Transmission System for Terahertz Pre-amplified Coaxial Digital Holographic Imager

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Abstract- **The application of terahertz wave holographic imaging technique in the study of the disease detection has attracted great interest. In this paper, a high-resolution terahertz coaxial digital holographic imaging transmission system operating at 3THz is presented. This design is used in the THz imaging system for the study of the disease detection. The physical optical propagation analysis method (POP) and an advanced three dimensional numerical calculation software MATLAB are used to analyze the results. The simulation results indicate that the design meet the requirement of the proposed system.**

Index Terms — **THz imaging, Digital holography, pre-amplification, spatial resolution, THz propagation.**

I. INTRODUCTION

Currently, THz imaging has received worldwide attention due to its extensive application potentials. Owning to the nondestructive and non ionizing capability, THz imaging shows great application prospects in biomedicine, security, and quality control [1]-[3]. Especially for the occasions where the visible light can't pass through and the contrast radio of the X-ray imaging system is not enough, THz imaging system is almost the only choice. With the development of suitable sources and detectors, there has been much research interest in THz imaging. The first THz imaging system based on electro-optic THz time-domain spectroscopy (THz-TDS) techniques was introduced by Hu in 1995 [4]. Years later, in order to improve the resolution to λ/4, S. Hunsche put forward the THz near-field imaging [5]. Then Mitrofanov reported the improved THz near-field imaging based on photoconductive antenna mechanism [6]. However, due to the long wavelength, the spatial resolution of these THz imaging systems is constrained and the obtained results are blurred. Therefore, improving the imaging resolution and image quality of THz imaging systems is always a research focus.

Digital holography is a new imaging technique, which numerically records the hologram and reconstructs the target from the hologram. Compared with the traditional THz-TDS imaging system, the greatest advantage of holography is that it can perform not only structural imaging, but also functional imaging, which can improve the image quality. Recently, digital holography has become a fast-growing research field with increasing attention [7]-[8]. Mahon carried out off-axis digital holography experiment using a 100 GHz Gunn diode oscillator [9]. However, the resolution of the result is limited by the long wavelength. Usually, the resolution of the system is determined by the numerical aperture of the detector. Nevertheless, the detector applied in THz is still in the earlier stage of commercialization. To achieve high spatial resolution, the recording distance between the object and the detector must be very small, which makes it difficult to realize in practical engineering. Generally, the optical structure can be classified as the coaxial Fresnel digital holographic system without pre-amplified, the lensless Fourier transform digital holographic system, and the pre-amplified off-axis digital holographic system [10].

In this paper, considering the high-resolution, the coherence length and the image reconstruction, the transmission system of the pre-amplified coaxial digital holographic system is presented and numerically evaluated.

II. PRINCIPLE OF THE DESIGN

This article reports on the use of holography and THz techniques to design a transmission system with target specifications of < 100um spatial resolution, a maximum imaging area of Φ10mm×50mm, and 11^0 divergence angle.

The source spot of the system is QCL which resembles a Gaussian distribution. Based on the assumption of the paraxial approximation, the Gaussian beam propagation can be induced. In a homogeneous medium, the propagation of electromagnetic waves can be written by the Helmholtz equation

$$\nabla^2\psi + k^2\psi = 0 \tag{1}$$

Where ψ is the component of E or H. Beam radius along the optical path can be deduced as flow

$$w = w_0[1+(\frac{\lambda z}{\pi w_0^2})^2]^{0.5} \tag{2}$$

The divergence of a Gaussian beam in the far-field region is given by the beam divergence half angle:

$$\theta \approx \frac{\omega(z)}{z} \approx \frac{\omega_0}{z_0} = \frac{\lambda}{\pi\omega_0} \tag{3}$$

In order to give full play to the role of the lens, usually the resolution capability of the detector is chosen to be higher than the lens resolution capability. Therefore, the spatial resolution of the pre-amplified coaxial holographic system is determined by the numerical aperture of the lens. Fig.1 shows the diagram of the pre-amplified coaxial digital holographic system.

The ultimate resolution of the lens and the resolution of the detector are shown as follows

$$\triangle\delta=0.61\frac{\lambda}{\sin\theta}=0.61\frac{\lambda}{NA} \qquad (3)$$

$$\triangle\delta=\frac{1}{M}\frac{\lambda d}{L_{CCD}} \qquad (4)$$

Where $\triangle\delta$ is the spatial resolution, NA is the numerical aperture of the lens, M is the magnification, L_{CCD} is the size of the effective detection area of the detector, d is the record distance.

For the pre-amplified coaxial digital holographic system, the minimum recording distance can be estimated by

$$\frac{1}{2\Delta N}=\frac{2}{\lambda}\sin\frac{\alpha_{\max}}{2} \qquad (5)$$

$$d_{\min}=\frac{MX-L_{CCD}}{2\tan\alpha_{\max}} \qquad (6)$$

Where ΔN is the element size of the plane array detector, X is the size of the sample, d is the distance between the object and the CCD. In order to make the best of the imaging area of the detector, the spot in which all the object light can be received is chosen as the actual recording spot of the whole system, which is shown in Fig. 1.

The actual recording distance and the optical path difference can be estimated by the following equations:

$$d=\frac{MX-L_{CCD}}{MX+D}d_i \qquad (7)$$

$$\Delta L=\sqrt{(\frac{D-X}{2})^2+d_0^2}+\sqrt{(\frac{D+L_{CCD}}{2})^2+d_\phi^2}-d_0-d_\phi \qquad (8)$$

In this system, the Off-Axis-Parabolic (OAPs) are used to change the direction of the optical and make the beam parallel. Fig.2 shows the parameters of the 90° off-axis parabolic mirror. Parabolic mirrors are the most common type of aspherical mirrors used in optical instruments. They are free from spherical aberration and thus focus the parallel beam to a point or point source to infinity. In some applications the central part of the mirror obscures the beam path and therefore distorts the beam. For such systems, off-axis mirrors offer many advantages versus the traditional paraboloids, including minimized system size and cost.

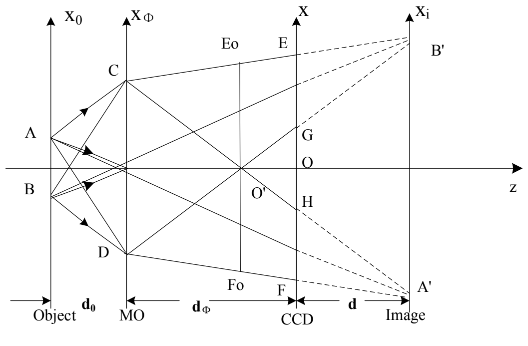

Figure 1.The diagram of the pre-amplified coaxial digital holographic system

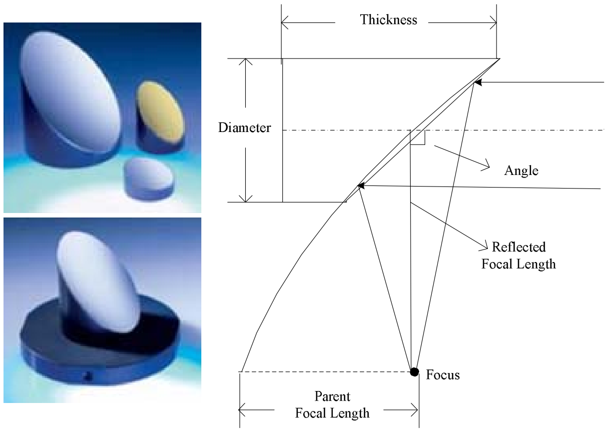

Figure 2. The 90° off-axis parabolic mirror

Following the previously introduced processes, The structure of the pre-amplified coaxial digital holographic system is shown in Fig. 3.The key parameters of the pre-amplified coaxial digital holographic system can be determined. And the parameters are presented in Table I.

III. SIMULATION VERIFICATION

Following the process previously introduced, the whole transmission system can be established, which is shown in Fig. 4. A POP method is used to analysis the results of the system. Fig.5-Fig.9 shows the irradiance and beam size in each surface.

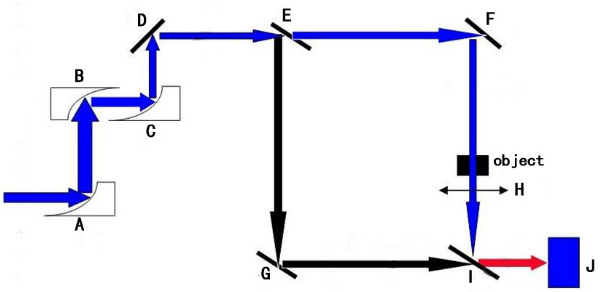

Figure 3.The optical structure diagram of the pre-amplified coaxial digital holographic system. (A,B,C: OAP, D,F,G: mirror, E:splitter, H: lens, I: combiner, J:detector.)

TABLE I

PARAMETERS OF THE TRANSMISSION SYSTEM

λ	X	M	NA	L_{CCD}
100um	10mm	6	0.8	10mm
•δ	D	d_0	d	•L
76um	40mm	15mm	45mm	12.7mm

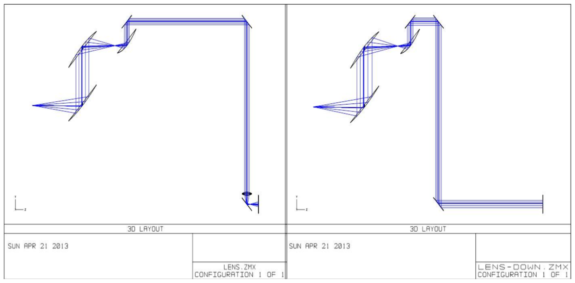

Figure 4.The diagram of the transmission part of the pre-amplified coaxial digital

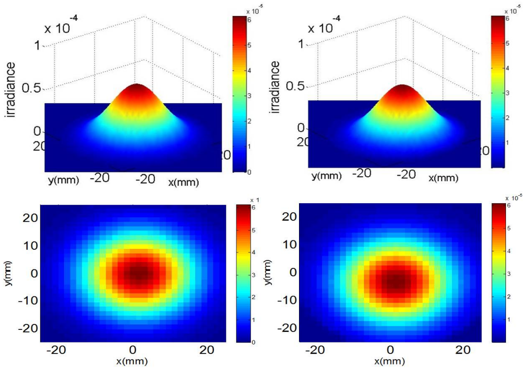

Figure 5. The irradiance and beam size on the surface A and B.

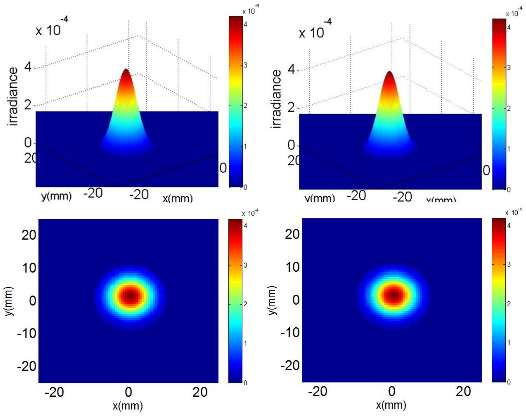

Figure 6. The irradiance and beam size on the surface C and D.

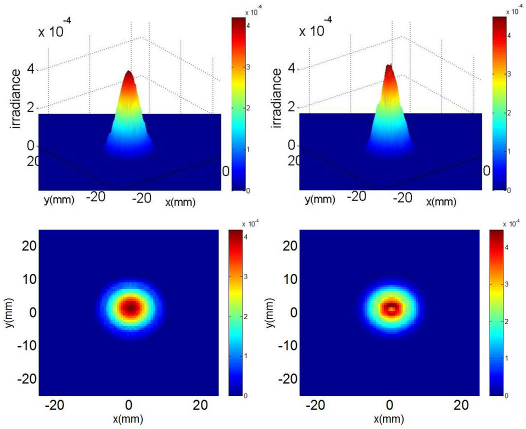

Figure 7. The irradiance and beam size on the surface E and F.

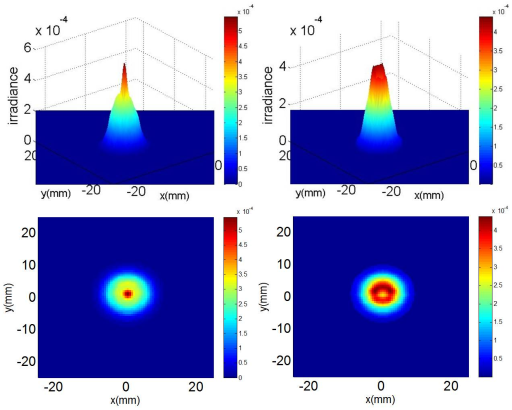

Figure 8. The irradiance and beam size on the surface G and H.

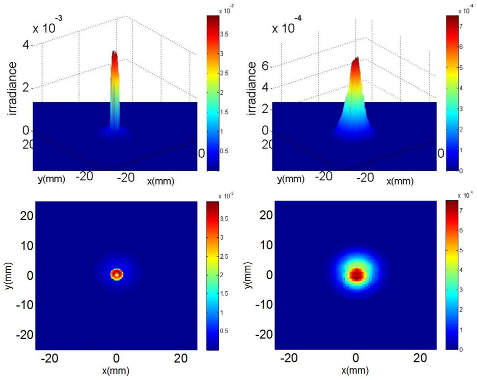

Figure 9. The irradiance and beam size on the surface I and J.

From the figures we can see that the THz beam transmits through the whole system successfully with no large scattering, and the beam size reaches the requirements.

IV. CONCLUSION

This paper presents the design of the transmission system for the THz pre-amplified coaxial digital holographic imager. The system is simulated by a three dimensional visual software, and an advanced numerical calculation software MATLAB is used to analyze the results. The simulated results are presented, and the required specifications are acquired.

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