Imaging with Indirect Holographic Method at 310 GHz

Aleksi Tamminen, Juha Ala-Laurinaho, and Antti V. Räisänen

TKK Helsinki University of Technology, Department of Radio Science and Engineering, SMARAD, MilliLab, P.O. Box 3000, FI-02015 TKK, Finland aleksi.tamminen@tkk.fi, juha.ala-laurinaho@tkk.fi, antti.raisanen@tkk.fi

INTRODUCTION

Indirect holographic imaging is suitable to be used in detecting, e.g., concealed weapons in personnel screening. At millimeter/submillimeter range, clothing material is partially transparent [1] and high resolution imager is possible to be realized with reasonable-sized aperture. As opposed to many other active imaging methods, heterodyne detection is not needed, reducing the complexity of the detectors.

The image is formed with a synthetic-aperture-type approach, where the complex electric field reflected from the target is back-propagated computationally. The complex field is not measured directly but by using the holographic method familiar from optics. The complex field is retrieved from interference of two fields, the target field and the pre-defined reference field. In optics, usually, the reference field is a plane wave from a laser source. As creating a plane wave is not trivial at millimeter/submillimeter wavelengths, a spherical reference field is used instead.

In this paper, indirect holographic imaging is experimentally studied. Images taken with a 310-GHz imager are presented. Also dynamic range and standard deviation are presented. These statistical quantities are means to assess the signal-to-noise ratio (SNR) of the imager as well as to evaluate the number of grayscale levels in the image.

INDIRECT HOLOGRAPHIC METHOD

The principle of indirect holographic imaging is shown in Fig. 1. The Gunn-oscillator-based source is connected to a directional coupler which divides transmitter power into the reference field and illuminating field in ratio of 1:10. Both of the source antennas are corrugated horns. The interference pattern is recorded at the aperture by raster scanning a single receiver with an open-ended waveguide as an antenna.

As presented in [2], the interference pattern (1) encloses the complex object field

$$I = |\mathbf{E_o}|^2 + |\mathbf{E_r}|^2 + \mathbf{E_o}\mathbf{E_r}^* + \mathbf{E_o}^*\mathbf{E_r}\,, \tag{1}$$

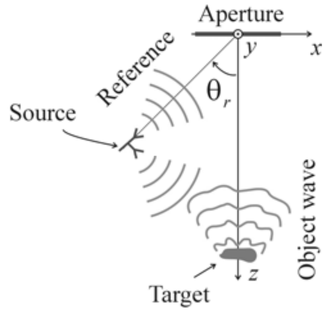


Figure 1: The geometry of indirect holographic imaging

where $\mathbf{E_o}$ and $\mathbf{E_r}$ are the object and the reference fields and * stands for complex conjugate. Further, the object field (2) is retrieved from (1) by using Fourier Transform and the knowledge of the pre-defined reference field

$$\mathbf{E_o} = \left(\mathrm{F}^{-1}\left(\mathrm{F}\mathbf{E_o} \otimes \mathrm{F}\mathbf{E_r}^{*}\right)\right)/\mathbf{E_r}^{*}\,, \tag{2}$$

where F and F^{-1} are Fourier Transform and its inverse, respectively, $\otimes$ stands for convolution. The amplitude of the complex reference field in (2) is measured and the phase is calculated according to the measurement geometry.
The retrieved object field is finally back-propagated to the object as explained in [2].

DYNAMIC RANGE AND STANDARD DEVIATION

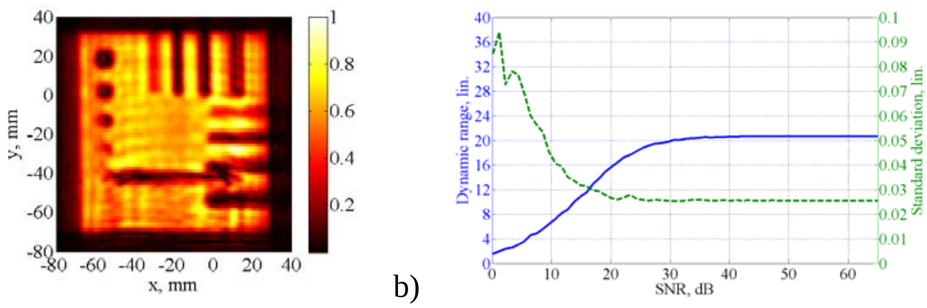
The brightness B of an image is defined as the absolute value of the back-propagated object field. Dynamic range D of the image is the ratio of the mean brightness in the lightest and the darkest areas

$$D = \overline{B}_{light} / \overline{B}_{dark}\ . \tag{3}$$

SNR of the imaging system receiver can be approximated by computationally adding white Gaussian noise N_a in the measured interference pattern with system noise N_s. When $N_a < N_s$, the dynamic range remains constant, and when $N_a > N_s$ dynamic range reduces. The theoretical number of grayscale levels can be approximated by the ratio of dynamic range and standard deviation of the brightness σ_B in dark area of the image.

MILLIMETER-WAVE IMAGES

The 310-GHz millimeter-wave image taken 1.5 m away from the object is presented in Fig. 2 a. The aperture size is 400 x 400 mm^2 yielding theoretical resolution of 2 mm at the distance of the object. The 100 x 100 mm^2 aluminum object consists of 2-8 mm slots and 2-10 mm holes, of which all the slots are discerned. The dynamic range and variance are presented in Fig. 2 b. The dynamic range increases to value of 21, when the SNR is increased to ca. 40 dB, and at the same time σ_B reduces to 0.03. Both qualities also remain at these values, indicating 40-dB SNR of detection to be adequate for high resolution imaging, and also yielding ca. $D/\sigma_B = 807$ grayscale levels in the image.



a) b)

Figure 2: a) Mm-wave image b) D (solid line) and σ_B (dashed line) of the image

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