

Microwave Tomography Application and Approaches – A Review

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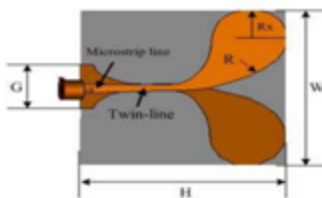
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Graphical abstract



Abstract

The objective of this paper is to review microwave tomography based on its field, application and antennas approaches. Researches on microwave tomography system have been done unceasingly for several decades especially in determine the dielectric properties for the material. Firstly, the dielectric properties and its influencing factors will be briefly described. Besides, although it has the potential to overcome other process tomography system, it still have some drawbacks. So, the general advantages and disadvantages are listed. Next, survey on the application of microwave tomography and type of antennas used will be discussed. Followed by the trend for the future.

Keywords: Microwave tomography; dielectric properties; advantages; disadvantages; application; antenna

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1.0 INTRODUCTION

In 1950s, the development of microwave sensors had been initiated. There was an activity to produce better methods for measuring the permittivity and to research the interaction between the permittivity and the physical properties of materials and mixtures was done by R. Von Hippel [1]. Initially, microwave sensors were for a long-term utilization for only a limited range of application due to their restricted obtainability, oversized components, high cost and the deficiency of signal processing power [1]. After the intensifying supply of solid state components during the 1970s and the establishment of the microprocessors embedded into the measuring devices in the early 1980s, the situations have change completely [1]. In Hornbuckle and Ancona 's work, they had come out with a microprocessor which can handle both analysis and synthesis simultaneously five times faster and without hardware modifications, cost effective and able to perform real-time digital signal processing in a small computer [2].

There are many kinds of microwave sensors, such as, free-space transmission sensor, special transmission sensor, guided wave transmission sensor, reflection, time domain reflectometry (TDR) and radar sensor, tomographic sensor, resonator sensors and radiometers. Microwave tomography uses tomographic

sensors. It is based on electromagnetic imaging as a diagnosis tool based on its unique features [3]. It utilizes non-invasive imaging method based on active wave [4]. It had been applied in many field. Besides, it has several advantages and disadvantages.

The literature about the research direction on the development of microwave tomography has been stated in the work of Pastorino *et al.* [5] and Mojabo *et al.* It requires two corresponding research objectives. First of all, the concerning of the design and the construction of fast, efficient and portable illuminating and measuring systems is necessitated [5, 6]. Next, the focus is correlated to the achievement of precise and robust inversion properties [5, 6]. Microwave tomography is a type of process tomography can be divided into three main parts. The three major parts are the sensing system, interfacing and image reconstruction algorithm [7]. The microwave's sensing system consists of antennas, antennas' signal measurement circuits and a signal conditioning circuit to amplify and filter the signal before it is applied to the interfacing part. The interfacing part denotes to the data acquisition system (DAS). Next, in the image reconstruction algorithm, it can divided in to parts which are forward and inverse problem. Conversely, in microwave tomography, it mostly refers to an inverse problem [4-6]. Microwave tomography is based on antennas used to measuring

medium of interest. When deal with microwave, dielectric properties will always be an inseparable factor.

Herein, dielectric properties and advantages and disadvantages of microwave tomography will be briefly discussed before enter the main purposes of this paper. The objectives of this paper are to do a review of the application of microwave tomography and types of antennas have been used. It is useful to know the trend of application so that improvement can be made. Besides, it is also important to know the types of antenna used in order to evaluate the feasibility of others antennas in the same field and operate with same frequency for the ease of comparison.

■2.0 DIELECTRIC PROPERTIES

Each material has its own dielectric properties. Dielectric properties of materials are those electrical characteristics of poorly conducting materials that can be polarized by an electric field.

2.1 Dielectric Properties Definition

Microwave tomography is based on the relationship between microwaves and the medium of propagation is absolutely determined by the relative permittivity of the medium [1]. The formula below represents the complicated permittivity relative to free space.

$$\varepsilon = \varepsilon' - j\varepsilon'' \quad (1)$$

where ε' is the dielectric constant and ε'' is the dielectric loss factor. The real part of the Equation (1) indicates the capability of dielectric material to store energy in the electric field. Meanwhile, the imaginary part of the Equation (1) denotes the capability of dielectric material to dissipate energy from the electric field which is then converted into heat energy in dielectric. Besides, the loss angle of dielectric is of concern with the assist of ε' and ε'' . So, the tangent of the loss angle, δ is given as in Equation (2).

$$\tan \delta = \frac{\varepsilon''}{\varepsilon'} \quad (2)$$

Furthermore, the conductivity of the dielectric, σ cannot be neglected. It is defined by Equation (3).

$$\sigma = \omega \varepsilon_0 \varepsilon'' \quad (3)$$

where ε_0 is the permittivity of free space which is equivalent to $8.854 \times 10^{-12} \frac{F}{m}$ and $\omega = 2\pi f$, where f is frequency (Hz).

2.2 Influencing Factor

The variation of dielectric properties of the material is due to some influencing factors. To start with, the factor that affect the dielectric properties of the material is the capability of material attract and hold water molecules in the air [8-11]. This normally refers to hygroscopic material such food and agriculture product. Next, the dielectric properties is being determined by the frequency of the applied alternating current field, material's density, temperature, composition and physical state [8, 9, 12, 13, 16, 18]. In addition, the bulk density of the air-particle mixture is a factor that influences the dielectric properties of the material especially in granular or particulate material [8, 12, 14, 16]. The bulk density can be altered by the shape and dimensions of particles and their surfaces [8]. Last but not least, the chemical composition is one of the influencing factor that alter the dielectric properties of the material [8, 15]. This mainly occurs on the existence of mobile ions and the permanent dipole

moments correlated with water and any additional molecules composing the material of interest [8].

■3.0 A REVIEW OF MICROWAVE TOMOGRAPHY

The pros and cons of different uncommon sensors depend on the specific application, but some general remarks can be given for microwave tomography.

3.1 Advantages of Microwave Tomography

Unique characteristics of microwave tomography that make it beneficial for applicable field can be listed as follows:

- Microwave tomography do not require mechanical contact with the object [1, 17, 18]. Thus, it is achievable to execute real-time measurements from a distance without interference to the process [1, 19].
- Microwaves propagate and penetrate all materials all straight lines [16, 17, 21]. However, they are not operational on metals due to the reflection of microwaves on metals' surface [1, 16, 20]. Therefore, the measured result is represented by a volume and surface of the material [1, 16].
- Microwave tomography has a significance difference with water, gases and other materials [1]. So, it is suitable for measurements of minute volumes of water and gases concentration in complex mixture with particular microwave frequencies [16].
- Microwave tomography is insensitive to environmental conditions, such as water vapor and dust, compared to infrared sensors [1, 16].
- Microwave tomography can operate in high temperatures in contrast to semiconductor sensors [1, 22].
- Microwaves are much safer and very fast to be applied [1, 16, 21, 23, 24]. (contrary to ionizing radiation which is kept as low as possible of safety reasons)
- At low frequencies which are applied in sensors such as capacitive and resistive sensors, the dc conductivity often controls material's electrical properties. The dc conductivity is being influenced strongly by temperature and ion content [1]. The influence of the dc conductivity seldom be spotted in microwave frequencies. The effect of DC conductivity which decreases with frequency, is much smaller for microwaves than at lower radio frequencies, which makes moisture measurement easier [1, 16].
- The microwaves do not affect the material under test in any way [1]. Hence, they enable high-speed, constructive and incessant monitoring [16, 24].

3.2 Disadvantages of Microwave Tomography

The cons for microwave tomography are as below:

- The cost of subsystem of the microwave tomography is very expensive if the measurement requires higher frequencies yet there is an omission of the frequency bands activated by radars and other high volume applications [1, 25]. Conversely, the price level will decrease gradually as time passed as the product has its own life span and market value.
- There is a necessity to calibrate microwave tomography separately for dissimilar materials [1, 26].
- The result from microwave tomography is not trustworthy if there is more than one variable, the sensors is sensitive.

Therefore, extra counter measure are needed in some cases for compensation [1, 16, 19, 27].

- The workable spatial resolution in microwave tomography is restricted due to the relatively long wavelengths [1, 27, 28].

3.3 Application of Microwave Tomography

As aforesaid, microwave tomography can be used in many fields. The survey of the application of microwave tomography according to year is presented in Table 1.

Table 1 Survey of different application for microwave tomography

Year	Author	Antenna	Field	Application
1999	A.T. Nugroho and Z. Wu [30]	• 32 transmitting and receiving antenna	• Medical	• Construct image of bone, fat, muscle and water
2000	A. Vertiy, S. Gavrilov, I. Voynovskiy, S. Aksoy, A.O. Salman [29]	• Horn antenna	• Geographical prospecting	• Detect buried mines • Determine the Brewster angle to decrease the surface reflection
2007	M. Pastorino, A. Salvade, R. Monleone, T. Bartesaghi, G. Bozza, A. Randazzo [31]	• None	• Agriculture	• Analytic and mathematical approaches had been done to optimize the measuring setup for microwave tomography for detecting wood defect
2008	Serguei Y. Semenov and Douglas R. Corfield [28]	• Ceramic loaded waveguide	• Medical	• To capture image of deep brain tissues and stroke detection.
2008	A. Salvade, M. Pastorino, R. Monleone, A. Randazzo, T. Bartesaghi, G. Bozza, and S. Porreti [24]	• Log periodic antenna	• Agriculture	• Identifying the interior of wood trunks
2009	Z. Wu, H. McCann, L. E. Davis, J. Hu, A. Fontes and C. G Xie [32]	• Monopole	• Oil and gas	• Apply image reconstruction algorithm in a simulation model with same antennas as the experimental system, at 4.5GHz, images of gas and oil distributions with different oil and gas phase fractions (0%, 25%, 50%, 75% and 100% of oil) will be constructed.
2010	Jeong-Ki Pack, Tae-Hong Kim, Soon-Ik Jeon, Jong-Moon Lee, Ki-Chai Kim [33]	• Monopole antennas	• Medical	• Investigation of the reconstruction of breast cancer's image by using microwave tomography in two-dimension. 1 transmit and 15 receive antennas had been used.
2011	Laeq Riaz [34]	• Printed elliptical monopole antenna	• Design Analysis	• Study the performance of antenna and antenna array (12) in air and different matching liquids
2011	Amir H. Golnabi, Paul M. Meaney, Shireen Geimer, Tian Zhou, and Keith D. Paulsen [35]	• Monopole antenna	• Medical	• Apply microwave tomography for heel imaging and explain the conformal mesh imaging and reconstructed images from a simulation trial.
2012	Majid Ostadrahimi, Puyan Mojabi, Sima Noghianian, Lotfollah Shafai, Stephen Pistorius, and Joe LoVetri [36]	• Vivaldi antenna	• Design Analysis	• To test the feasibility of the proposed system by using modulated scattering technique. The phantom used is a nylon rod.
2012	Sultan Almazroui, Dr. Weiji Wang [37]	• None	• Security (Simulation)	• Study of microwave tomography for security purpose by using dielectric property analysis of human body to be utilized in stimulation and describes the minimum resolution and microwave frequency to be used in the imaging for security application
2013	A. I.Smirnov, D. V.Yanin, A. G.Galka, A. V.Kostrov, A. V.Strikovskiy [38]	• resonance sensor	• Medical	• Design a microwave tomography to investigate and study biological tissue in order to perform on skin
2014	Ilaria Catapano, Antonion Affinito, Luciana Bertolla, Jorge Luis Porsani, Francesco Soldovieri [15]	• ground penetrating radar	• Oil and gas	• Oil detection and monitoring by using GPR and construct 3D microwave tomography.
2014	Matteo Pastorino, Andrea Randazzo, Alessandro Fedeli1, Andrea Salvadè, Samuel Poretti, Manuela Maffongelli, Ricardo Monleone, Matteo Lanini [40]	• Log periodic antenna	• Agriculture	• Come out with a diagnosis tool for wood characterization in the food product industry. Investigation was done on wood in green and dry condition.

From the survey in Table 1, at early stage microwave tomography mostly dominated in medical for non-invasive biological imaging applications. Through microwave tomography infection under the skin and bone can be diagnose in order improve human's health. After few years, microwave tomography started to be popular in the field of agriculture. The reason microwave tomography is utilized is to increase and

improve efficiency of crop production and enhance crop quality. Then method is then also being applied in the field of oil and gas, geographical prospecting and security for the purpose of detecting and monitoring.

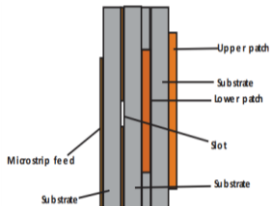
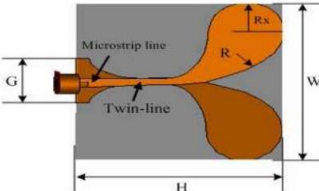
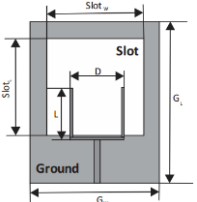
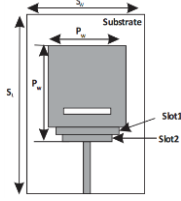
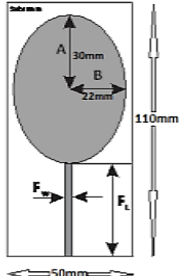
4.0 TYPES OF ANTENNAS IN MICROWAVE TOMOGRAPHY

In microwave tomography, ultra wide-band antennas (UWB) have been used for measurement. The frequency band for UWB is in range from 0.3GHz to 300GHz. In the system, it consists of a transmitting and receiving antennas. There are some requirements when designing these antennas for microwave tomography. Factors to classify a good ultra wide-band antenna for microwave tomography is based on its structures, size, electromagnetic field distribution and cost [34]. The structure of the antenna must be simple so that it is easy to be modelled in computation program [41]. This will result in low computational power and high modelling accuracy [34]. Next, the size of the

antenna must be as small as possible. Furthermore, for electromagnetic field distribution of the antenna, the radiated energy concentrated in the object under test will be emphasized. Cost will always be the factor that people will stressed on. So, try to minimize the cost for fabricating the antennas.

In literature, different kind of UWB antennas have been suggested such as horn antenna, two log periodic antenna, stack patch antenna, wide slot antenna, Vivaldi antenna, printed monopole antenna and pyramidal horn antenna. A variety of antennas were studied with the purpose of finding appropriate antenna for microwave tomography as shown in Table 1. In the work of L. Riaz [34], the comparison of several antennas with pros and cons based on its feasibility to be used in microwave tomography is presented in Table 2.

Table 2 The comparison of several antenna with pros and cons based on its feasibility to be used in microwave tomography [34]

Antennas	Pros	Cons	Illustrations
Stack Patch Antenna	<ul style="list-style-type: none"> • Good radiation characteristic [42] • Allowing a suitable time-domain characteristic [42] 	<ul style="list-style-type: none"> • Directive • Complicated Structure 	
Vivaldi Antenna	<ul style="list-style-type: none"> • Can yield large bandwidth 	<ul style="list-style-type: none"> • Complicated Structure 	
Wide Slot Antenna	<ul style="list-style-type: none"> • Can obtain wide impedance bandwidth if the distance between the radiating arms and ground plane is selected properly 	<ul style="list-style-type: none"> • Large size at the frequency band of interest. 	
Taper slot antenna	-	<ul style="list-style-type: none"> • Does not meet the requirement on size and structure for microwave tomography 	
Printed Elliptical Monopole Antenna	<ul style="list-style-type: none"> • Wide bandwidth can be achieved • Simple structure • Size suitable array design • Height-few mm • Easily mounted on ordinary plastic casing • Broadside radiator with omnidirectional radiation pattern • 3D radiation pattern 	-	

From the comparison above and based on requirements on microwave tomography antennas, it can be concluded that printed elliptical monopole antenna is the most suitable antenna for tomography currently. Unfortunately, they are not widely

used. Therefore, a further investigation needs to be done to evaluate its efficiency for microwave tomography.

5.0 FUTURE TREND

From the survey above, it is so obvious that microwave tomography start to be well-known in agriculture. So, in future, microwave tomography will be emphasized in agriculture. Since agricultural sector will contribute to the growth and major contributors to national income and export earnings. Advancements in agricultural production and postharvest technology can increase citizens' living quality. Therefore, knowledge of science and technology must be used in agriculture aggressively to improve the quantity and quality of the crop as well as to reduce the effort and cost of crop production. In agriculture application, agriculture products can be discriminate through their dielectric properties by using microwave which makes them useful for enhancing the production in this field. So, the research of a portable, cheaper, simple structure and precise spatial resolution microwave antenna is should be worked out to support the application of microwave tomography in agriculture especially in agarwood industries.

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