are less than -41.3 dBm in indoor communications. Again, the low-powered radiation effects the environment very less, which is ideal in medical diagnostic applications involving human body where organs are very close to each other.

Low processing energy consumed. As UWB utilizes very short-duration pulses, this permits the use of long-life battery-operated devices. These features are quite analogous with the wireless sensor network (WSN) nodes which essentially have to be operable under strict power control and high power efficiency.

UWB encompasses numerous utmost sought practical features for any electrical instrumentation used in medical applications. These features include noninvasiveness, low power, noncontact remote operation, biocompatibility, biological friendliness, environmental friendliness, detection, and localization. But in terms of tissue imaging, their physiological understandability by the users, high sensitivity (true-positive rate), and high specificity (true-negative rate), UWB requires more research. In this respect, the way human tissues behave with UWB waves emitted on them, i.e., their channel impulse response, is a very important aspect in the research of UWB applications in health monitoring and diagnostic systems.

5.1. UWB microwave tomography

The objective of microwave tomography is to use the inverse scattering method in finding the dielectric properties of the tissue under study. This gives a dielectric contrast of it. It produces a chart of permittivity and conductivity through inversion scattering.

In a microwave tomography breast cancer investigation system, the breast is lowered into a cylinder-shaped antenna system which covers the breast completely. Microwave measurements are then made with all possible combination of antennas, acting as both transmitter and receiver, respectively. Since the microwaves are spread, scattered, and reflected when they

penetrate inside the tissue, the wave field becomes very complicated. The large amount of data generated from the extensive wave field is analyzed with a radical image reconstruction algorithm that constructs an image of the internal dielectric properties of the whole body part (tissue under examination). This detection technique depends highly on the dielectric and electromagnetic properties, which are the permittivity, conductivity, and electrical parameters of the cancerous tissue. These properties have been investigated to be much different than those of normal breast tissue [12].

Basically, the system comprises of two things: (1) transmitting and receiving antennas and (2) image reconstruction algorithm. In the measurements each antenna is operated as a transmitter as well as a receiver for every possible combination of antennas. To perform the measurements, a network analyzer with switch multiplexer module can be employed to automatically connect and disconnect transmitting and receiving antennas to the PNA. The low amount of radiated power (typically in milliwatts) is considered harmless for the patient and surrounding environment. In most of the research work, a 2D or two-dimensional image reconstruction algorithm has been used. This is most suitable for imaging 2D objects with dielectric properties that are constant in the z-direction which is taken perpendicular to the antenna plane. However, imaging a three-dimensional or 3D object, the accuracy of a 2D imaging technique is severely bounded. This means that effects would be generating in the z-axis but not being modeled using a 2D image reconstruction algorithm. Therefore, a 3D algorithm is required to accommodate all the effects. In the current systems to develop a clinical prototype, the most suitable designs consist of an antenna array where antennas are placed also outside the plane in a 3D pattern to get z-axis effects. This can be obtained by constructing a cylindrical antenna array. Together with a 3D reconstruction software, the potential for improved accuracy is optimized. However, this has significantly increased computational burden in the reconstruction algorithm.

Although the technique of microwave tomography for detection of cancers has a great potential, but still it is in the experimental stages. The clinical practice of it is still underway and has not been employed as a regular technique like other modalities discussed above. In some clinical studies, the capability to detect breast cancer tumors with microwaves has been shown. However, further clinical studies need to be undertaken in order to get a complete picture of the prospective for microwave imaging in practice. An important aspect related to breast cancer is that depending on the mixture between fatty and glandular tissues in the breast the distinction varies largely between individual patients.

5.2. UWB radar imaging

UWB microwave radar imaging rebuilds the image using the reflected wave from objects. This technique unlike microwave tomography reconstructs the scattering power distribution when microwaves are emitted on the breast and their reflected waves are analyzed. It works very much like a ground-penetrating radar (GPR). The origin dates back in 2001 by Hagness and Xu Li in Wisconsin University, USA [13]. In this context it therefore becomes very important to understand the behavior of human tissues as channel to propagate the UWB-emitted waves.

In this relevance, authors in [14] have developed an analytical body propagation model equation for human breast tissue in terms of scattering parameters toward (S_{11} or reflection

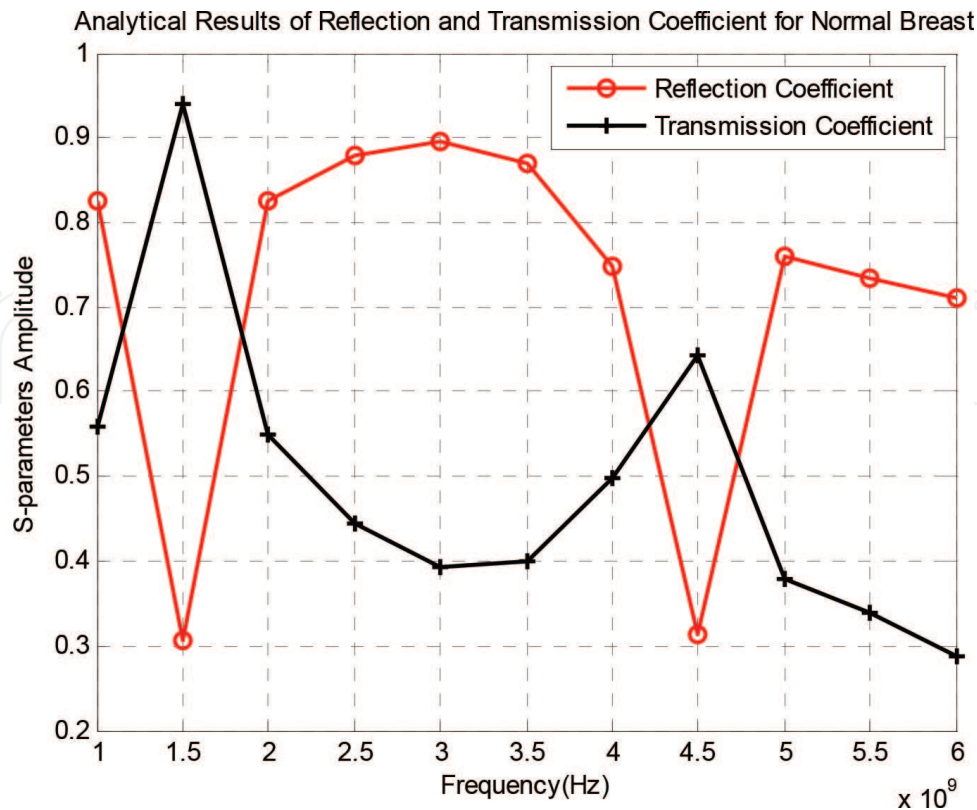


Figure 1. Trends in reflection and transmission coefficients for normal breast [14].

coefficient and S_{12} or transmission coefficient) the design goal of a suitable ultra-wide band (UWB) transceiver for early breast tumor detection. Both of these scattering parameters can be treated as channel impulse response, depending if the communication system is using reflection or transmission of waves at the receiver end. The consideration was a heterogeneous breast model comprising skin, adipose, and glandular tissues as body (breast) channel with one layer of tumor. Due to dispersive nature of heterogeneous breast, S_{11} and S_{12} varied with frequency. Modeling and simulations were performed for a 4.5 GHz center frequency UWB system. The backpropagated (reflected/scattered) signals showed approximately 63.3% higher amplitude than forward propagated signals for the breast channel with tumor. Analytical expressions were derived and formulated for S_{11} and S_{12} scattering parameters and were simulated for UWB frequency band of 1–6 GHz as shown in **Figures 1** and **2**.

In these simulations, the following interpretations can be made readily:

1. The simulations were carried out from 1 to 6 GHz.
2. Reflection and transmission coefficients show 180° out of phase at any frequency.
3. The dispersions are present in reflection and transmission coefficients. The scattering parameters are not constants but vary randomly as the frequency changes.
4. The trends are highly nonlinear. This is because the breast tissue is a nonlinear channel.
5. The concern of center frequency is very important.

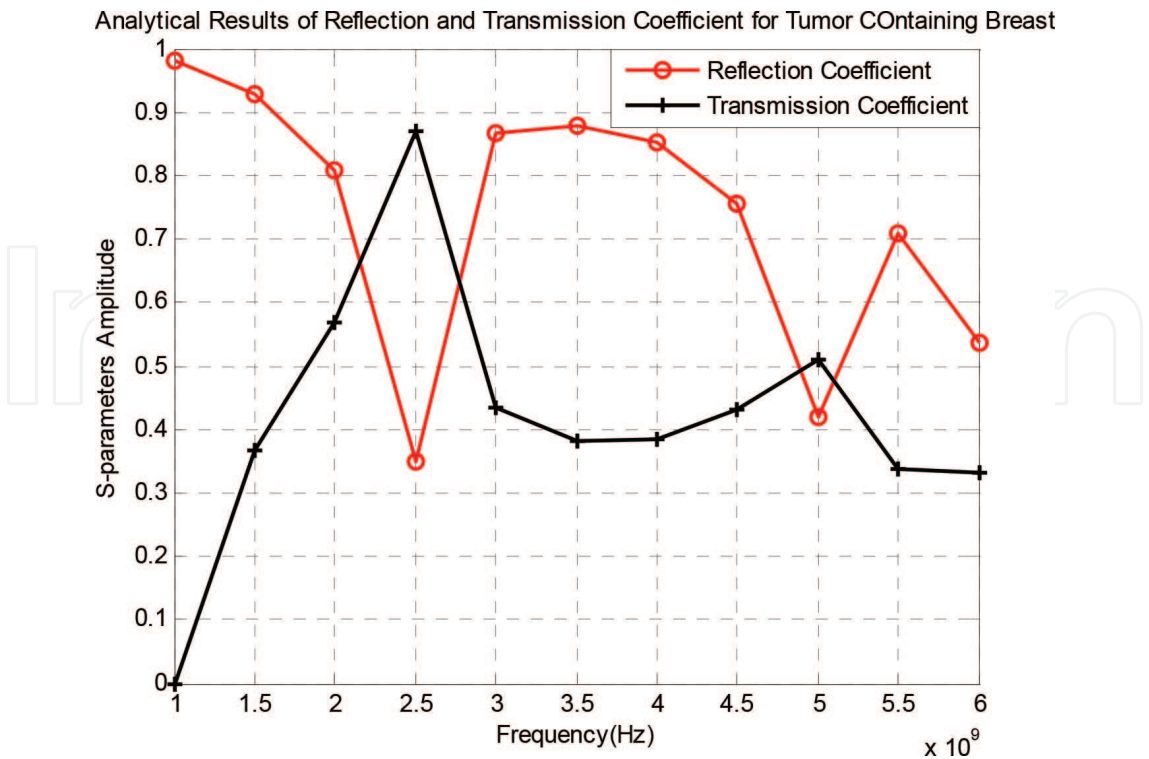


Figure 2. Trends in reflection and transmission coefficients for tumor-containing breast [14].

The simulation in **Figures 1** and **2** suggests that investigations along with the body propagation model can lead to more affirmative results to determine and predict the cancerous abnormalities in the breast. For example, at 4 GHz, the reflection coefficient of a normal breast tissue is reaching to 75%, but at the same, the frequency for a tumor-containing breast is reaching to 90%.

6. Research areas in UWB breast cancer detection

6.1. Receiver design

As discussed, screening and diagnostic testing for the presence of cancer is a probabilistic process; therefore, UWB should also have a percentage of accuracy, efficiency, and other associated probabilities. However, UWB for breast cancer detection is still not completely used for clinical testing. So, these probabilities haven't been determined yet. But it must be well understood that increasing the true-positive rate and true-negative rate is very much dependent on the accuracy of the received signal. This puts a good responsibility on the receiver to detect the signals correctly. Hence, receiver design is very important. In this regard, two things could be catered: (1) antenna engineering and (2) inducing intelligence in the receiver to separate and classify the signals coming from normal and cancerous breast.

6.1.1. Antenna engineering and receiver intelligence

In the antenna engineering part of the UWB research, researchers have mostly employed patch antenna with their many variants and arrays of them [15–18]. Researchers have also explored many beam-forming techniques to associate them with the antenna structures (adaptive antennas) so that information could be extracted from the received signal. Researchers have used different artificial intelligence tools like neural networks and support vector machines to classify the signals coming from cancer cells and normal cells, which have proved to be very effective in the laboratory [19, 20].

6.2. Breast phantoms

When coming to experimental investigation of UWB for breast cancer detection, another important aspect is the design and development of tissue/organ phantom under investigation. The results obtained on phantoms are expected to be obtained on real tissues. Therefore, phantom making is a research-oriented subject. UWB systems need realistic phantom model tailored to the biochemical as well as morphological features of the breast tissue. Existing breast phantoms are available both in solid and liquid structures [21]. Solid phantoms as compared to liquid phantoms have the ability to hold the desired geometrical shape, thickness, and inhomogeneity as that of multilayered tissues and can be fabricated with controlled electrical properties. The concept of a thin, solid tissue phantom along with its analytical model is a challenging task and has gained attention only in the recent past. After fabrication, extraction of information from such solid phantoms requires precise characterization with respect to changes in composition for different breast density characteristics. This could be done with proper analytical model or channel impulse response of the tissue phantoms. In [22] authors have contributed toward developing a numerical model for both normal and cancerous breast tissues using finite-difference frequency techniques.

7. Conclusion

This chapter has briefly discussed about the procedures of different breast cancer screening and detection including x-ray mammography, MRI, PET, and ultrasound. These are the techniques which are clinically being used commonly around the world. However, survey showed that these testing methods do not give a very good quality measures. In this regard UWB technology for early detection of breast cancers is discussed with their two important methodologies, namely microwave tomography and UWB radars.

Although many experimental researches have been conducted, but still the clinical translation of this research is not deployed. The clinical practice of UWB will definitely produce new problems which would rectify and improve the UWB technology for screening and detection of breast tumors. But still because of the advantages that UWB has promised to provide are surly to take it a long way and unbeatable competitor against x-ray mammography, MRI,

PET, and ultrasound. However, it can be seen that UWB in combination with other screening methods can prove useful in early detection of breast cancers. UWB has an advantage of being low cost, non-ionizing, and noninvasive. This makes it a human health-friendly technology.

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