High resolution terahertz raster imaging

Daniel Molter[a], Garik Torosyan[a], Christian Wiegand[b], Michael Theuer[a,b], and René Beigang[a,b]
[a] Fraunhofer Institute for Physical Measurement Techniques IPM, Kaiserslautern, Germany
[b] University of Kaiserslautern, Kaiserslautern, Germany

***Abstract*—We present recent progress in on-the-fly broadband raster transmission and reflection terahertz imaging with a focus on the data evaluation. Possibilities to enhance the resolution by frequency domain filtering as well as terahertz tomography are discussed.**

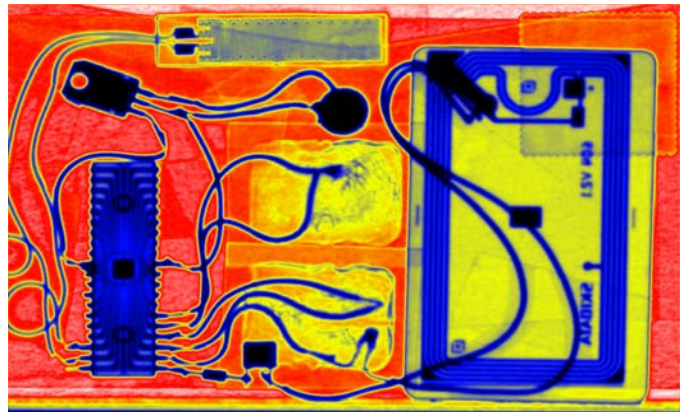
I. Introduction and Background

TERAHERTZ (THz) imaging is one of the most impressive ways to show the potential of this specific part of the electromagnetic spectrum for various applications. Although THz imaging by raster scanning the sample is expected to be replaced by other imaging techniques in the near future, it is still a powerful and reliable tool for preliminary studies. The challenge of this technique lies not only in the physical hardware but also in the data evaluation process, where the balance between data acquisition speed and image resolution has to be met.

A step-by-step raster scan of the sample and taking a normal time domain trace with a conventional linear stage as an optical delay line offers the access to good spectral information at each pixel, but limits the resolution of the image and therefore the acquisition time. A continuous movement of the sample and a commercial shaker as delay line dramatically increases the measurement speed (and thus the image resolution), but limits the quality of the spectral information for each pixel. Therefore we have implemented a possibility to define a certain area of interest in our data evaluation tool, in which the spectral information of the pixels in this area are averaged and as a consequence quality in spectral information is gained. The information obtained in this way is sufficient for most applications: High resolution for the overall transmission intensity image for overview and sufficient frequency domain information for area evaluation.

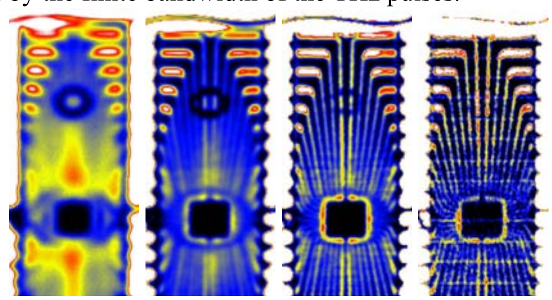
II. Results

As an example, many details can be resolved easily in a false color picture from a mail bomb mockup (e.g. microprocessor, RFID-card, various electronic components, post stamp) and spectral information of the contained bags of spectral significant substances are available (here lactose and salicylic acid). This picture was acquired at a detection speed of 40 pixels per second which is at the moment only limited by the speed of the commercial delay line. The implementation of an improved optical delay line capable of scanning at repetition rates above 200 Hz by having an optical delay of larger than 140 ps is just in progress and will enhance the acquisition time once more.



By acquiring the time trace for each pixel one also has the possibility to enhance the image resolution by filtering the low frequency (long wavelength) part of the spectrum. This is a useful tool to resolve hidden features in the simple transmittance intensity picture. An example for this can be seen in the comparison of four different pictures of the same measurement. From left to right the evaluated frequency band is shifted to higher frequencies (0.2-0.5 THz, 0.5-1 THz, 1-1.5 THz and 1.5-2 THz).

This comparison also demonstrates the limits of this method, which is the lower signal-to-noise ratio at higher frequencies caused by the finite bandwidth of the THz pulses.



The timetrace and therefore the spectral information for each pixel is recorded, so in principle one could evaluate each pixel for spectral information. In most applications, the spectral features of one single pixel are not of interest, but spectral information of a certain area is required. Therefore the quality of the spectrum can be enhanced by averaging the spectra of this specific area. As an example three spectra of different numbers of pixels of the lactose bag in the mail bomb mockup are compared. Clearly the signal-to-noise ratio is enhanced by taking a larger area of interest. The lactose features can clearly be resolved.

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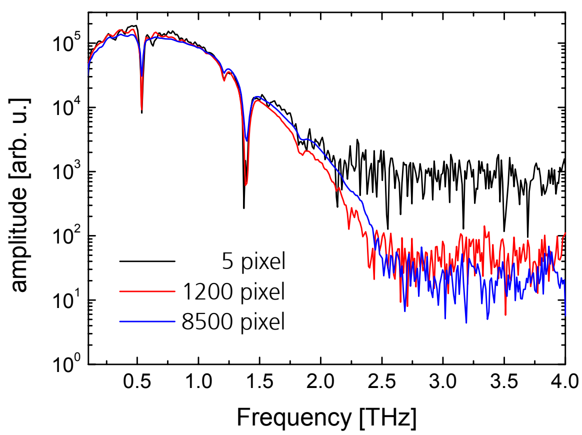
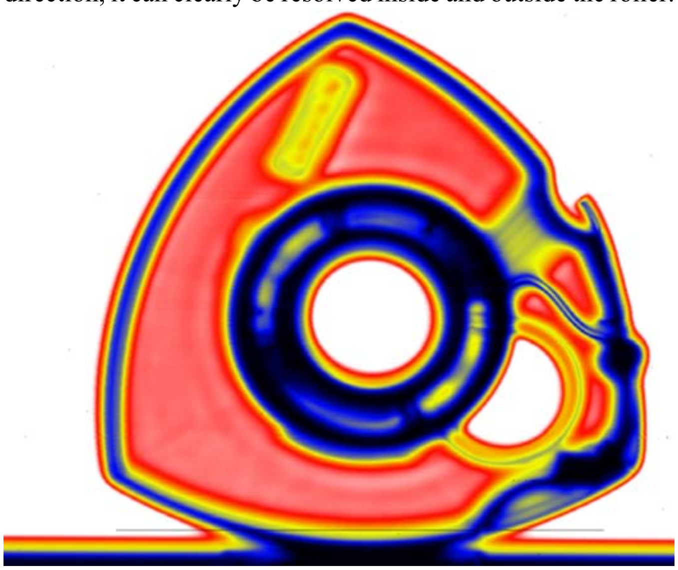
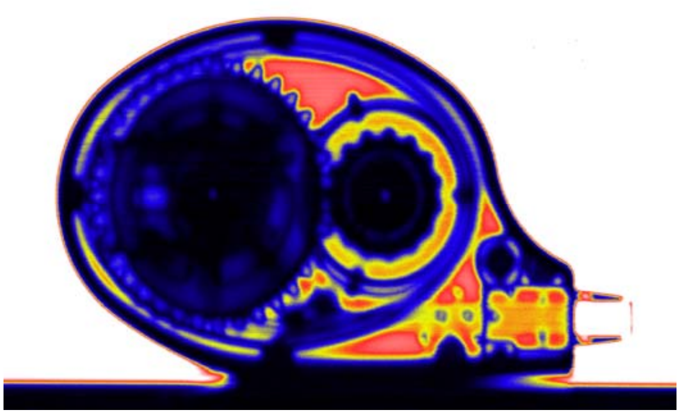
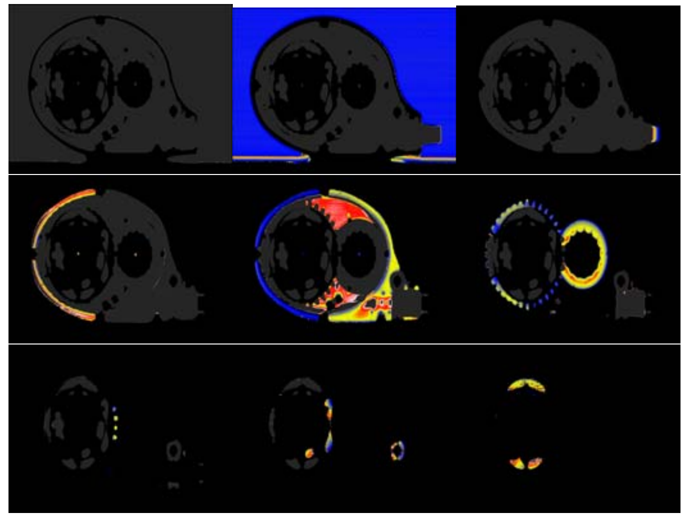


Two further examples for the high resolution are shown in the THz images of a scotch tape and a correction tape roller. Even though the scotch tape is perpendicular to the THz direction, it can clearly be resolved inside and outside the roller.



The very thin correction tape is also resolved in the THz image as well as the internal gear. By evaluation of the time position of the maximum, tomographic pictures can be produced.





The time order of these pictures are left to right, up to down. To produce these pictures a time window was moved over the time domain and the false color indicates the pulse maximum position in the window. Pulse maxima at times before the window are displayed black, maxima at times after the window are displayed grey. The interior of the device is black because of a filter function, as the signal there is too low.

Detailed information about frequency domain enhanced resolution measurements as well as the gain of information by the use of the time domain information (THz tomography) will be given.

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