Influences of Real-World Conditions on Terahertz Stand-Off Detection: Simulation and Experiment

S. Wohnsiedler[a], M. Theuer[a], M. Herrmann[a], S. Islam[a], J. Jonuscheit[a], R. Beigang[a], F. Hase[b]
[a] Fraunhofer Institute for Physical Measurement Techniques IPM, Kaiserslautern, Germany
[b] Forschungszentrum Karlsruhe, Institute for Meteorology and Climate Research, Karlsruhe, Germany

***Abstract*—Terahertz spectroscopy has become a well-established tool under laboratory conditions but terahertz stand-off detection in the real world is hampered by a number of influences related to the environment and the sample properties such as air humidity, surface roughness and angle of detection. A terahertz stand-off system must be calibrated in order to account for these influences. We have performed experiments and simulations in order to probe the limits of terahertz stand-off detection under real-world conditions.**

I. Introduction And Background

TERAHERTZ (THz) spectroscopy is a promising technique for the stand-off detection and characterization of hidden objects. The THz band is particularly suitable firstly because THz radiation penetrates many dielectrics such as plastics, paper and clothes and secondly because many potentially hazardous substances have characteristic signatures in the THz spectrum.

Despite of the high selectivity of other techniques such as laser-induced optical breakdown spectroscopy (LIBS), molecularly imprinted polymers (MIPs) or neutron activation, none of those have reached widespread market acceptance because the devices are insufficiently developed, too expensive, dangerous to humans or simply not accepted by the public.

In order to develop the full potential of THz radiation for detecting possible hazards and recognizing characteristic signatures, disturbing influences must be accounted for. In particular, real-world THz spectra show absorption from water molecular rotation lines unless the THz path is purged with dry air or nitrogen which is not always possible. Therefore precise knowledge of the absorption accumulated in ambient air is indispensable. Parameters such as humidity, temperature, pressure and propagation length have to be taken into account.

Other substances in the THz beam path such as clothes may also impair a THz spectrum. The surface properties of the sample are important as well. A surface may be flat and reflect like a mirror, or it may be rough and scatter the THz radiation into a wide range of angles with the intensity depending on frequency, thus affecting the measured THz spectrum.

II. Results

Water vapor absorption affects the THz spectra. Its absorption lines are very strong, however, since the properties of the atmosphere are known to the operator of the THz setup, these effects can be arithmetically removed unless the signal is below the signal-to-noise ratio. Since the absorption lines are strong and narrow, the calculation must be precise. We have checked various models well-known in meteorology [3] covering the infrared and the microwave region of the electromagnetic spectrum. By extending the models into the THz region, an accurate description of the measured spectral absorption is reached.

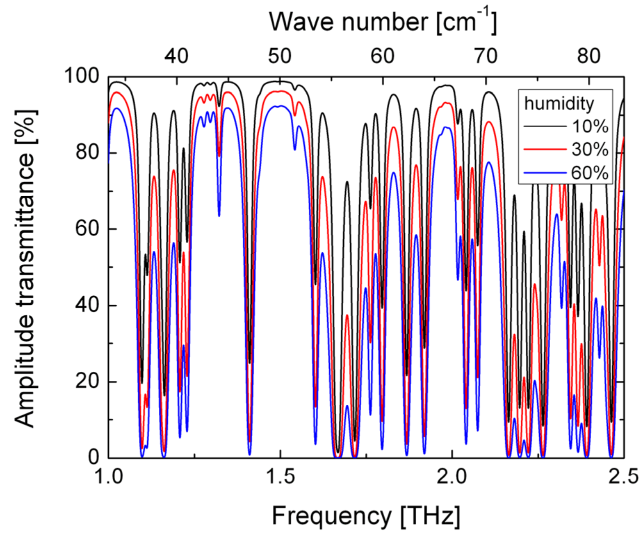

Fig 1. Amplitude transmittance spectra simulated for a humidity of 10 %, 30 % and 60 % at 1 m path length.

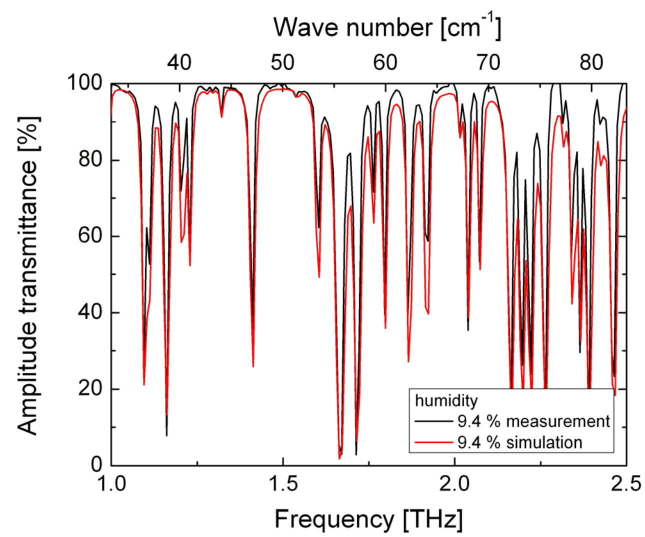

Fig 2. Measured and simulated amplitude transmittance for a humidity of 9.4 % at 1 m path length.

In Fig. 1 we show three transmission spectra simulated for a THz beam path length of 1 m at 10 %, 30 % and 60 % humidity. For increasing values of humidity, however, the simulated spectrum shows stronger absorption lines, so that

978-1-4244-2120-6/08/$25.00 ©IEEE.

there are less frequency bands where THz can be used for stand-off detection.

Figure 2 shows a typical transmission spectrum simulated at a humidity of 9.4 % for a THz beam path length of 1 m and the corresponding measured spectrum. In the range between 1.0 and 2.5 THz, simulation and measurement show a good agreement. A comparison and calibration for other values of humidity, temperature and pressure were also performed. Other path lengths have also been measured and simulated to check the feasibility limits of stand-off detection under real-world conditions

In THz reflection measurements, dielectrics such as clothes as well as the surface properties of a sample typically show up as broadband structures caused by absorption or interference. In a known configuration these disturbing effects may be calculated and removed in order to recover the spectral signature of the sample under test. In a real-world stand-off measurement, however, the type of dielectrics and the nature of the surface are usually unknown. In order to recover the characteristic signatures of potential hazards, we study the nature of these effects and derive algorithms that help us to distinguish between the signatures and the fakes.

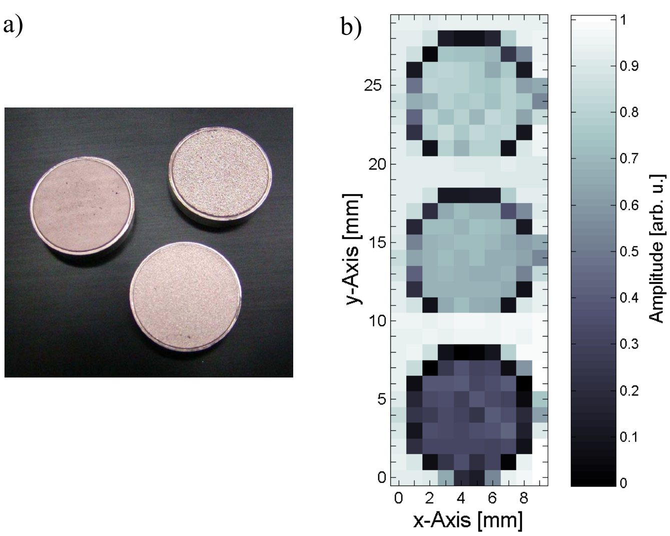

Fig 3. a) Photo of three samples with various grit sizes. b) Reflected amplitude at normal incidence, grid designation of P2000 (top), P1200 (middle) and P150 (bottom).

In our studies the transmission spectra for different substances such as clothes were tested, also the influences of varied surface properties. As a surface can be flat or rough and scatter the THz radiation into a wide range of angles with the intensity depending on frequency, these effects must be taken into account for the measured THz spectrum. Sandpaper of various grit sizes was glued on metal discs and coated with copper to generate reflective surfaces to analyze the influences of surface properties as presented in Fig. 3a). Figure 3b) represents the reflected amplitude for three samples at normal incidence with a grid designation of P150 (max. size of granules: 169 µm), P1200 (max. size of granules: 21 µm) and P2000 (max. size of granules: 13 µm). The rough surface shows smaller values of amplitude than the finely granulated one. The array with low values of amplitude at the edge of each sample can be explained as boundary effects caused by the sample preparation.

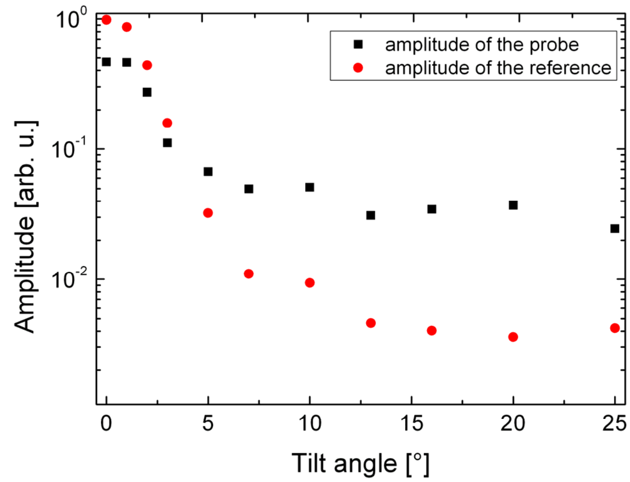

Fig 4. Amplitude for different tilt angles between 0° and 25°.

We have also performed measurements for different grit sizes and tilt angles to find out the influence of the surface roughness. In Fig. 4 we show the maximum amplitude for measurements under different tilt angles between 0° and 25°. For increasing tilt angles, however, lower values for the amplitude are reached.

III. Conclusion

We are currently creating a look-up table to show which parts of the THz spectrum can be used for THz stand-off detection at which combinations of values for the various parameters such as humidity, pressure, temperature, THz beam path length and surface roughness.

References

[1] M. van Exter, Ch. Fattinger, and D. Grischkowsky, "Terahertz time-domain spectroscopy of water vapor", Opt. Lett., vol. 14, no. 20, pp. 1128-1130 (1989).

[2] T. Yuan, H. Liu, J. Xu, F. Al-Douseri, Y. Hu, and X.-C. Zhang, "Terahertz time-domain spectroscopy of atmosphere with different humidity", SPIE, Orlando, FL, USA, vol. 5070, no.1, pp. 28-37 (2003).

[3] F. Hase, T. Blumenstock, and C. Paton-Walsh , "Analysis of instrumental line shape of high-resolution FTIR-spectrometers using gas cell measurements and a new retrieval software", Appl. Opt., vol. 38, no. 15, pp. 3417 - 3422 (1999).

978-1-4244-2120-6/08/$25.00 ©IEEE.