Investigation of THz imaging artifacts generated by oversampling and interpolation of diffraction-limited low-resolution data

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***Abstract* – In this work, we investigate artifacts that can be generated during the post-processing of THz imaging data using spatial oversampling and interpolation – as often applied to artificially increase the impression of spatial resolution. We also present Terahertz (THz) near-field measurements with sub-wavelength resolution and compare them to diffraction-limited far-field measurements.**

I. INTRODUCTION

Terahertz (THz) measurements as inspection method for material and device characterization as well as for quality control is more and more used throughout various research and industry sectors. For some applications already the knowledge of a frequency-independent THz amplitude reduction is sufficient [3], while for others a high spectral resolution is required e.g. to obtain "THz fingerprints" of the material under test [4]. With the availability of fast THz time-domain spectroscopy systems (TDS) [1] and the use of automated sample scanning tables, spatially (and spectrally) resolved THz images are more widely used for inspection tasks. Already, THz conductivity mappings are used as a reference to benchmark other (pure electrical) methods [2].

For all this applications, it is important not to over-estimate the capability of the employed THz tools, and to be aware of its limits especially in terms of spatial resolution. In far-field systems, it is a result of the usable spectral range and the applied optics determining the achievable diffraction-limited THz focus spot-size. In practice, THz scanning imaging systems with typical spot-sizes of several 100µm´s are operated using much smaller raster-steps of only a few µm´s.

Here, we demonstrate (the theoretically obvious, but unfortunately often forgotten) fact, that no additional information can be gained in this way and care has to be taken with specifications mixing up over-sampling capabilities with real spatial resolution. In order to do so, we compare high-resolution THz near-field measurements with interpolated measurements that were acquired using low-resolution measurement equipment. With "interpolation" we refer to digital data interpolation during the post-processing as well as to artificially smoothed measurements by oversampling using a "too small" step-size.

II. EXPERIMENTAL AND RESULTS

The test sample we use for this investigation is based on a high-resistive silicon substrate with chromium-layers of varying thickness. The layer thickness is chosen to cover a range of sheet resistivity values from 1 to 350 Ohm/sq.. The sample size is 5x5cm and the metal structures are fabricated using standard semiconductor process techniques. Typical resolution test-structures are manufactured: concentric rings, a Siemens-star and bars of different size and different orientation.

Near-field measurements in transmission mode are done in a THz time-domain pump/probe setup with a femtosecond fiber-laser generating pulses of 100 fs duration and 780 nm center wavelength to pump a bias-free Terahertz emitter and to gate a photoconductive near-field micro-probe detector. A spatial resolution of a few µm can be achieved by scanning the sample with the detector tip held in close distance [1]. In order to conduct measurements at a lower spatial resolution, we "de-tune" the setup by increasing the distance between the THz detector-tip and the sample.

III. RESULTS

Figure 1 shows measurement results from the same sample, but with different setup configurations. For image (a) and (b) the chosen raster-stepsize equals the specified setup resolution. For (c) the same setup configuration as for (b) has been used, but with significantly reduced step-size, so that the measurement data contains as many pixels as (a). Clear blurring effects due to this oversampling are visible, but smaller features still cannot be resolved. So while the image in (a) shows clearly

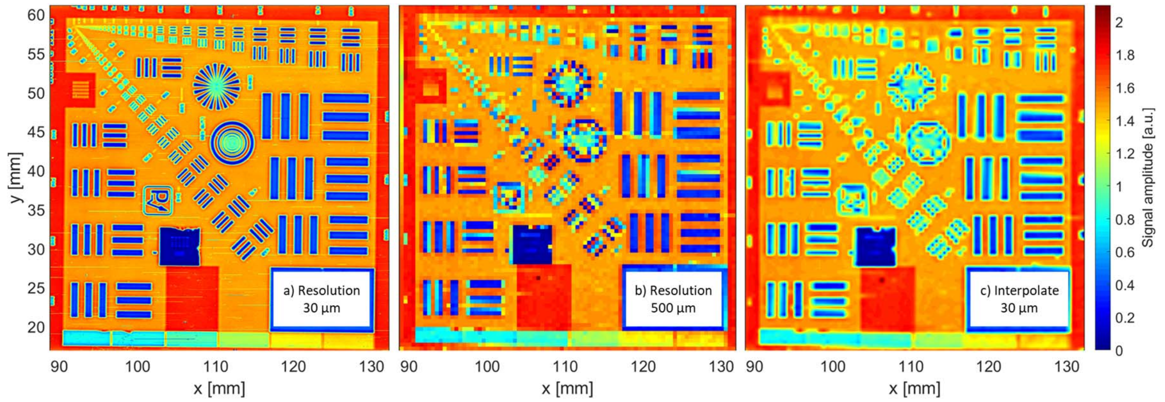

Fig. 1: The figure shows 3 measurements in different configurations at the same sample. The measurement in (a) is performed with a step-size of 30µm in a setup, that is specified for 30µm resolution. Results in (b) were acquired in a setup configuration with an estimated resolution of 500µm using a 500µm step-size. The picture (c) shows a measurement that was taken in a setup with nominally 500µm resolution, but was acquired with a step-size of 30µm.

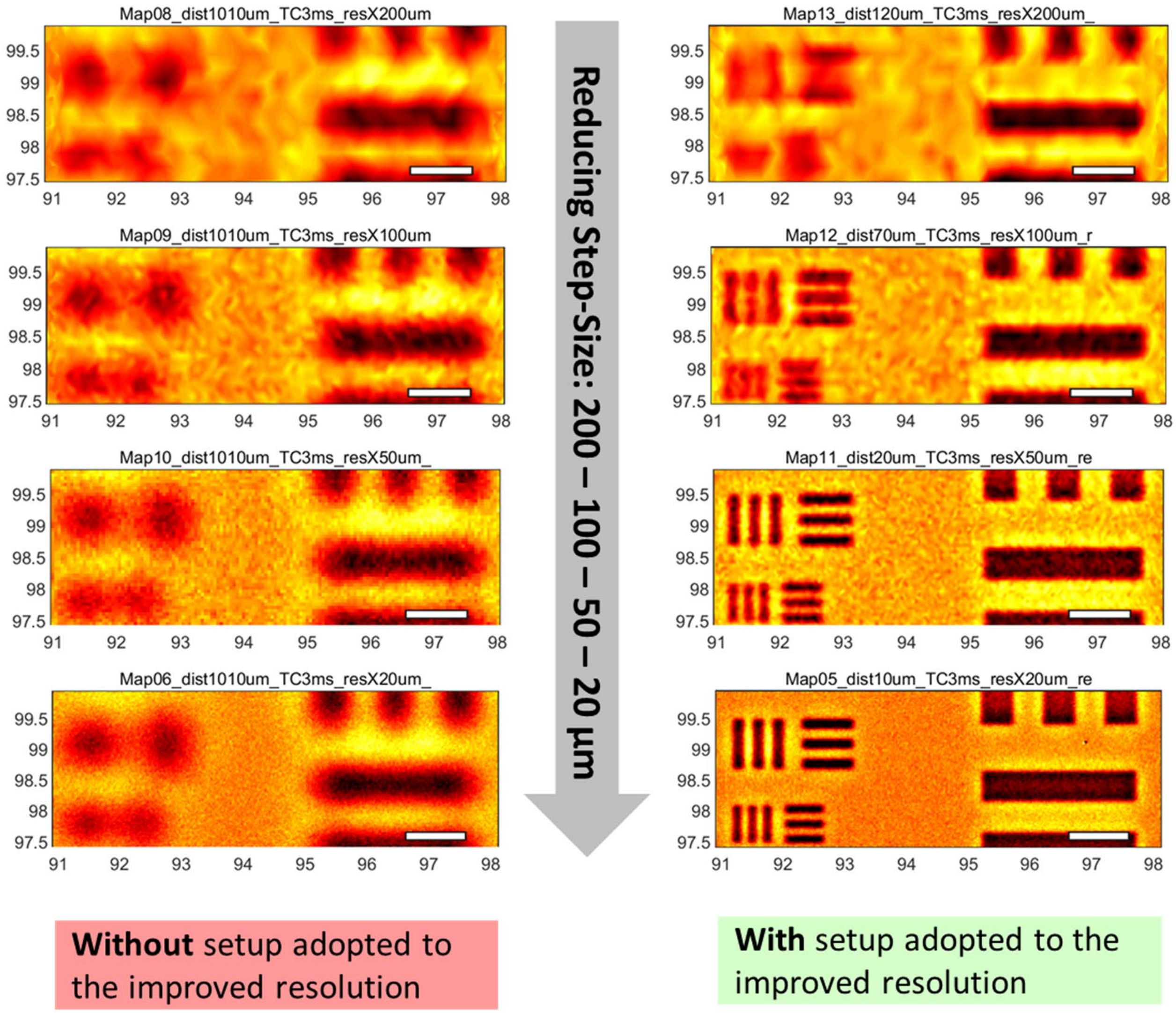

Fig. 2: The figure shows 8 different measurements that are recorded in the same setup by repeated measurements of the same sample-region with different settings. From top to bottom the pixel-size (that is the step-size by which the sample is moved between to adjacent measurement points) is reduced. It is set to 200µm at first, the reduced to 100µm, then to 50µm and finally to 20µm.

For the images on the left side the spatial resolution of the setups has not been changed between the different measurements. For the images on the right side the spatial resolution capabilities of the setup has been adjusted with every mapping to match the corresponding step-size.

One can clearly see, that for the measurements on the left side, the pixel-density increases, but the visible features get not significantly sharper and no new features are resolved. The images on the right side however show that with every resolution-improvement new structural features become visible or edges become visible more clearly and the position of edges gets more clearly defined.

more details than (b), it is disputable if (c) provides in any aspect more information than (b). If for a sample under test the features are not as clearly defined as for such a dedicated test samples, or when the sample structure is not known before (what is typically the case for a real sample), the effects of oversampling or interpolation will not be as obvious as they are here. Therefore, oversampling should only be used with care, to avoid misleading data interpretation that might suggest smoothness or even homogeneity, where the sample-structure contains sharp features in fact.

IV. CONCLUSION

Tools having a limited spatial resolution should not be "adapted" for high-resolution measurements at fine sample structures by either interpolating the measurement data or by raster-scanning with a small step-size.

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