令和６年度　未来研究ラボシステム　研究成果報告書

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研究課題名：テラヘルツセルフミキシング信号の干渉・偏光情報によるターゲット認識

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研究成果：

(概要)

Terahertz (THz) sensing offers a wide range of potential applications for its high resolution and transparency. However, the integration and cost reduction of THz transceivers remain significant challenges. With this project, we present an integrated THz sensing system enabled by a resonant tunneling diode (RTD) transceiver and MHz-band circuits. The system operates a single RTD as a THz-band self-oscillating mixer and a tunable oscillator simultaneously. As a proof of concept, the proposed system achieved sub-millimeter resolution 3D imaging and thin-layer estimation down to 12 μm at the 240-GHz band using the radar interferometric technique. Furthermore, the polarimetric technique is introduced to distinguish targets with different physical properties.

(本文)

As outlined in the summary, this research will **focus on two key areas of development:**

(a) A compact THz sensing module utilizing a single RTD

Building upon the progress made during FY2024, **the RTD imaging system has been further integrated using a customized FPGA board instead of the experimental setup using expensive equipment** such **as** oscilloscope. The concept of the proposed system was initially introduced in [3] and previous reports, with the system configuration summarized in **Fig. 1.** By leveraging the unique characteristics of the RTD, the entire THz-band frequency-modulated continuous wave (FMCW) radar imaging system has been miniaturized into a compact, portable form factor, as shown in **Fig. 2.** Since both the bias signal and the detected self-mixing signal remain below 1 MHz, the system can be seamlessly integrated onto a customized circuit board. Data acquisition is performed using a commercial MHz-band FPGA board, with further signal processing carried out on a connected laptop.

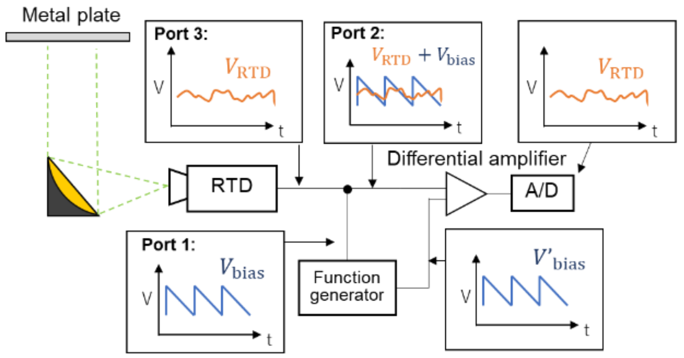


Fig. 1 Concept the FMCW radar using an RTD transceiver. The RTD module was connected to Port 3 of a T-bunch, which was used to provide bias voltage V_{bias} to the RTD module at Port 1. Both voltage of the self-mixing signal V_{RTD} and V_{bias} were detected at Port 2. A differential amplifier was employed to extract V_{bias} using a synchronized channel V'_{bias} from a function generator.

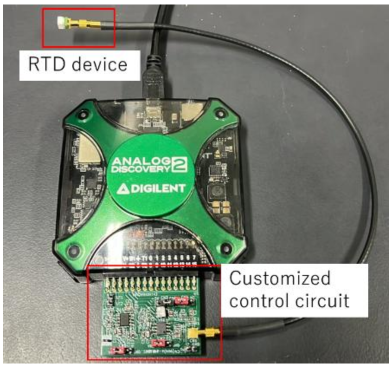


Fig.2 The integrated RTD sensing system, which can be applied for the 3D imaging and precise thickness measurement by connecting to a laptop, as introduced in section (b).

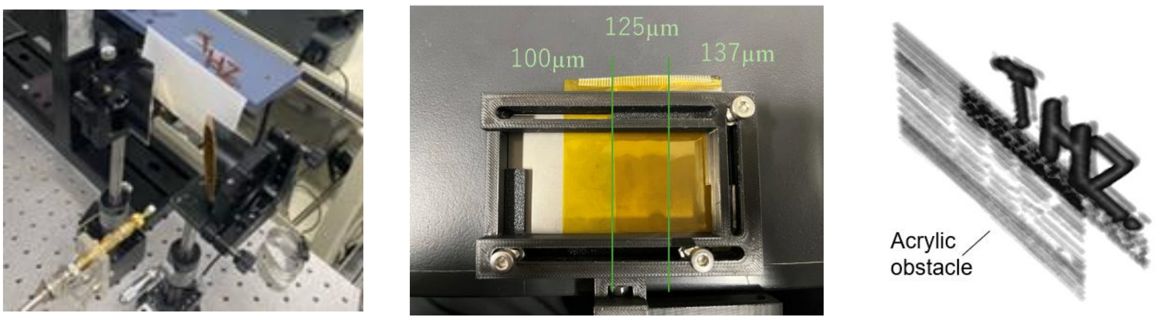
(b) Interferometric and Polarimetric Signal Processing for THz Band Sensing Applications

As shown in **Fig. 1**, the proposed system generates and detects THz band chirp signals with a ~10 GHz bandwidth, enabling FMCW radar signal acquisition using a single RTD. The interferometric radar signal allows for 3D imaging, as illustrated in **Fig. 3**. However, the limited bandwidth of RTD still cannot compete with THz systems utilizing expensive photonic technology.

To enhance sensing capabilities, an interferometric radar technique was introduced for detecting minor displacements and thickness variations. This method measures the phase delay of the self-mixing signal relative to a reference signal obtained from a position where no displacement or thickness change occurs.

The high SNR of the RTD self-mixing signal enables precise detection of thickness variations with the experimental configuration shown in **Fig.3(a)**. The model was made by stacking three layers material as shown in **Fig.3(b)**, and a minimum displacement of 12 μm can be detected.

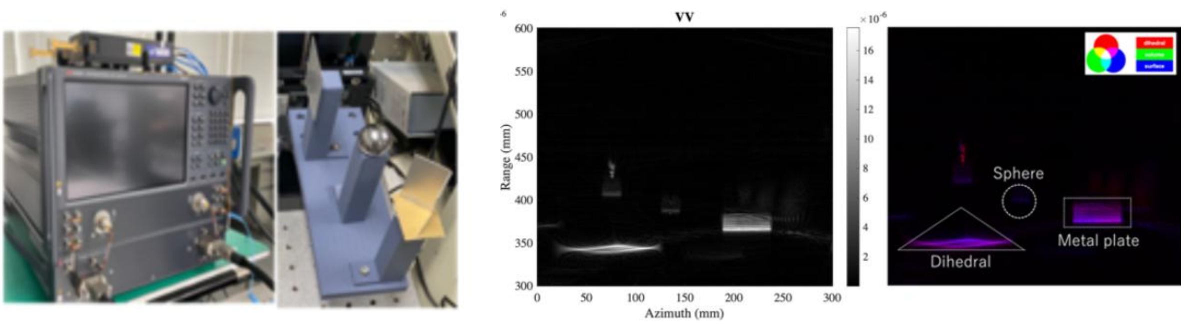
Additionally, the interferometric technique has been successfully applied to 3D imaging applications. As demonstrated in the system configuration and imaging results shown in **Fig. 3(c)**, the 3D imaging through an acrylic plate can be achieved with a spatial resolution of ~2 mm.



(a) (b) (c)

Fig. 3 (a) Imaging/sensing configuration using the proposed system; (b) layer material model used for the thickness measurement; (c) 3D imaging result including an obstacle at the front. The target consists of three characters, "THZ" made using a 3D printer, with a width of 15 mm.

In addition, we developed a Vector Network Analyzer (VNA)-based THz polarimetric imaging system at NICT. This system enables precise extraction of phase information from THz band mixing signals, allowing for the retrieval of polarimetric data to distinguish different target shapes, as demonstrated in the preliminary results shown in Fig. **4**. However, the polarimetric imaging results using the RTD device is still under investigation.



(a) (b) (c)

Fig.4 THz imaging using VNA system; (a) experiment setup; (b) conventional imaging result; (c) target classification using polarimetric information.

研究経費（R6 年度）の内訳 ：

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0 円	241,129 円	369,143 円	円	139,728 円	750000 円

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N/A

発表論文等（令和 7 年 3 月 31 日現在）：

〔雑誌論文〕

N/A

〔著書〕

N/A

〔学会発表〕

[1] Suyun Wang, Li Yi, Study on Terahertz Polarimetric Imaging for Target Recognition、シンポジウム「テラヘルツ科学の最先端 X」、2023/12/20.

[2] L. Yi, Y. Inuse, N. Ngo, S. Wang, Y. Nishida, M. Fujita "Resonant Tunneling Diode Transceiver For Integrated Terahertz Band 3D Image Sensor," in 2024 49th International Conference on Infrared, Millimeter and Terahertz Waves (IRMMW-THz), Perth, Australia, 2024. (Keynote)

〔その他〕

[1] JST 新技術説明会で発表（https://shingi.jst.go.jp/list/list_2023/2023_osaka-u.html）
[2] 易利・水野遼子・冨士田誠之「信号検出装置」特願 2022-131358
[3] 易利・猪瀬裕太・冨士田誠之「信号補正装置および信号補正方法」特願 2023-210597
[4] Li Yi, Ryoko Mizuno, Masayuki Fujita, “Signal Detection devices and signal detection method”, US Patent Application, 18/995602

外部資金獲得状況・申請状況 ：

2025 企業共同研究

2025 科研費基盤研究 B（分担）

参考となる HP 等 ：

N/A