Three-Dimensional Imaging of Materials at 0.1 THz for Inner-Defect Detection

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***Abstract*: A 3D frequency-modulated continuous-wave (FM-CW) radar system operating in the frequency band 75–110 GHz for contact-free non-destructive material inspection is presented. We propose an original FM-CW setup that includes a large delay on the reference signal to avoid redundant signals that spoil the signal of interest for materials with multiple inner defects, while keeping attractive transverse resolution and long measurement depth. Specific signal-processing techniques are presented to compensate for the lack of maturity of THz components. Tomography experiments were conducted on building materials showing 3D imaging with theoretically-limited longitudinal and transverse resolutions, of 5 mm and 20 mm, respectively.**

Imaging at THz frequencies is a good compromise if compared to X-rays, millimeter or optical systems, in terms of safety, resolution and penetration. As dry and non-conductive materials are concerned, unless crystalline structures are involved, penetration suffers from high losses due to diffraction as material granulometry is often of the same orders of magnitude than the wavelength. Therefore, imaging in the sub-THz frequency range is a good compromise between resolution and penetration, especially for construction materials.

We present a frequency-modulation continuous-wave (FM-CW) system that operates in the 75–110 GHz range for contact-free non-destructive material inspection. FM-CW systems operating in the THz range have been reported in [1], showing possible tomography features but these are not fully exploited, the aim being to detect the concealed object. Tomography feature were specifically reported in [2], using a dual-source FM-CW setup. Here, we present an alternative setup that offers theoretically-limited spatial and transverse resolutions, and propose specific signal-processing techniques to compensate for the lack of maturity of (sub-)THz components.

Using quasi-standard FM-CW setup, we confirm that images are principally degraded by parasitic reflections in the system, and by the source non-linearity that is specifically significant for frequency-multiplied sources. Additionally, if materials with multiple inner defects or interfaces are concerned, beat signals appear for every couples of interfaces, therefore N (N-1)/2 beat signals appear for N interfaces. As shown in Fig. 1, a PTFE object with an inner cavity has been used to evaluate the performances of the FM-CW setup. As shown in the middle figure, multiple signals appear in a cut of the tomographic image. We will present a method that allow to get rid of these ghost interfaces by adding a reference mirror in the setup at a long distance, and discuss how to reduce the impact of parasitic reflections and source non linearity in this specific setup, offering higher-quality images as shown in the Fig. 1 (right).

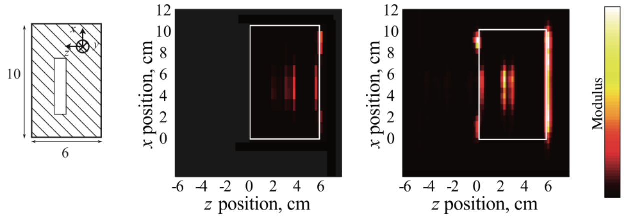

Fig. 1. Cut of 3D THz images. Left: mechanical drawing of the material under test (units are cms). Center: straightforward FM-CW measurement showing ghost interfaces due to cross-interfaces beatings Right: Ghost-free image obtained using a largely-delayed reference.

We will show that an averaging technic based on measurements at different distances of the target, along with a spectral shift of the acquired spectra allow to reduce the deleterious signals due to parasitic reflections. Source non linearity can be corrected using signal-processing methods that are similar to the one reported in [1] or [3], consisting in a preliminary calibration of the setup without any target. We will demonstrate that our specific setup using an additional reference signal offers a more practical implementation of this technic.

To demonstrate the possible application of such a system to real materials, we will present tomography experiments offering theoretical-limited resolutions (transverse and longitudinal) of building material such as reinforced concrete samples, and demonstrate that this specific setup offers a possible solution for civil infrastructure monitoring.

References

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