Terahertz Characterisation of Living Plant Leaves for Quality of Life Assessment Applications

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***Abstract* – This paper presents a preliminary results on employing terahertz (THz) technology for measuring the water content of leaves. The main purpose of this work is to highlight transmission constraints of terahertz radiation through the plants in THz frequency region. Multiple leaves of plants are examined using THz Swissto12 system and the effect of thickness and water content on transmission loss and attenuation are observed at different frequency regions, which can lead to meaningful information to study and analyse the existence of any pesticides in leaves with terahertz frequencies. The results in this paper paves a way for applicability of terahertz frequencies for sensing the quality of life in plants.**

Index Terms: **Terahertz (THz) radiation, propagation, sensing, agriculture**

I. INTRODUCTION

In recent years, the emerging applications of terahertz (THz) technology has captivated numerous researchers and scientists with a different background working on wide range of subjects owing to its distinctive characteristics and due to viable opportunities offered in various fields [1][2]. Some of the applications that have been derived from these unique features are medical imaging for non-invasive diagnostics of dental care and skin cancer, security imaging of invisible items, atmospheric studies, processing the quality control of food, high- frequency communication and non-contact imaging for protection of paintings and manuscripts [3][4].

Although there has been the enormous progress of THz applications in various fields such as biomedical imaging, diagnostic applications. However, its potentials to propagate satisfactorily through plants is still of one of the least examined research areas until now. In this respect, some of the elementary and significant aspects of THz transmission through various sections of vegetations, e.g. fruits, vegetables, leaves need to be accomplished [5][6].

The effects of global climate change is leading to growing aridification and the estimation of leaf water content is of immense interest to the cultivator, horticulturists, researchers, as well as scientists in various fields of applied plant biology [7]. It contributes immensely to avoiding plant drought stress as well as provides valuable information in irrigation management. The water detection in a plant has mainly relied upon the degree of water existence in plants, because water is considered as a strong absorber of THz frequency, and for this reason, the increment of water content level in plants will also increase the transmission loss of plants material and vice versa [7][8].

Taking a different frame of references into consideration and emphasizing on the deployment of THz practical applications in the communication sector. It is predicted that the implementation of wireless nano-sensor networks would be considered a satisfactory solution for achieving better monitoring, controlling and precision in agriculture. Due to hardware limitations of nano-sensor, it is envisioned that networks, as mentioned earlier, will be more useful because of its communications in THz band. Moreover, it can also be employed for real-time, in-depth observation of vegetation emissions [1][9].

Over the past few years, significant amount of efforts are made in the field of agriculture such as monitoring and controlling of environmental systems, crops productivity enhancement, protection of crops from any pathogen attacks, and particularly, monitoring the appropriate amount of water content in leaves and plants by using various methods [1][10][11]. In this context, the focus is mainly deployed on THz technology for the investigation of water content in leaves, which have been vastly researched in numerous publications aiming for the detection of dehydration response in plants and remote sensing of vegetation conditions [2][12].

Presently, a large part of current literature about THz communications sector is mainly focused on the channel characterization and modelling for body-centric communications and also presented on-body path loss models for different body scenarios [5].

However, aforementioned models are inadequate to anticipate any transmission loss directly in a medium that contains plants leafage. To overcome this corresponding drawback authors in [13] have proposed numerical method of elementary THz path-loss models that envisage the absorption and scattering reaction of plant leaves for estimating the total signal loss. In spite of the fact these models are based on simulation results, described in the literature for distinct leaves and leaf types, can be approved by comparing them with some practical measurements of plants. This paper aims to introduce for the first time a preliminary study for measuring the live plant leaves in the range of 0.75 to 1.2 THz frequency using Swissto12 system. Twelve leaves of various plants were examined to measure the absorption and attenuation of leaf's water content due to the effect of thickness, and presence of water contents in leaves, which can lead to meaningful information to study and analyse the existence of any pesticides in leaves with terahertz frequencies.

This paper is structured as follows: Section II presents the experimental setup, Section III presents measurement results of different leaves and analysis of results. Finally, in section IV, conclusion is drawn.

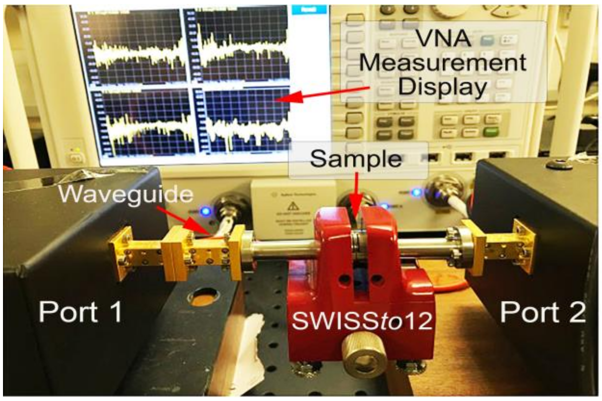

Fig. 1 Measurement setup for measuring transmission response use Swissto12 THz system

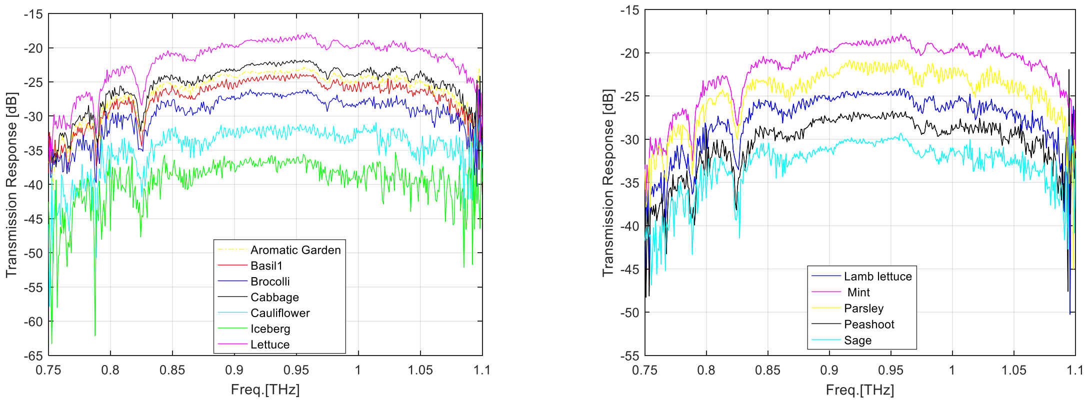

Fig. 2 THz transmission response obtained using Swissto12 THz system of twelve different leaves with thickness range from 0.15 mm to 0.80 mm

II. EXPERIMENTAL SETTINGS

The THz transmission measurements were performed using Swissto12 system [14] by using state of art calibration technique as shown in Fig. 1. The Swissto12 system can measure in the frequency range of 0.75 to 1.2 THz for sample of up to thickness range of 40 μm to 4 mm. A fully two port calibration (wR-1.0) was performed known as (Short-Open-Load-Through) to avoid any measurement errors. Both the reflection coefficients (S_{11}, S_{22}), and transmission coefficients (S_{12}, S_{21}) were measured in each measurement.

The thicknesses of twelve leaves were calculated using high precision measurement tool called "Vernier calliper" as shown below in Table 1; and were found in the threshold range of the system (40 μm – 4 mm) enabled to perform experiments on

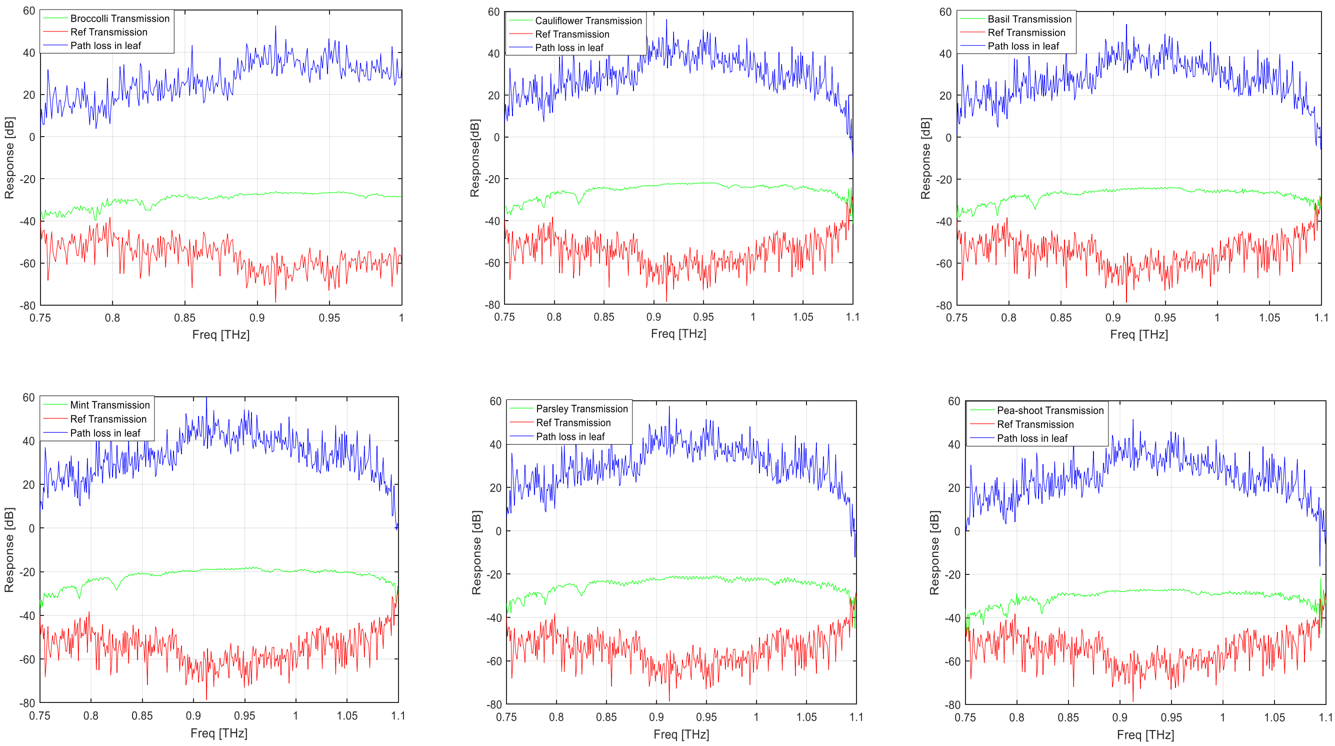

Fig. 3 Response of different leaves considering the effect of different thickness of leaves, and changes in leaf water content

them. This process was repeated to obtain the thickness of leaves at different positions. Twelve different leaves were studies namely; aromatic garden, mint, parsley, basil, broccoli, cauliflower, pea-shoot, lamb lettuce, lettuce, cabbage, iceberg, sage. In each case, three measurements were performed on each leaves to clarify the fact that leaves may contain different water content levels at different positions.

III. MEASUREMENT RESULTS

Figure 2 shows the transmission response for twelve different leaves. It can be observed that attenuation of leaves in plants is related to the water content presence in the tissue of plants. It is noted from the Fig. 2 that transmission losses are due to the combined effects of absorption, reflection, and scattering.

Fig 3 shows the path loss occurred in leaves of various plants and the pathloss is affected by leaf thickness, surface roughness and also depends on the level of water content present in tissue of leaves. It is absorbed that there is deep transmission radiation at 0.79 THz and 0.83 THz frequencies showing a more sensitive frequency region and precise determination of changes in water content. From the Fig. 3, it can also be observed that much loss has occurred in leaves of plants, i.e. broccoli, basil, cauliflower, and mint. The variation in transmission loss obtained from leaves is distinguished from each other indicating the leaves appeared to have different thickness, absorption of water content, and have components of plants physiology. It also indicates that leaves possess different propagation properties in the process of growth. Results show that leaves of mint show a high variation of loss from 0.8 THz to 1.08 THz approximately. For a valid evaluation of mint leaf, measurement results can also be verified from the Table 1 represents the highest mean value of mint leaf compare to other leaves of plants. It should be noted that actual terahertz technique applied here represents only possibility of water content or detection of any pesticides. For more effective quantification of water content, percentage of water content must be known, which is future work. Table 1 shows the mean path loss occurred in different leaves with thickness of each leave. Results clearly shows that relation of thickness and water contents on the loss.

IV. CONCLUSION

This paper mainly aims to highlight the significance and development of terahertz technology applications for water content detection in some common agricultural leaves of different plants. For this purpose, transmission loss and power transmittivity of THz wave propagation were investigated through multiple layers of leaves using Swissto12 system. In this work, the possibility of employing this technology was tested which can be

TABLE I. THICKNESS AND MEAN VALUES

Leaves	Thickness of leaves	Path Loss Mean(0.75-1.2THz)
Aro. Garden	0.15mm	-26.7764
Mint	0.27mm	-39.7794
Parsley	0.17mm	-24.9294
Basil	0.26mm	-27.7798
Broccoli	0.22mm	-30.1573
Cauliflower	0.21mm	-25.8243
Pea shoot	0.17mm	-30.8454
Sage	0.33mm	-33.4639
Cabbage	0.80mm	-26.8524
Iceberg	0.31mm	-35.1237
Lamb lettuce	0.26mm	-28.0579

very useful and beneficial to obtain more accurate and detailed monitoring of water content in leaves. Considering the measured results, it can be concluded that transmission loss occurred in various leaves of plants depends on the thickness of leaves, presence of moisture in leaves and possibility of any pesticides presence in leaves.

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REFERENCE

[1] A. Afsharinejad, A. Davy, P. O. Leary, and C. Brenann, “Transmission Through Single and Multiple Layers of Plant Leaves at THz Frequencies,” pp. 0–5, 2017.

[2] A. Afsharinejad, A. Davy, and M. Naftaly, “Variability of Terahertz Transmission Measured in Live Plant Leaves,” *IEEE Geosci. Remote Sens. Lett.*, vol. 14, no. 5, pp. 636–638, 2017.

[3] T. Kürner and S. Priebe, “Towards THz communications - Status in research, standardization and regulation,” *J. Infrared, Millimeter, Terahertz Waves*, vol. 35, no. 1, pp. 53–62, 2014.

[4] I. E. Carranza, J. P. Grant, J. Gough, and D. Cumming, “Terahertz metamaterial absorbers implemented in CMOS technology for imaging applications: scaling to large format focal plane arrays,” *IEEE J. Sel. Top. Quantum Electron.*, vol. 23, no. 4, pp. 1–8, 2017.

[5] Abbasi, Q. H., Ur-Rehman, M., Qaraqe, K. and Alomainy, A. (Eds.) (2016), Advances in Body-Centric Wireless Communication: Applications and State-of-the-art. Series: IET telecommunications series. Institution of Engineering and Technology: London. ISBN 9781849199896

[6] J. M. Jornet and I. F. Akyildiz, “Channel modeling and capacity analysis for electromagnetic wireless nanonetworks in the terahertz band,” *IEEE Trans. Wirel. Commun.*, vol. 10, no. 10, pp. 3211–3221, 2011.

[7] C. Jördens, M. Scheller, B. Breitenstein, D. Selmar, and M. Koch, “Evaluation of leaf water status by means of permittivity at terahertz frequencies,” *J. Biol. Phys.*, vol. 35, no. 3, pp. 255–264, 2009.

[8] R. Gente and M. Koch, “Monitoring leaf water content with THz and sub-THz waves,” *Plant Methods*, vol. 11, no. 1, p. 15, 2015.

[9] A. Afsharinejad, A. Davy, and B. Jennings, “Dynamic channel allocation in electromagnetic nanonetworks for high resolution monitoring of plants,” *Nano Commun. Netw.*, vol. 7, pp. 2–16, 2016.

[10] N. Born *et al.*, “Monitoring Plant Drought Stress Response Using Terahertz Time-Domain Spectroscopy,” *Plant Physiol.*, vol. 164, no. 4, pp. 1571–1577, 2014.

[11] B. Breitenstein *et al.*, “Introducing terahertz technology into plant biology: A novel method to monitor changes in leaf water status,” *J. Appl. Bot. Food Qual.*, vol. 84, no. 2, pp. 158–161, 2011.

[12] V. Torres *et al.*, “Monitoring water status of grapevine by means of THz waves,” *J. Infrared, Millimeter, Terahertz Waves*, vol. 37, no. 5, pp. 507–513, 2016.

[13] A. Afsharinejad, A. Davy, B. Jennings, and C. Brennan, “Performance analysis of plant monitoring nanosensor networks at THz frequencies,” *IEEE Internet Things J.*, vol. 3, no. 1, pp. 59–69, 2016.

[14] Swissto12, "http://www.swissto12.com/ [accessed on 15 Dec., 2017]