Tomography is defined as a diagnostic technique in which the shadows of structures before and behind the section under scrutiny do not overlap. In diagnostic medicine, a tomogram displays a cross-section of a body at a desired location and at a particular orientation. In most cases, the object is illuminated from many different directions either sequentially or simultaneously and the image is reconstructed either from reflected or transmitted data.

The most spectacular success of tomography in the field of radiology using non-diffracting sources is X-rays. X-ray computed tomography derives its clinical significance from the fact that it shows the anatomical morphology of any desired cross-section of the human body with great sensitivity and good resolution with no superposition. Other modes of medical imaging are Ultrasound Computed Tomography and Nuclear Magnetic Resonance Tomography. However in the recent decades, there has been an increasing interest in extending the image reconstruction technique using microwaves also. This interest has been spurred particularly by the radiation hazards of X-rays which make them unsuitable for detection of cancerous tumors, the limitations of ultrasound for imaging of soft tissues only, and a possibility of hazard in case of NMR imaging, by the induced currents that could cause ventricular fibrillation, cardiac arrest, inhibition of respiration etc.

The practice of employing radiation in the microwave range (e.g. 1 GHz to 10 GHz) for imaging of biological bodies is a new field of exploration. Research in this subject progressed very slowly because of the belief that decimetric wavelengths are too long to allow usual spatial resolution or that when the wavelength is sufficiently short, attenuation through the bodies of interest would be prohibitively high. The analysis overlooked the fact that the wavelength at a frequency can be shortened significantly by propagating in a medium of high relative permittivity such as water. Again the resolution of the imaging system that operates in the near field of an antenna improves as aperture size is reduced. Thus by filling an antenna with a higher permittivity material the aperture size is reduced, its radiating properties are maintained and spatial resolution is improved.
Microwave energy interacts with bio-systems on the basis of complex permittivity and the frequency of the interrogating radiation. Complex permittivity is defined as $\varepsilon = \varepsilon' - j\varepsilon''$ where $j = \sqrt{-1}$. It consists of a real part $\varepsilon'$ and imaginary $\varepsilon''$ part, identified as the dielectric constant and loss factor respectively. The later is often, described by the dielectric conductivity, which includes ohmic losses due to oscillations of dipole molecules in the rapidly alternating included fields where no direct conductivity may exist.

Furthermore, these parameters show dispersion which may be used to characterize many features of biological bodies. The very high dielectric constant of water allows a measure of the tissue discrimination on the basis of water content. When energy in the microwave region propagates through a biological body, its phase velocity and absorption depends on the type and the functional state of the tissue. It follows that the total time delay and the attenuation through an object is a function of tissue type, functional state of the tissue and the thickness of the tissue through which the wave travels. Therefore measurement of the total time delay and attenuation through an object can be used to characterize certain properties of the tissues at microwave frequencies which are not fully addressed by the forms of radiation such as X-rays or Ultrasound.

1.1. REVIEW OF TOMOGRAPHIC MEDICAL IMAGING

1.1.1 Introduction

The imaging technique of Computed Tomography (CT) using X-Ray has caused a revolution in the field of medical radiology. The conventional radiographic imaging suffers from the fact that the image is two dimensional projection from a three dimensional object. In computed tomography, conventional X-Ray technique combines with the sophisticated computer signal processing to obtain the image of any cross section of a biological target. Interference shadows from the structures outside the cross-section no longer arises. Computed tomography, now a days has become a popular tool in the field of medical diagnostics.
1.1.2 Historical development

The analytical foundation for the reconstructive tomography was established in 1917 by J. Radon [1], an Austrian Mathematician concerned with gravitational theory. He proved that any two-dimensional cross-section can be reconstructed uniquely from an infinite set of projections. The first practical reconstructions of objects were accomplished by the Radio Astronomer R. Bracewell [2]. He was able to determine the regions of the sun which emit microwave radiation.

The same mathematical problem subsequently arose in electron microscopy in the study of complex bio-molecules. In this case, it was desired to reconstruct molecular structures from a series of micrograms taken at various angles. Methods of reconstruction were developed independently of the earlier radio-astronomy work [3]-[4]. Techniques of image reconstruction were also developed for optical applications [5]-[6].

The invention of CT scanner in 1972 was a major breakthrough in medical imaging. The first generation tomographic machines were the head scanner with the typical scan speed of two minutes. The second generation of the tomographic machines came up with higher scanning processing speed along with the usage of multiple detectors for simultaneous multiple views for the full body scan. The third generation machines use the fan beam geometry, taking many detector measurements simultaneously and typically do a scan in 5 sec.

Although the results have been particularly spectacular with the X-ray transmission, the technique of computed tomography has been successfully applied in nuclear medicine imaging. The aim of the emission CT scan is to make cross sectional images of radioactive isotope distribution within the human body which is administered to the patient either by inhalation or injection. Several researchers and scientists had their significant contributions in this field [7]-[9].

Ultrasound tomography is another clinically well-established tomographic imaging mode. With ultrasound CT, the aim is to make cross-sectional image on the basis of acoustic parameters of the tissues. The two parameters that have received the greatest attention are the attenuation coefficient and the refractive index. The first such tomograms were obtained by Greenleaf et al. [10]-[11].
Imaging techniques has also been explored using electromagnetic interrogating waves at different frequencies. Some measurements have also been made in the radio frequency spectrum. Higher frequency microwave systems have been explored using both the reflected wave and the transmitted wave.

Previous attempts of the use of microwaves for the reconstruction have been made in Geology and Medicine. Lytle et al [12] attempt to locate tunnels in the ground using cross-borehole data. Larsen and Jacobi [13] made a map of transmission coefficient through a canine kidney, along with the large effects of diffraction.

Spectral Methods [14]-[18] used for diffraction tomography have been investigated with application to microwave. The advantage of such methods results from the existing fast numerical algorithm. However, the diffraction tomography suffers from the fact that it is marred in strongly inhomogeneous media where Born and Rytov approximations are not valid [19]. The other methods based on moment method solutions [20]-[21], are being explored rigorously, but the stability depends on the measurement accuracy due to ill-conditioning of the matrix.

1.1.3 Reconstruction Algorithms

Microwave imaging, as in X-ray tomography, obtaining images of a biological object’s material properties by measuring the object’s influence on an applied wave, depicted in Figure 1.1. In case of X-rays, the biological tissue density is imaged.

![Figure 1.1: The Field Scattering Effect during microwave imaging.](image_url)
The algorithms used in X-ray tomography is based on straight path approximation according to which it is assumed that the ray travels in a straight path to the receiver. Thus the ray coming at each point on the observation plane can be related to some characteristics of the medium only along the straight line connecting the transmitter and the observation point.

Different mathematical approaches have been used for the image reconstruction. The methods which have played an important role in medical imaging are broadly classified as analytic reconstruction and the iterative reconstruction. Analytic reconstruction is based on exact mathematical solutions to the image equations. Filtered back projection is the simplest algorithm for reconstruction to estimate the density at a point by adding all the ray sums through that point. This method is now used in almost all X-ray scanners. But this analytic reconstruction limits the spatial resolution of the image. This is done by band-limiting i.e. the image will contain no spatial frequencies greater than a maximum frequency.

Iterative methods may be thought as a ‘Brute - force’ way of solving the image equations. They are employed by Hounsfield in the original EMI scanner, and are still used in radioisotope imaging. Another alternate reconstruction method proposed by Gardon [22] is the Algebraic Reconstruction Technique (ART). Basically this approach and its modified version, Simultaneous Iterative Reconstruction Technique (SIRT) assumed a model that partitions the object into pixels whose values is to be determined.

The iterative method seems to offer advantages over the analytic methods when (a) fewer projections than required are available, (b) the samples within the projections are noisy and (c) when the projections are taken over a limited range of angles. However, most modern scanners, which obtain data at regularly spaced intervals, employ reconstruction algorithms based on analytic method as because it is inherently faster than iterative methods and performs well when adequately sampled.

The two major approaches of microwave imaging today are tomographic methods where cross-sectional slices of the dielectric properties are generated and radar approaches where strong scatterers
are found inside an object using radar techniques. A review of the radar approach techniques has been published in [23].

The tomographic methods are based on the inverse scattering problem and divided into two different groups namely a) Diffraction Tomography and (b) Nonlinear deterministic approach.

The imaging scheme of computed tomography using X-ray has revolutionized biomedical imaging. With the increased interest has also come the awareness of the dangers of using ionizing radiation. Due to which, for example, X-ray CT becomes unsuitable for mass screening in female breasts. As a result, much interest has been given to imaging with alternative forms of energy like ultrasound and low level microwaves. Unfortunately, the quality of tomographic reconstructions obtained with sound or electromagnetic radiation are inferior to those obtained with X-rays. This is due to the fact that X-rays being non-diffracting travel in straight lines and therefore the transmission data measures the line integral of some object parameter along straight lines. This makes it possible to apply Fourier Slice Theorem. But when the tomographic imaging is done either by sound or microwaves, the energy often does not travel in straight path. When the object inhomoginities are large compared to wavelength, energy propagation is characterized by refraction and multiple paths. To some extent, bending induced by the refraction can be taken into account by algebraic reconstruction algorithm with digital ray tracing and ray linking algorithm. When the object inhomoginities become comparable to the wavelength, the energy transmission must be discussed in terms of wavefronts and fields scattered by the inhomoginities. Consequently, the reconstruction of the constitutive parameter distributions of an object using electromagnetic wave should rather be considered as an inverse scattering problem. The conventional CT algorithms like ART do not account for these effects and hence are not suited for the use with such wavefields.

In spite of the difficulties mentioned above, it has been shown [24]-[26] that under certain approximations, a Fourier Slice like theorem called Fourier Diffraction Projection Theorem can be formulated. Whenever an acoustic or electromagnetic wave is considered to be the source signal, obviously as we know, it doesn't travel along straight rays and the projections aren't line integrals. So we have to describe the flow
of energy with a wave equation. The propagation of waves in a homogeneous object is described by a wave equation, which is a second-order linear differential equation. Now there are no direct methods for solving the problem of wave propagation in an inhomogeneous medium. In practice, approximate formalisms are used that allow the theory of homogeneous medium wave propagation to be used for generating solutions in the presence of weak inhomogeneities. The better known among these approximate methods go under the names of Born and Rytov approximations. In more common form, the diffraction tomography is formulated as an approximate inversion of the Helmholtz Equation with a spatially varying coefficient along with Born and Rytov approximations. This method is a very computation efficient method for quasi Real-Time Imaging [27]-[28]. In situations of small objects with a low contrast with respect to the background medium this is a very efficient method. But it is not useful for larger objects with large contrast to the background medium. This is the case in the most situations of biomedical applications, where a non-linear method is needed. However, still the diffraction tomography formalization may be used in spectral domain to obtain real-time images of the equivalent currents inside the object [29].

The second group, a non-linear deterministic approach was first introduced by Joachimowicz et. al. and Chew et. al. in the beginning of the 90s. In [30], Joachimowicz et. al. proposed a spatial iterative algorithm for electromagnetic imaging based on the Newton-Kantorovich procedure for the complex permittivity reconstruction of inhomogeneous lossy dielectric objects having arbitrary shape. Starting from integral representation of the electric field and using the moment method, this technique has been developed both for the 2-D objects and 3-D objects. Its performance has also been compared with spectral techniques of classical diffraction tomography, the modified Newton method, and the Pseudo-Inverse Method.

Chew et. al. [31], used the distorted Born Iterative Method (DBIM) to solve two-dimensional inverse scattering problems, and also provided a general method to solve the two-dimensional imaging problem when the Born and the Rytov approximations are inapplicable. Numerical simulations are performed using the DBIM and the results show that the
DBIM shows faster convergence rate compared to the Born iterative method (BIM), while the BIM is more robust to noise contamination compared to the DBIM.

Caorsi et al. [32] also had some early contributions in this domain of non-linear deterministic approach. They proposed a numerical approach which detects the locations and the dielectric permittivities of unknown inhomogeneous dielectric cylindrical objects of arbitrary cross sections that might be present inside a fixed area of interest. The two-dimensional Lippmann-Schwinger integral equation of electromagnetic scattering is transformed into matrix form by the moment method assuming that object under test has been illuminated with the electric field vector polarized along the cylindrical axis. The system obtained is solved by using a pseudo-inversion algorithm to overcome ill-conditioning problems. The first-order Born Approximation is also applied when the dielectric inhomogeneities are weakly scattering.

Non-linear Inverse Problem in microwave imaging has gained attention and interest in many groups. K. D. Paulsen et al. [33] focus on the microwave imaging problem using the Hybrid Element (HE) method in conjunction with a dual mesh scheme to image complex wavenumbers $k^2$. The dual mesh scheme has been introduced to improve the reconstructed images of tissue properties and is ideally suited for systems using Finite Element Methods as their computational base. As the electric fields typically vary rapidly over a given body when irradiated by high-frequency electromagnetic sources, a dense mesh is needed for these fields to be accurately represented. Conversely, the complex wave numbers fairly remain constant over sub-regions of the body which would allow for a less dense sampling of this parameter in those regions. They employed the dual mesh system where the first mesh type is uniformly dense and is used for calculating the electric fields over the body whereas the second mesh, which is nonuniform and less dense, has been used for representing the complex wavenumber $k^2$ distribution within the region of interest. The researchers also examined the 2-D TM polarization case for a pair of dielectric distributions on both a large and small problem to demonstrate the flexibility of the dual mesh method. They suggested that the dual mesh method is critical for FE based image reconstruction where rapidly varying physical quantities are
used to recover smoother property profiles, as can occur in microwave imaging of biological bodies.

An electromagnetic imaging iterative scheme based on Newton method has been proposed by P. M. Meaney et. al. [34] for reconstruction of the dielectric properties of arbitrarily shaped inhomogeneous, lossy bodies. Their algorithm, known as Hybrid Element method, is based on a Finite Element (FE) representation coupled to a Boundary Element (BE) formulation for the forward solution of the electric fields. The algorithm utilizes FE discretization of only the area of interest while incorporating the RE method to match the conditions of the homogeneous background region extending to infinity. Their research work has been extended to the image reconstruction for the 2D TM polarization case for different classes of dielectric distributions which demonstrate the flexibility of this method.

A variant of the Newton method, which uses a fast solution of the direct problem and a dual mesh, has been proposed by A. E. Souvorov et. al. [35]. They have considered simple two-dimensional high-contrast phantoms and a full-scaled image of a two-dimensional mathematical model of a human torso has been obtained.

K. D. Paulsen et. al. [36] introduced a modified form of the Maxwell equation model-based image reconstruction algorithm which directly incorporates log-magnitude and phase of the measured electric field data. By doing so, measured phase variation can be unwrapped and distributed over more than one Riemann sheet in the complex plane. Their simulation studies and microwave imaging experiments show the significant image quality enhancements for large high-contrast objects. They suggested different simple strategies for visualizing and unwrapping phase values as a function of the transmitter and receiver positions. The new algorithm recovers high-quality images without using the priori information on object contrast and size as previously required.

A tomographic time-domain reconstruction algorithm has been described by Hfager et. al. [37] for solving the Inverse Electromagnetic Problem. Reconstructions have been made from experimental and numerically simulated data for objects of different sizes in order to investigate the relation between the spectral content of the illuminating pulse and the quality of the reconstructed image. Their work
has shown that the spectral content is crucial for a successful reconstruction. Also it has been intimated in their work that imaging of the objects with different scale lengths is an advantage to use a multiple step procedure. They used low frequency pulse to image the large structures and the reconstruction process then proceed by using higher frequency data to resolve small scale lengths. They have achieved a good agreement between the results obtained from experimental data and simulated data.

The algorithm, being highly computational, therefore has been used mainly for two-dimensional imaging. However, some efforts have been initiated in the three-dimensional case [38]-[41]. The computation saving approximation used here is the infinity approximation of the coupling medium, i.e. the interaction between the antennas, surroundings and the object are ignored. This approximations very useful as long the background medium is lossy, like water. However the antenna interaction has been implemented in some cases [42]-[45].

In the recent past, different alternative optimizing schemes have been reported. The basic problem in target identification or in medical imaging remains the same i.e. to determine the shape, location and constitutive parameters (the complex refractive index of an object for example) from the measurements of the scattered filed, when the object is illuminated successively with by the electromagnetic waves. This problem is nonlinear and ill-posed, but useful reconstruction algorithms have been developed during these years. Previous research in the field of microwave imaging was mainly focused on time domain techniques and linearisizing the assumptions about the wave propagation. Most of these algorithms made use of the domain integral equation for the field inside the scattering object and the related integral representation for the field outside the object. The methods are mostly iterative in nature and each iteration requires the solution of the forward problem.

The success of the iterative solutions of the forward scattering problem inspired Kleinman and Van den Berg [46] to introduce the modified Gradient Method, where both the unknown field and the unknown material contrast are updated simultaneously in each iteration. This method combines the features of gradient, and conjugates gradient methods by remodeling the Inverse Problem as an optimization problem.
in which a cost functional is minimized. The cost functional is defined as the superposition of the mismatch between the measured field data with the scattered field data of the object with a particular contrast function and the error in satisfying the object equation. The necessity of a full solution of a Forward Problem in each iteration is avoided by the simultaneous updates of the fields and the contrast. The modified gradient method was refined by Kleinman and Van den Berg [47] and further extended with a minimization of Total Variation [48] and thus become an efficient way of reconstructing the complex refractive index.

The modified gradient method initiated further researches in this domain. This method together with the source-type integral equation method, being introduced by Habashy et al. [49], formed the base of the Contrast Source Inversion (CSI) method [50]. The CSI algorithm is nothing but the variation of the Alternating Direction Implicit (ADI) method introduced by Kohn and McKenney [51]. In the CSI method the contrast sources and the contrast itself, are iteratively reconstructed by alternately updating the sources and the contrast which is contrary to the modified gradient method, where the fields and the contrast are updated simultaneously. But, unlike in the modified gradient method, there is no full inversion of the object equations involved in each iteration.

The CSI method is computationally faster, has less memory and data requirements and accommodates easily a priori information and hence outperforms the modified gradient method.

Although the addition of the total variation to the cost functional has a very positive effect on the quality of the reconstructions, the drawback is the presence of an artificial weighting parameter in the cost functional. This weighting parameter can only be determined through considerable numerical experimentation and a priori information of the desired reconstruction. Abubakar et.al, [52]-[53] introduced a new approach by including the Total Variation (TV) as a multiplicative constraint instead of an additive constraint so that the weighting parameter is determined by the inversion problem itself. In this case the original cost functional is treated as the weighting parameter of the regularizer. This eliminates the choice of the artificial regularization parameters completely. Numerical experiments have demonstrated that this multiplicative type of regularization has handled the noisy as well as
limited data in a robust way without the necessity of artificial parameters. Thus, when the multiplicative term is introduced in the CSI method, the method is known as Multiplicative Regularized Contrast Source Inversion Method (MR-CSI). Several researchers have their significant contributions in this reconstruction algorithm [54]-[57].

Caorsi et al. [58]-[61], has proposed the global optimization methods using neural networks, genetic algorithms and nondestructive evaluation of the object. In [58], they have applied the neural network approach to detect cylindrical objects as well as their geometric and electrical characteristics inside a given investigation domain. The electric field values scattered by the object are fed into the network, which produces the dielectric permittivity, and the location and radius of the cylinder as its output. The results are evaluated using different sets of testing data, and also the dependence of the various output parameters to the input is considered. The algorithm performance shows that the approach is able to solve the inverse scattering problem quickly and may be useful for Real-Time Remote-Sensing applications.

In [59], they proposed a numerical approach is proposed based on multi-illumination as well as multi-view processing. They re-casted the Inverse Problem as a global nonlinear optimization problem, which is solved by a genetic algorithm with an objective of the image reconstruction of highly contrasted bodies.

In [60], their approach is concerned to the application of a hybrid version of the genetic algorithm to tomographic imaging of dielectric configurations. Also they proposed another algorithm in which the buried inhomogeneities are schematized as multilayer infinite dielectric cylinders with elliptic cross sections. The cost function is constructed in terms of the field which is expressed in series solution of Mathieu Functions. The iterative minimization of the functional is performed by a new optimization method called Memetic Algorithm.

In [61], the same researchers proposed a global optimization technique based on a genetic algorithm for microwave nondestructive evaluation. Starting from an integral formulation of the inverse scattering problem, the detection of a flaw in a known host medium is reduced to the minimization of a suitable nonlinear functional relating the measured field to the field predicted at a given iteration. The
geometrical parameters of the flaw are retrieved by using a tomographic imaging approach. Numerical results are reported concerning cracks in lossless and lossy structures. The effects of the noise on measured input data are also analyzed. These methods avoid local minima, however at the cost of a slower convergence and higher computation load.

Meilianet.al. [62]-[63] proposed a parallel algorithm integrating Finite Difference Time Domain (FDTD) and Genetic Algorithm (GA) for detecting tumors using microwave tomography technique. The Genetic Algorithm is used to search the presumed dielectric property profiles space to find the globally optimized profile which produces forward computation data close to the measurement. The Finite Difference Time Domain (FDTD) is used to compute the scattered field at the observation points, thereby providing the information needed for the generation of the GA optimization procedure. Since the scattered fields calculation must be done several times per generation in the GA procedure followed by FDTD procedure, the computation is quite time consuming. To reduce the computation time, they have proposed a parallel algorithm integrating the GA and FTDT procedure for detecting tumors which starts with GA followed by FDTD using a master-slave approach using a distributed memory machine. Their simulated result is quite accurate in comparison to that of CT and MRI images. The experimental results for microwave imaging based on FDTD and GA has been reported in [64]. A wooden block has been used here as the object and the reconstructed image is quite acceptable with an error tolerance of four percent. However further analysis should be performed for a complete assessment of the methodology.

A similar 2-D fused image reconstruction approach has been suggested by Bindu et. al. [65]. The forward solver in this imaging algorithm employed the FDTD method of solving the time domain Maxwell’s equations with the regularization parameter computed using a stochastic approach. Born iterative and distorted Born iterative methods have been employed for image reconstruction with the extremity imaging being done using a differential imaging technique. The algorithm performed well in the presence of noise with good reconstruction accuracy but with heavy computational burden.
Martin Burger et. al. [66] introduced a class of stabilizing Newton-Kaczmarz methods for nonlinear ill-posed problems and analyzed their convergence and regularization behavior. In case of iterative methods for solving nonlinear ill-posed problems, conditions on the nonlinearity have to be imposed in order to obtain convergence. They concluded that the nonlinearity conditions obtained for the Newton-Kaczmarz methods are less restrictive than those for previously existing iteration methods and is verified for several practical applications. They also discussed the discretization and efficient numerical solution of the linear problems arising in each step of a Newton-Kaczmarz method, and carried out numerical experiments for two model problems.

In [67], Markus Haltmeier et.al. have developed and analyzed two iterative regularization techniques for the solution of systems of nonlinear ill–posed operator equations. Their basic idea is to consider each equation of the system separately and incorporated a loping strategy. The first technique, known as loping Landweber–Kaczmarz (ILK) method is a Kaczmarz type method, equipped with a novel stopping criteria. The second method known as embedded Landweber–Kaczmarz (eLK) method is obtained using an embedding strategy with a Kaczmarz–type approach. Both their methods proved well-posedness, stability and convergence.

Constantin Popa [68] proposed a constrained version of Kaczmarz Extended Algorithm for improving image reconstruction from projections in computerized tomography. The convergence of the algorithm has been proven in the general inconsistent case to a “constrained” least squares solution of the reconstruction problem, under weaker hypothesis than those proposed by Koltracht and Lancaster for classical Kaczmarz’s Projection Method. Numerical experiments and comparisons are also performed on some model problems from the field of Electromagnetic Geo-tomography.

The Microwave Tomography imaging of deep brain tissues presents a significant challenge, as the brain is an object that as located inside a high dielectric contrast shield, comprising the skull and the Cerebrospinal fluid (CSF). However, several attempts have been made by the researchers in producing biologically meaningful simulated images of the brain including images of stroke through nonlinear Microwave
Tomography inversion methods. The nonlinear Newton based reconstruction approach as proposed by Semenov et. al. [69] has shown its potential performance characteristics of MWT for brain imaging with a particular focus on stroke detection. The multi-frequency approach further improved the imaging results. In [70], Scapaticci et. al. have suggested simple design tool to devise guidelines to properly set the working frequency as well as to choose the optimum matching medium needed to facilitate the penetration of the probing wave into the head. Also they have proposed an imaging strategy based on a modified formulation of the linear sampling method, which allows a quasi-real time monitoring of the disease’s evolution. The accuracy of the design guidelines and performance of the imaging strategy are assessed through numerical examples dealing with 2D anthropomorphic phantoms.

Until now single frequency solutions are most widely used, but different groups are working on multi-frequency solutions [71]-[73]. It is known that the low frequencies lower the effect of phase non-linearity and stabilize the algorithm, while the higher frequencies increase the resolution, and the idea is that a combination will improve the reconstruction. Fang et. al. [71] proposed a multiple-frequency-dispersion reconstruction algorithm utilizing a Gauss–Newton iterative strategy for microwave imaging. This algorithm facilitates the simultaneous use of multiple-frequency measurement data in a single image reconstruction. The parameters reconstructed in this implementation are now frequency-independent dispersion coefficients instead of the actual properties and may provide new diagnostic information. Kurilo et. al. [72] proposed an approach based on scalar integral scattering equation under Born approximation. Scattering equation in discrete form is reduced to the system of linear equations, which is solved to obtain object image. Scattered field data has been gathered using multiple incident frequencies. They used Tikhonov regularization to overcome problem ill-posedness and achieved better radial resolution compared to frequency domain approach. Bin Guo et.al. [73] introduced Microwave-induced Thermal Acoustic Imaging (TAI) for early breast cancer detection technique, which combines the advantages of microwave stimulation and ultrasound imaging and offers a high imaging contrast, as well as high spatial resolution at the same time. A Multi-frequency Adaptive and
Robust Technique (MART) is presented for image formation. Due to its data-adaptive nature, MART can achieve better resolution and better interference rejection capability than its data-independent counterparts, such as the delay-and-sum method. The effectiveness of this procedure has been shown by several numerical examples based on 2-D breast models. The finite-difference time-domain method has been used to simulate the electromagnetic field distribution, the absorbed microwave energy density, and the thermal acoustic field in the breast model. Jacob D. Shea et. al. [74] proposed a multiple frequency inverse scattering technique to investigate the performance of 3-D tomography using low-power microwaves to reconstruct the spatial distribution of breast tissue dielectric properties and to evaluate the modality for application to breast density characterization. The forward solver in their imaging algorithm employed the finite-difference time-domain method of solving the time-domain Maxwell's equations, and the dielectric profiles were estimated using an integral equation form of the Helmholtz wave equation. A multiple-frequency, bound-constrained, vector field inverse scattering solution has been implemented that enabled practical inversion of the large-scale 3-D problem. Knowledge of the frequency-dependent characteristic of breast tissues at microwave frequencies has been exploited to obtain a parametric reconstruction of the dispersive dielectric profile of the interior of the breast. Imaging has been performed on a high-resolution voxel basis and the solution was bounded by a known range of dielectric properties of the constituent breast tissues. Imaging results were presented for each numerical phantom and robustness of the method relative to tissue density has been shown. In each case, the distribution of fibro-glandular tissues was well represented in the resulting images. The resolution of the images at the frequencies employed was wider than the feature dimensions of the normal tissue structures, resulting in a smearing of their reconstruction.

However, the frequency dependence of biological tissues is difficult to understand in this approach and need future research efforts and dedication focusing this area.
1.2. MOTIVATION OF THE CURRENT WORK

In the previous section (Section 1.1.3), different reconstruction algorithms have been discussed in detail starting from their inception. Computed tomography using X-ray caused the revolution in the field of medical imaging. Due to the radiation hazards of X-ray, imaging with alternate forms of energy like ultrasound and low-level microwaves attracts more interest. This leads to next generation algorithms based on Diffraction Tomography. Several authors had their significant contributions to this segment of medical imaging. But Born Rytov approximation used in Diffraction Tomography is not applicable for strong inhomogeneities which is the case in the majority of situations of medical applications. So the researchers focus on the non-linear deterministic approaches for electromagnetic imaging to have a reconstructed image of the high-contrast biological objects. Researchers proposed several algorithms both in 2D and 3D imaging. But till date, none of the algorithms has been successful to provide commercially viable results with desired degree of accuracy.

The researchers have explored the possibilities of reconstruction using different microwave frequencies (1-10GHz) and adopted different mathematical approaches to achieve it. Also, they have used different biological models for reconstruction purposes. So, the critical assessment of the performance of different approaches is not possible in the present context.

Several researchers in the recent past have adopted multi-frequency solutions instead of widely used single-frequency solution with an idea that low frequencies stabilize the algorithm whereas higher frequencies increase the resolution and hence the combination will improve the reconstruction. However, more research efforts are required to understand the complicated frequency dependence of biological tissues.

In this context, the author of this thesis has chosen the single frequency approach for medical tomography as it has already been established that the low frequency solution provides more stable algorithms. On the foundation of single frequency approach, the author accepts the challenge to develop algorithms to have a high resolution reconstructed image under noisy conditions.
1.3. PROBLEM STATEMENT AND CONTRIBUTION TARGETED

The current work deals with the development of some novel algorithms based on single frequency solution which will reconstruct the biological object with higher accuracy.

The algorithms must deal with the nonlinearity and ill-posedness of the Inverse Problem. Also so called Inverse Crime has to be avoided using different mesh sizes for Forward and Inverse Problem respectively.