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Latest Trends in Microwave Bioimaging & Diagnostic Technology

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ABSTRACT: Future trends in medical applications of microwave technique and technology can be seen in development of latest diagnostic and imaging methods based on high frequency EM field. Interactions of EM field with biological systems are utilized in the area of therapy (oncology, physiotherapy, urology atp.) Applications include biomedical imaging concealed weapon detection, through-the-wall imaging, non-destructive testing and evaluation. There is an emerging biomedical imaging modality with great potential for non-invasive assessment of functional and pathological conditions of soft tissues . This paper presents a review of researches and focuses on various potential clinical applications of MWT. There is a very high dielectric contrast between bones and fatty areas compared with soft tissues. MWT is applicable for extremities imaging, breast cancer detection, diagnostics of lung cancer, brain imaging and cardiac imaging. The lower frequency up to 1GHz is applicable for imaging larger objects, for example whole-body imaging. Higher frequencies (up to 3–4GHz) are applicable (in terms of penetration) for extremity imaging, producing higher resolution images.

KEYWORDS: MWT (Microwave tomography), DUT (Device under test) , NDT (Non destructve testing)

I. INTRODUCTION

The mm-wave range lies between 30 and 300 GHz, with corresponding wavelengths between 10 and 1 mm. Many optically opaque objects appear transparent, making mm-wave imaging attractive for a wide variety of commercial and scientific applications like nondestructive testing (NDT), material characterization, security scanning, and medical screening. The spatial resolution in lateral and range directions as well as the image dynamic range offered by an imaging system is considered the main measures of performance. They are used in near field imaging of dielectric bodies. The relatively long wavelength (1 mm to 1 m) allows these waves to penetrate many optically opaque materials such as living tissues, wood, ceramics, plastics, clothing, concrete, soil, etc. On the one hand, X-ray images have an inherent high lateral resolution due to the extremely short wavelength (m $\sim 10^{-2}$ nm – 10 nm). But on the other hand, the energy of the photons is high enough to ionize organic and inorganic matter. Therefore, health aspects are critical with respect to imaging of humans, especially in the case of personnel screening at airports. For most ultrasonic devices, an appropriate coupling medium is required for an efficient coupling of the ultrasonic wave in the respective device under test (DUT). In contrast, electromagnetic mm-waves offer a contactless inspection of materials with non-ionizing radiation and a high spatial resolution. Since spatial resolution and penetration depth are conflicting parameters regarding the wavelength, e.g., the E-band (60–90 GHz with λ=5 to 3.3 mm) is a good compromise for NDT applications to detect flaws, material in homogeneities, and inclusions in dielectrics. A lateral resolution of ~2 mm is sufficient for many applications, e.g., the personnel screening at airport security checkpoints are created. A significant importance for the future can be identified for the following methods: 1) Microwave tomography, 2) Microwave radiometry, 3) Measurement of complex permittivity, 4) Imaging in the Terahertz waves band, 5) Microwave diagnostic radars.

The work has been organized as Section II. includes microwave imaging techniques , Section III includes antenna parameters studied for the imaging applications , Section IV includes diagnostic tissue malignances , Section V includes applications , Section VI includes conclusion & then references.

II. MICROWAVE IMAGING TECHNIQUES

a. *Microwave Tomography*

Studied object will be placed in water phantom. It will be irradiated by transmitting antenna while scattered EM field will be monitored by receiving antenna and evaluated by a network analyser. Receieving antenna will be scanning around studied object [1]

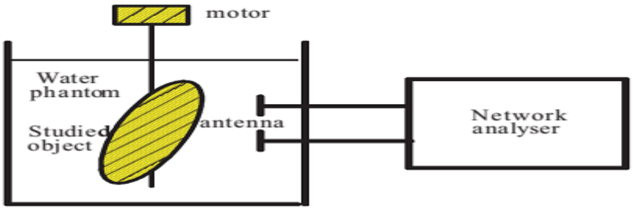

Fig .1 Experimental setup of microwave tomography for biomedical imaging

b. *Microwave Radiometery*

Microwave radiometry is based on measurement of a very weak EM signal, which radiate anyobject, whose temperature is superior to absolute zero. It is based on utilizationof Planck radiation law. Interest in microwave radiometry is given by possibility of itsutilization at diagnostics of cancer and also of inflammatory disorder (e.g., appendicitis, arthritis, atp.) because tumors and inflammatory processes causes temperature rise. Microwave radiometer as a tool for biomedical imaging applications has the possibility to “monitor” a thermal noise produced by objects with the temperature over absolute zero. Next figure gives a basic idea about experimental setup. Advantage of microwave radiometer is ability to “see” the temperature increase under the surface of human body. Therefore we need to scan studied area of the tissue with a sensor and to evaluate the results of temperature measurements.[1]

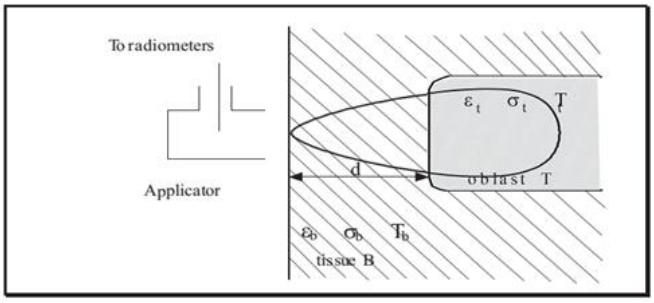

Fig.2 Principal of imaging by a microwave radiometer

c. *Microwave diagnostic RADARS*

Among four S-parameters two can be measured for the two antennas at each scanning position: S_{11} is a measure of the scattered wave received by antenna 1 when the same antenna is transmitting, S_{21} is a measure of the scattered wave received by antenna 2nd when antenna 1st is transmitting, S_{12} is a measure of the scattered wave received by antenna 1st when antenna 2nd is transmitting, and $S_{22}$is a measure of the scattered wave received by antenna 2 when the same antenna is transmitting. The parameters S_{11} and $S_{22}$are referred to as the reflection S-parameters for antennas 1st and 2nd, respectively, whileS_{21} andS_{12} are referred to as the transmission S-parameters. The collected data from each S-parameter can be processed to create an imageof the target. In this case, we obtain four separate images with various resolutions. To reconstruct a single image, the datasets of all S-parameters must beused simultaneously. All reconstructed images reproduce the shape ofthe target accurately. In contrast, the 2D images of the S-parameter magnitudes do not provideany clue about the shape of the target. It is worth noting that since the object is dielectric, thetransmission S-parameters (S_{21} and S_{12}) are stronger than the reflection S-parameters (S_{11}andS_{22}) and this leads to reconstruction of images with better quality [2].

d. Measurement of complex permittivity

In active imaging, it is additionally possible to reconstruct the spatial extend of the DUT along the range direction. With a sufficiently large signal bandwidth, it is furthermore possible to analyze multiple reflections resulting from a stratified dielectric medium. This information can be used for instance to investigate delamination for NDT applications or to identify explosive sheets or other concealed objects for personnel screening application. The last named application requires a reflection setup since the human body is not transparent in the mm-wave region with the penetration depth of human skin in the range of submillimeters. Due to the high water content of the human skin, it behaves as a strong reflector for mm-wave signals. Thus, the reflection imagery is dominated by the specular reflections, making active imaging on large distance inappropriate. We can then evaluatesymmetry resp. unsymmetry of the measurement results and from this information we can make hypothesis about possible medical problems. There is a very high dielectric contrast between bones and soft tissues in the extremities. This might help to image bones, but the goal is to image soft tissues.

III. ANTENNA PARAMETERS

The contrast between the electrical properties of the components of a dielectric body enables its imaging using microwave measurements. In a typical active microwave imaging scenario, power is radiated via an antenna and the scattered power is received by one or more antennas. The scattered signals are then analyzed to detect and evaluate possible scatterers (targets). The method has been applied to biomedical imaging, non-destructive testing and evaluation of materials through-wall imaging, concealed weapon detection etc. The design and fabrication of high-performance antennas present significant challenges in the implementation of all categories of microwave imaging [3]. Typical design requirements that have been considered in the literature are wide impedance bandwidth, high directivity, as well as small size group velocity, fidelity, and efficiency. Various types of antennas have been proposed for near-field microwave imaging and in particular for tissue sensing applications. Examples include the planar monopole, the slot antenna, the Fourtear antenna, a microstrip patch antenna, a ridged pyramidal horn and a cross-Vivaldi antenna. The amount of power coupled to the tissue through the front aperture is quantified by a parameter called near-field directivity (NFD)

The antenna operates as a sensor with the following properties:

1) Direct contact with the imaged body
2) More than 90% of the microwave power is coupled directly into the tissue
3) Performance
4) Excellent de-coupling from the outside environment
5) Small size
6) Simple fabrication.

The antenna characterization includes:

A. ANTENNA EFFICIENCY

The efficiency of one antenna is estimated:

$$e_A \approx \frac{|S_{21}|}{\sqrt{(1-|S_{22}|^2)(1-|S_{11}|^2)\cdot \mathrm{NFD}}}.$$

B. Group velocity

The variation of the group velocity with frequency is a measure of the distortion of the transmitted pulse due to the antenna.

$$S_{21} = \frac{V_2}{V_1} = e^{-(\alpha_1 + j\beta_1)L_1} e^{-(\alpha_2 + j\beta_2)L_2}$$

where V_2 and V_1 are the assumed voltages at the two-antenna terminals, β_1 and β_2 are the phase constants associated with the signal delay in each antenna, α_1 and α_2 are the respective attenuation constants, and L_1 and L_2 are the lengths of the antennas from the coaxial feed point to the center of the aperture. Since the two antennas are assumed identical, we define as $\alpha_1 = \alpha_2 = \alpha_A$, $\beta_2 = \beta_1 = \beta_A$& $L_1 = L_2 = L_{A.}$ $\theta_{21} = 2\beta_A L_{A.}$ Then the group velocity

$$Vg = (\delta \beta_A / \delta w)^{-1} = 1/ 2\, L_A (\delta \theta_{21}/ \delta w)^{-1}$$

C. Antenna fidelity

In order to investigate the distortion of the pulses by the proposed antenna into homogenized breast tissue, the antenna fidelity is computed. The fidelity is the maximum magnitude of the cross-correlation between the normalized observed response and an ideal response derived from the excitation waveform at the antenna terminals, where r(t)is the observed -field normalized to unit energy, and f(t)is the input signal at the antenna terminals also normalized to unit energy The reason for the drop in the fidelity with distance is the tissue dispersion and Dissipation .

$$F = \max_{\tau} \int_{-\infty}^{\infty} \hat{f}(t)\hat{r}(t+\tau)dt \quad .$$

D. SNR

The coupling between the two antennas is sufficiently strong to obtain reasonable signal-to-noise ratio (SNR) with conventional test instruments, e.g., vector network analyzers. the image of a tumor , which has only permittivity contrast but no conductivity contrast with the background, appears larger than the image of tumor ,which has the same size and shape but has contrast in both permittivity and conductivity. Here, we define the numerical SNR as the ratio of the signal strength at the position of the tumor and the S-parameters mesh convergence error of the simulations. In all simulations, the mesh convergence error is set at 0.001. It is observed that the SNR decreases drastically with increasing frequency.

E. Resolution

The spatial extension of the aperture determines the lateral resolution $\delta_{x,y}$ given approximately by

$$\delta_{x,y} \approx \frac{\lambda}{D_{x,y}} L.$$

where Dx,y denotes the length of the aperture in the corresponding direction, λ is the wavelength, and L is the distance between object and aperture . The resolution δz in range direction is determined approximately by the signal bandwidth B of the measured RF signal thus given by

$$\delta_z \approx \frac{c_0}{2B}$$

Accordingly, a large signal bandwidth B results in an equivalent short pulse duration and hence in a high range resolution. This is for example interesting for monitoring delamination effects in NDT or the detection of thin dielectric explosive sheets in personnel screening. In practice, the bandwidth is often limited by the employed semiconductor components, e.g., oscillators, mixers, and amplifiers. High lateral resolution results from a large aperture dimension D.

IV. DIAGNOSTIC OF TISSUE MALIGNANCIES

a. Malignancies & dielectric properties of tissues

1) The contrast in dielectric properties ‘between malignant and normal a dipose dominant tissue in breast is considerable, as large as 10:1
2) Dielectric properties of ex vivo malignant liver tissue are 19–30% higher than normal.
3) The differences in dielectric properties between normal and malignant lung tissues (contrast in dielectric properties) are approximately 10–15%.

The calibration involves a measurement scan of a predetermined tissue phantom, also referred to as background medium. The choice of the background medium is expected to affect strongly the images. Several types of background mediums will be studied including: (i) high-water content homogeneous phantoms (dielectric properties close to those of malignant tissue); (ii) medium-water-content homogeneous phantoms (dielectric properties close to those of fibro-glandular tissue); (iii) low-water-content homogeneous phantoms (dielectric properties close to those of fat tissue); and (iv) patient-specific heterogeneous background (e.g., left breast serves as background for imaging of the right breast of the same patient). Since each of the above background mediums can offer certain advantages, it is expected that a successful imaging algorithm will make intelligent use of all of the above calibration measurements

V. APPLICATIONS

The dielectric properties of wood were related to microwave processing. The advantages of microwave heat processing are numerous, such as: fast processing, small space occupied by the equipment, less temperature degradation of the products compared with other conventional heating techniques, dimensional stability of the products, selective heating of materials and, lower heat loss to the surroundings. The industrial applications were originally oriented primarily toward improving of drying and gluing technology.

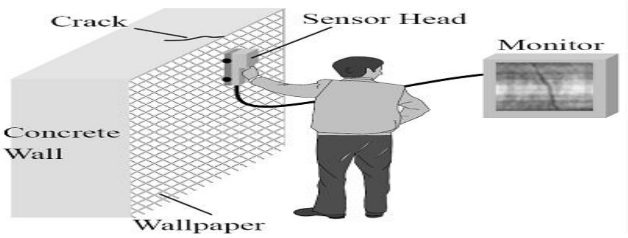

Fig. 3 Practical scene of crack scan

Today, the industrial applications of the microwave imaging technique are related to the detection of internal defects such as knots, spiral grain, slope of grain, structural discontinuities, etc. of logs, lumber, and wood-based composites. Another interesting field of application of microwave imaging is the dielectric behavior of vegetative materials, including leaves, stalks and trunks under various moisture and temperature for the inspection of forests, logs, lumber and wood based composites. The microwave parameters used for image reconstruction are: the amplitude, the phase and the polarization. The system involves transmission of microwave energy through the samples or objects and measurements of reflected, refracted or diffracted fields. The properties of the reflected or transmitted microwave signals change in accordance with the properties of the dielectric properties and thickness of the layered structure under investigation

Table.1 Variation of dielectric constant w.r.t. moisture content

Moisture content (%)	Direction ε	L Tanδ	Direction ε	R Tanδ	Direction ε	T Tanδ
7	1.9	0.14	1.7	0.07	1.8	0.09
10	2.1	0.17	1.9	0.10	1.9	0.11
12	2.6	0.22	1.9	0.11	2.1	0.13
16	2.9	0.26	2.1	0.18	2.3	0.21
22	4.2	0.45	2.6	0.26	3.0	0.25

VI. CONCLUSION

This paper reviews results in areas of potential clinical applications of MWT imaging and presents our view on its state -of-the-art and potential clinical applications .Low Power densities are necessary to obtain useful signals (about10^{-4} mW/cm^2) which means eliminating possibility of thermal effects of electromagnetic waves. The comparison with other methods show that : with ultrasounds (5 MHz λ=0.007 cm) : microwaves cross media containing air without being attenuated and are absorbed by high water content media. When the ultrasounds are strongly attenuated, the microwaves are almost transparent for example, in bone tissues- attenuation of ultrasounds is equal 10.6db/cm and for 3 GHz microwave: 1. 18db/cm. X-rays on the one hand, the nature of interactions with matter is different - they occur at molecular level with microwaves and at atomic level, with X-rays. On the other hand, Gregg (12) has shown, in particular, that in mammary tissues containing a tumor, a better contrast is obtained with microwaves due to the dielectric variations of tissues (ratios 6 to 40 for the microwaves).

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