THz fiber-based swept-source imaging radar

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Abstract: We demonstrate an all-THz fiber-based swept-source imaging radar system. Our experiment shows that this radar can be used in real time to nondestructively detect and locate the concealed living objects with high stability and sensitivity.

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1. Introduction

An area of increasing interest in recent years has been the use of THz radiation for imaging technology. Due to the transparency characteristic of THz radiation to dry, nonmetallic, and non-polar substances such as paper, plastics, wood, leather, cloth, cardboard, and smoke, THz has been proved to be a powerful tool for concealed object detection and imaging [1,2]. For advanced THz imaging applications, a fiber-based system [3], which is well-known to be reliable and compact in the optical wavelength range, will be highly desirable. In this presentation, we will demonstrate an all-THz fiber-based swept source imaging radar system operated at room temperature with a THz fiber-based directional coupler. The system is similar to the swept source optical coherence tomography (SS-OCT) [4,5], but photonically different from the traditional all-electronic based radar. With the demonstrated real-time imaging radar, we successfully located the position moving of concealed living objects.

2. Experimental setup and results

Fig. 1(a) shows the schematic diagram of the demonstrated imaging radar system. With a tunable voltage from 0 to 7 volt applied to the YTO, microwave with a frequency in the K-band generated from the YTO was fed into several active and passive microwave components and finally delivered into a pyramidal horn antenna for CW THz wave radiation ranging from 108 to 143GHz. Fig. 1(b) shows the YTO's output frequency as a function of driving voltage. High tuning linearity was observed. The time for sweeping the entire 35 GHz bandwidth is 50ms. By tuning the angles with θ_1 about 10° and θ_2 about 12° shown in Fig. 1, large portion of power was transmitted to the sample arm. The measured intensity at the THz detector can be calculated as:

$$I = I_{ref} + I_{sample} + 2\sqrt{I_{ref} I_{sample}} \cos(2\pi(\Delta\varphi)), \qquad (1)$$

Where I_{ref}, I_{sample} are the detected THz intensities from the reference and sample arms respectively without considering the interference effect, and $\Delta\varphi$ is the phase difference between these two arms which determines the interference effect. In our experiment, when using a high scattering sample, I_{sample} is usually much smaller than I_{ref}, which means I_{sample} can be neglected under such a condition. The mouse' skin is wrinkle with a high water content, which is highly reflecting and scattering. By Fourier transforming the difference between the result and the reference we can clearly identify and locate the position of the object, for example a living mouse.

We applied this fiber-based swept source imaging radar to detect the location of a living mouse inside an optically-opaque cardboard box. By fast sweeping the THz frequency accompanied with rotating the parabolic mirror in 85.5° (96 line scans), we can obtain a two dimensional THz radar image in less than 7 seconds. With a high refractive index in this wavelength regime [6], water provides strong back reflection and this specific radar system can thus provide strong contrast for living object imaging. Thus developed system also showed high stability. The image varied only when the sample object moved with time. This real time imaging capability made distinguishing a moving living object easier. As shown in Fig. 2 (d) and (e), the real time THz swept-source radar images not only successfully revealed the location of a mouse hidden inside a cardboard box, but also its movement with time.

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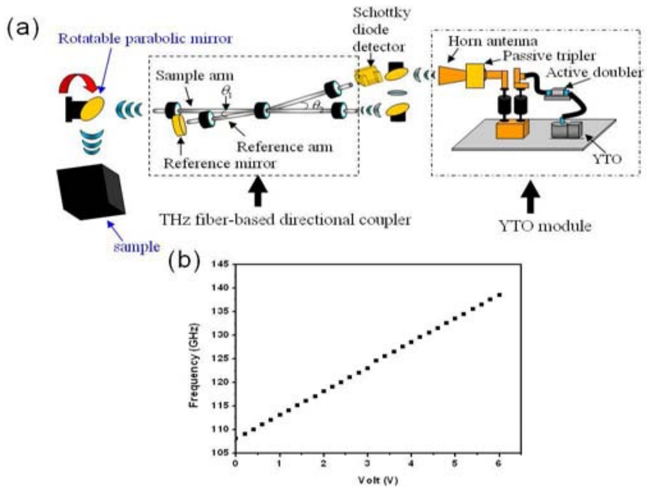

Fig. 1. (a) The schematic diagram of the THz fiber-based swept source imaging radar system. (b) The output frequency of the YTO module as a function of the driving voltage. High linearity can be observed.

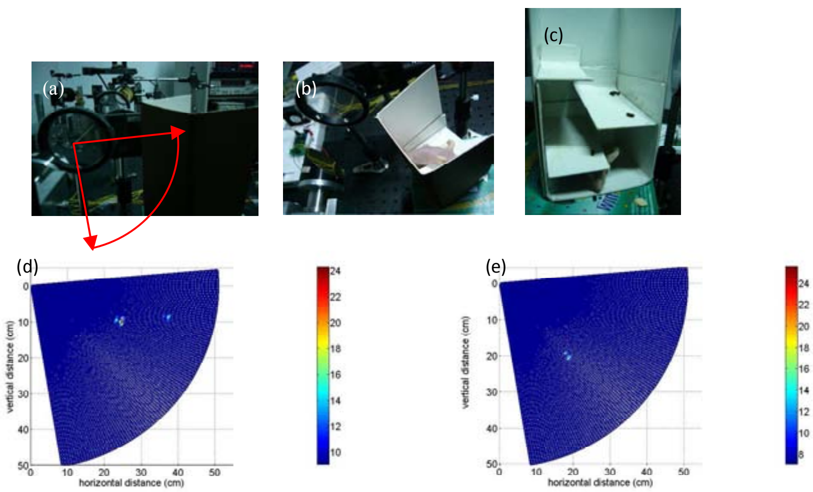

Fig. 2. THz fiber-based swept source radar images. (a) – (c) Photographs of the THz fiber-based swept-source image radar and the imaged mouse object. (d) and (e) shows the acquired real-time radar images with a time difference of 20 seconds. The location and the movement of the hidden mouse can be clearly identified.

In conclusion, we have demonstrated an all-THz fiber-based swept source imaging radar system which is simple, easy to implement, compact with a high imaging speed, and is less vulnerable to environmental disturbance. We successfully located the position of living objects with a strong water contrast noninvasively through the obtained fast 2D THz images. Moving and stationary objects can be easily distinguished due to the high stability and sensitivity of this system, which could be ideal for various ranging and sensing application, including living object identification in heavy smoke and various molecular and security applications.

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