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THz time domain monostatic radar cross section measurement of metallic plates and dihedrons

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Abstract: THz Radar Cross Section(RCS) measurement setup based on THz Time Domain Spectroscopy (TDS) is built to provide large scaled targets test ability in recent years. As calibrations, the metal plates and dihedrons are used in our experiments. The measurements are performed in a monostatic terahertz time-domain setup. The author proposed time domain and frequency domain calibration methods for angular RCS of calibrations, comparing the measurements with the theory to verify the ability of the time domain measurement setup.

Keywords: monostatic Radar Cross Section; Terahertz; metallic plates and dihedrons; THz Time Domain Spectroscopy
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1 Introduction

Radar Cross Section(RCS) measurement in THz band is attractive due to large scale factor in the higher frequencies[1-2]. Kinds of experiment setups are built to evaluate the scattering properties of military targets like tanks, aircrafts and warships etc[3-5]. Submilimeter-wave Technology Laboratory(STL) at UMass Lowell has developed 1.56 THz full polarimetric compact range using two far-infrared lasers to pump the THz transitions in the molecular gases difluoromethane and methanol. The output THz beam with Gaussian modes is typically 100 mW of power and the noise floor is about −65 dBsm[6]. The bandwidth is 10−18 GHz produced by microwave sweeper. The RCS and International Society for Astrological Research(ISAR) imagery of complex target simulator are measured and compared to numerical predictions to demonstrate the experimental ability[7]. Harbin Institute of Technology proposed a 2.5 THz measurement setup using only one THz gas laser to detect the magnitude of scattering signals without phase information[8].

Three kinds of THz RCS measurement technologies, viz. microwave up-conversion, laser down-conversion and terahertz time-domain spectrum. Microwave up-conversion can be used for low-frequency dual-station test. Laser down-conversion has a single frequency point and cannot obtain the RCS of a wide spectrum. There are also solid RCS systems in the lower THz range which using cascade multiplier chains and vector network analyzer to cover frequencies below about 600 GHz. The measured RCS and ISAR imagery are calibrated by metallic plate and dihedron etc in the frequency domain like the microwave regime. But the above systems cannot work at high frequencies and provide broad bandwidth simultaneously. Then time domain THz bistatic RCS measurement setups which consist of broadband emitter are proposed for high frequencies[9]. Based on the optical pump and optical probe coherent setup, time profiles of backscattering THz pulses are recorded. Though the RCS and ISAR imagery of metallic plate and scaled models are tested, there still lacks of high angular resolution RCS results of large targets with calibration.

In this paper, we propose time domain and frequency domain calibration methods for angular RCS of metallic plate and dihedron based on the measurement results of a monostatic THz RCS time domain setup.

2 Experiment setup

A monostatic terahertz time domain RCS measurement setup is built to record the reflected by the target model. The traditional THz time-domain spectroscopy technology mainly uses point illumination targets for measurement, while the

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terahertz time-domain spectroscopy RCS measurement system ensures full illumination of the target[10]. Secondly, the RCS measurement system requires that the THz wave reflected by the target model coincides with the THz incident wave to achieve monostatic RCS measurement, whereas the conventional reflective terahertz time-domain spectroscopy system emits and receives signals at a certain angle. The beam splitter of monostatic system will lose the power of the terahertz wave, resulting in a lower signal to noise ratio.

THz pulses from the backscattering surface of targets is shown in Fig.1[11]. The laser beam outputted from the femto-second laser with central wavelength 800 nm is split into bump beam and probe beam by beam splitter. The bump beam is incident on the THz wave generator which consists of photoconductive antenna and off-axis parabolic lens. Then the collimated THz beam illuminates targets which locate at the high precision rotator uniformly. The probe beam is phase retarded by time delay line and then overlapped with THz beam at the surface of THz detector. The silicon plate is used as THz beam splitter which converts the angle between illuminating beam and reflect beam to 0.

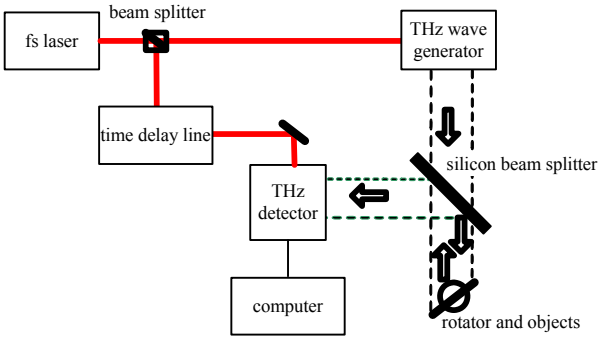


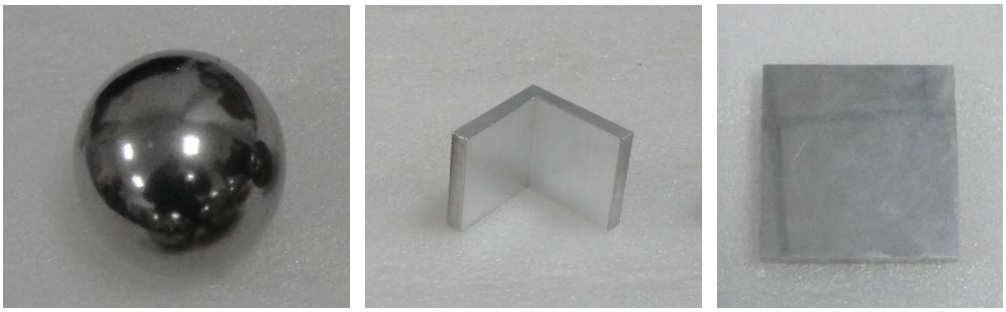
Fig.1 THz-TDS RCS monostatic setup

3 Experimental results of RCS measurement of metallic plates and dihedrons

3.1 Sample preparation

Metallic targets with analytical RCS like spheres, plates and dihedrons which are shown in Fig.2 are usually fabricated for calibration[12-13]. In the THz regime, surface roughness of targets plays significant roles on the electromagnetic scattering besides the geometry of targets due to the comparable wavelength of incident beams. According to Rayleigh criterion, the RCS of targets surfaces need to be smaller than $\lambda/8$.

The surfaces of targets are carefully polished and positioned at the low reflectivity holder made of polyethylene.



(a) metallic sphere (b) dihedron (c) plate with polished surface

Fig.2 Different metallic targets

3.2 Calibration methods in time domain and frequency domain

In the measurements, the reflected THz pulse signals of targets and background are recorded. The targets signals need to be calibrated by comparing to the relative amplitude of a selected stander target detected by the same THz TDS setup[2].

At the desired frequency, the frequency domain RCS can be defined as the follow[14]:

$$\sigma_{\omega}=\sigma_{\mathrm{cal}}(\omega)\frac{\left|E_{\mathrm{tgt}}(\omega)\right|^{2}}{\left|E_{\mathrm{cal}}(\omega)\right|^{2}-\left|E_{\mathrm{bg}}(\omega)\right|^{2}} \tag{1}$$

where $E_{\mathrm{tgt}}(\omega)$, $E_{\mathrm{cal}}(\omega)$ and $E_{\mathrm{bg}}(\omega)$ are the Fourier transform of time domain signals of targets, calibrated target and background. $\sigma_{\mathrm{cal}}(\omega)$ is the known RCS value of calibration target at the desired frequency.

The maximum value of angular RCS of a polished metallic plate when the surface of plate is perpendicular to LOS is used as known value. It can be calculated as the following equation.

$$\sigma = \frac{4\pi A^2}{\lambda^2} \tag{2}$$

where A is the area of rectangular plate surface, λ is the wavelength of the illuminating frequency.

The value of angular RCS of a polished metallic dihedron can be calculated as the following equation.

$$\sigma(\theta) = 2\sin^2\theta \frac{8\pi a^4}{\lambda^2} \tag{3}$$

Where a is the length of metallic dihedron, λ is the wavelength of the illuminating frequency.

3.3 Results of the measurement

3.3.1The frequency-domain measurement of terahertz signal source

The THz pulse time-domain signal reflected from a silver mirror at one azimuth angle is shown in Fig.3. The frequency domain test results of the time domain signal which is shown in Fig.4 can be obtained by Fourier transform. It shows the spectrum range of the terahertz source is 0.1–3 THz and the magnitude at 0.7 THz and 1.7 THz significantly shift down. This is due to the absorption of the water vapor.

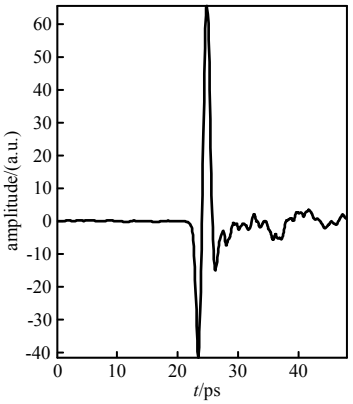


Fig.3 THz pulse time-domain signal

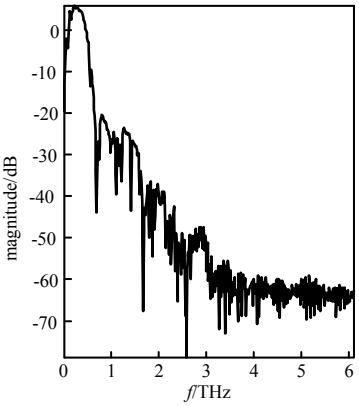


Fig.4 Frequency domain test results

3.3.2Angular scattering of metallic sphere

The THz pulse signals reflected from a metallic sphere with diameter of 7 cm at varied azimuth angles are shown in Fig.5. It shows the time domain profiles are slightly different due to the position precision. But the signal noise ratio is too low to be calibration reference.

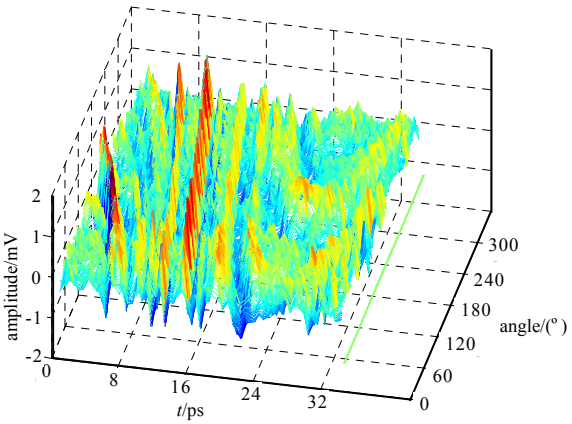


Fig.5 Reflected signals of a sphere

3.3.3Angular frequency domain RCS of metallic plates

The azimuth scattering signals of metallic rectangular plates with width of 5 cm are measured by using high precision controllable rotator. The angle resolution of rotator is 0.05° which is smaller than the main lobe width of RCS of plate at the high THz frequencies.

In the measurement, the position of plates where the magnitude of reflect pulse is the highest is sought and defined as the origin of azimuth angle and elevation angle.

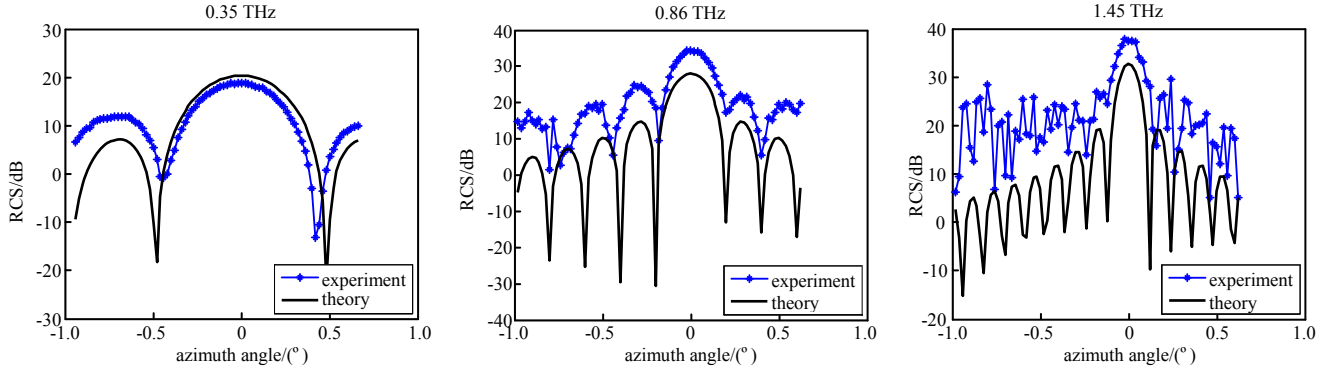


Fig.6 The calibrated RCS value of plate with width of 5 cm

From Fig.6, we can see the value and trend around main lobe of measured RCS of metallic plate agree with the theory results in the lower THz regime. At higher frequencies, the measured RCS at large azimuth angle is above the theory

results about 20 dB. This is due to the limited dynamic range of the system. The width of lobes are broadened and the profiles are asymmetrical around 0°. This is due to the non-uniformity of the THz wave.

3.3.4Angular frequency domain RCS of metallic dihedron

The azimuth scattering signals of metallic rectangular dihedrons with width of 5 cm are measured by using high precision controllable rotator. The angle resolution of rotator is 2° from 0° to 90°.

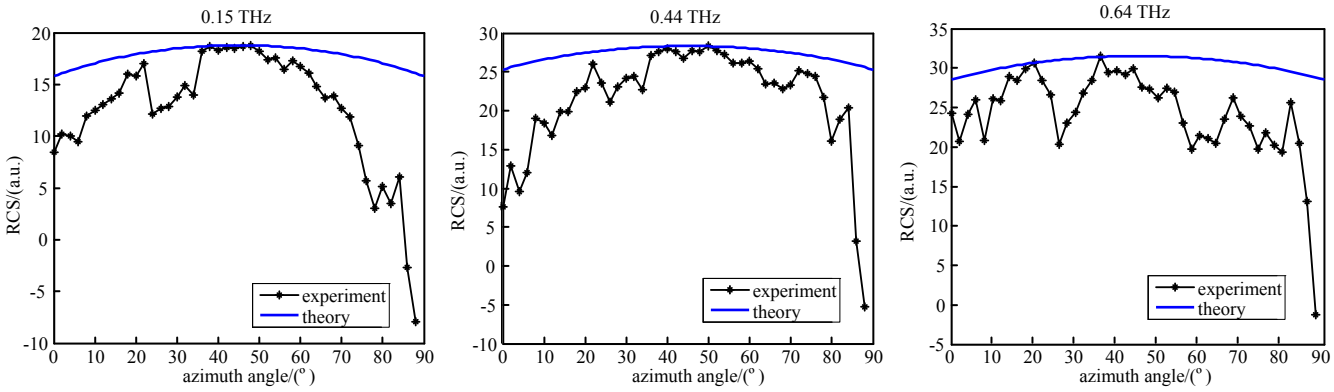


Fig.7 Calibrated RCS value of dihedron with width of 5 cm

From Fig.7, we can see that the value and mild trend of measured RCS of metallic dihedron agree with the theory results in the lower THz regime and the value of measured RCS drops quickly when azimuth angle is 90°. The measured RCS at each azimuth angle is above the theory results about 5–10 dB. The variation trend of measured RCS is not consistent with the trend of the variation of the adjacent azimuth angle at each frequency from 24° to 34°. This is due to the change of the photoelectric resistance of the system. Additionally, the center of the rotating shaft and the center of the sample are not completely overlapped.

4 Conclusion

In this paper, the monostatic THz time domain radar cross section measurement setup is built to detect electromagnetic scattering properties of targets. The RCS of plates and dihedrons at desired frequency are retrieved from the time domain signals and calibrated with the theoretical values. The high angular resolution RCS of metallic plate and high range RCS of dihedrons show the ability of the time domain measurement setup.

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International Workshop on Edge Intelligence and Computing for IoT Communications and Applications

November 16/17, 2019, joint with IoTaaS 2019, Xi'an, China

Nowadays, billions of IoT devices, e.g., sensors and RFIDs, arise around us providing not only computingintensive, but also delay-sensitive services, ranging from augmentedirtual realities to distributed data analysis and artificia intelligence. Unfortunately, in many application scenarios, the low response latency for IoT services are achieved at the cost of computing-complexity that far exceeds the capabilities of IoT devices. To feed this trend, multiple computing paradigms emerge, such as mobile transparent computing, edge computing, fog computing and big data analytics based framework. These paradigms employ more resourceful edge devices, e.g., small-scale servers, smart phones and laptops, to assist the low-end IoT devices. By offloading the computing-intensive tasks to the edge devices, it is expected to converge the data collection at IoT devices and the data processing at edge devices to provision computing-intensive and delay-sensitive services. However, lots of issues remain in the application of edge computing which impede its flourish in IoTs.

This workshop will solicit original research and practical contributions which advance the computing offloading and edge intelligence regarding the architecture, technologies and applications. Surveys and state-of-the-art tutorials are also considered. This workshop aims to bring together the active researchers in this field to share their timely and solid works on the Edge Intelligence and Computing for IoT Communications and Applications. Through this forum, it is expected to provide a comprehensive overview on this topic and inspire more valuable research orientations.

Topics of Interest:The topics related to the Edge Intelligence and Computing for IoT Communications and Applications include(but are not limited to):

•Architecture design for edge computing and intelligence in IoTs
•Data-driven energy consumption and delay model of edge computing in IoTs
•QoS-aware computing offloading in IoTs
•Edge intelligence and computing software design in mobile IoTs
•The management of software in edge intelligence and computing for IoTs
•Communication protocol design for edge intelligence and computing in IoTs
•Convergence of energy harvesting and computing offloading in IoTs
•Security, privacy, integrity, and trust in IoT computing offloading
•Hardware design and prototyping for edge intelligence and computing in IoTs
•Testbeds and simulation platforms for edge intelligence and computing in IoTs
•Big data framework and analytical optimization for edge intelligence and computing in IoTs
•Key scenarios/applications for edge intelligence and computing in IoTs(e.g., connected vehicles). Green network design and optimization for IoT