proceedings

Abstract

Understanding and Controlling Interference in Sub-Terahertz Wave Measurements

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† Kobe, Japan, September 15 to 19, 2025

Abstract: Interference caused by multiple reflections is a critical issue in transmission measurements using continuous wave (CW) terahertz and sub-terahertz radiation. This study proposes a practical method to reduce interference effects and improve the stability of transmittance measurements. By deriving analytical expressions for interference patterns under both normal and oblique incidence conditions, we demonstrate that oblique incidence simplifies the interference behavior and allows reliable extraction of transmittance values from maximum and minimum signal intensities. Using a 95 GHz CW oscillator and a 1 mm-thick PET sample, we conducted transmission measurements while varying the detector position. The derived method enabled the calculation of interference-free transmittance values that were consistent across different sample positions. This approach offers a practical technique for material characterization, especially in applications such as nondestructive testing and plastic recycling.

Keywords: Sub-teraherz, Continuous wave, Interference, Plastic

1. Introduction

In recent years, nondestructive testing (NDT) technologies have expanded their applicable frequency range from the mid-infrared to the far-infrared regions, including terahertz (THz) and sub-terahertz (sub-THz) waves. Notably, THz radiation can couple with whole-molecule vibrations, while sub-THz waves couple with phonon vibrations. These features make them promising for novel inspection techniques in structural health monitoring and materials recycling [1].

Among various THz sources, single-frequency continuous wave (CW) oscillators—based on semiconductor devices—offer a simple and cost-effective alternative to Fourier Transform Infrared Spectroscopy (FTIR), particularly since they do not require interferometers. However, CW systems are highly susceptible to interference caused by multiple reflections, which compromises measurement stability. Addressing such interference is essential for accurate characterization of material properties and reliable inspection [2].

This study investigates interference mitigation methods in transmission measurements using sub-THz CW devices. A practical method for transmittance measurement and associated data processing is proposed to suppress interference effects and enhance measurement reproducibility.

Citation: To be added by editorial staff during production.

Academic Editor: Firstname Lastname

Published: date

2. Methods

2.1. Interference in Reference Measurements

When performing reference measurements (i.e., without a sample), interference arises from reflections between the oscillator and the detector (Figure 1) [3]. The complex amplitude of the transmitted wave can be written as:

$$t = t_1 t_4 / \{exp[i(-\phi)] + r_1 r_4 exp[i(\phi)]\}$$

The detected intensity $T = |t|^2$ is:

$$T = \frac{{t_1}^2 {t_4}^2}{1 + {r_1}^2 {r_4}^2 + 2 r_1 r_2 cos2\phi}$$

By moving the detector, the minimum (T_{min}) and maximum (T_{max}) intensities can be obtained. Using these, the interference-independent product ${t_1}^2 {t_4}^2$ can be estimated as:

$${t_1}^2 {t_4}^2 = \left(1 - \frac{\sqrt{T_{max}/T_{min}} - 1}{\sqrt{T_{max}/T_{min}} + 1}\right)^2$$

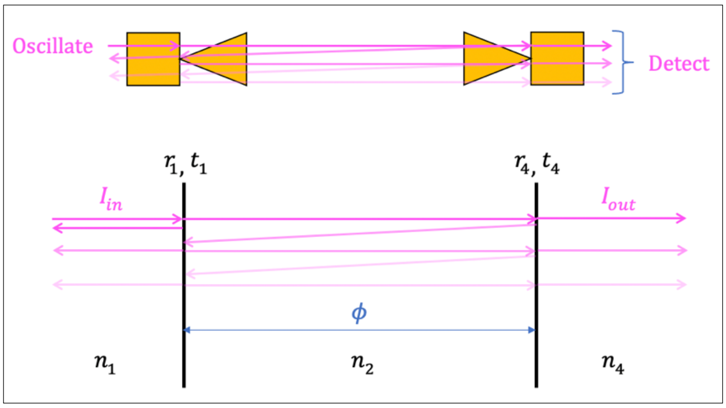

Figure 1. Interference model for the reference measurement without a sample.

2.2. Interference in Normal Incidence Sample Measurements

For transmittance measurements with normal incidence, multiple reflections occur at the four interfaces of the oscillator, sample, and detector. The transmitted amplitude becomes a complex sum involving the phase terms ϕ_1, ϕ_2, and ϕ_3, leading to a complicated interference pattern. Due to this complexity, interference effects cannot be easily canceled using extreme values as done in the reference case [3] [4].

2.3. Interference in Oblique Incidence Sample Measurements

To simplify the interference, measurements were performed with an oblique incidence (e.g., 45°) (Figure 2). In this configuration, some reflected components are redirected away from the detector, reducing the number of interfering terms. The transmission amplitude is then:

$$\begin{gathered} t = t_1 t_2 t_3 t_4 / \{exp[i(-L)] \\ + r_2 r_3 exp[i(-L + 2\phi_2)] \\ + r_1 r_4 exp[i(L)] \\ - r_1 r_3 r_4 exp[i(L - 2\phi_2)] \end{gathered}$$

Here, $L = \phi_1 + \phi_2 + \phi_3$. The detected intensity $T = |t|^2$ becomes:

$$T = (t_1 t_2 t_3 t_4)^2 / D$$

with:

$$D = \alpha + \beta cos(\delta(L))$$

Assuming $r_i < 1$, we approximate $\alpha \approx 1$, allowing the interference-independent transmittance to be calculated as:

$$(t_1 t_2 t_3 t_4)^2 = \frac{2 T_{max} T_{min}}{T_{max} + T_{min}}$$

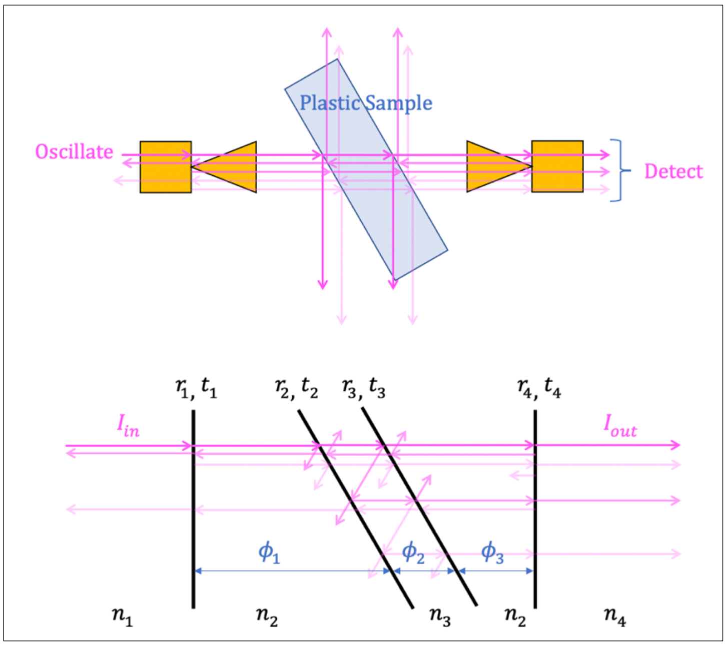

Figure 2. Interference model for transmission measurement of a sample under oblique incidence.

3. Transmission Measurement and Data Processing

Transmission measurements were conducted using a 95 GHz CW oscillator (Figure 3). A 1 mm thick PET plate was used as the sample, and reproducibility was evaluated at different sample positions.

The detector was motorized and moved over a 2 mm range—sufficient to capture a full interference cycle (greater than half-wavelength). Voltage data were recorded, and the transmittance was calculated using the maximum and minimum values obtained during movement. The angle of incidence was set to 45°.

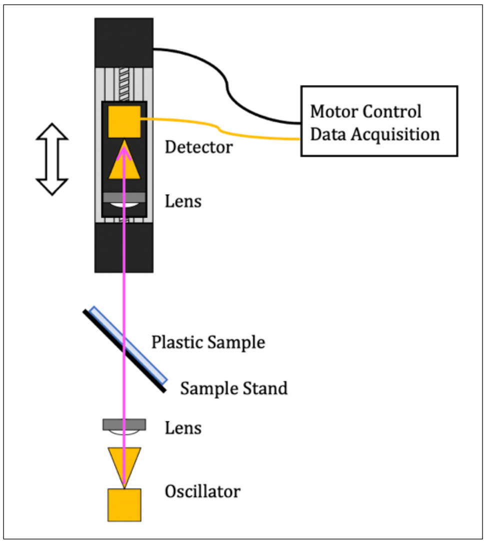

Figure 3. Experimental setup for transmission measurement of plastic samples.

4. Results

Figure 4 shows the calculated transmittance values at various sample positions. The results confirm that the proposed method yields stable and reproducible transmittance measurements, irrespective of the sample's position, by effectively suppressing interference.

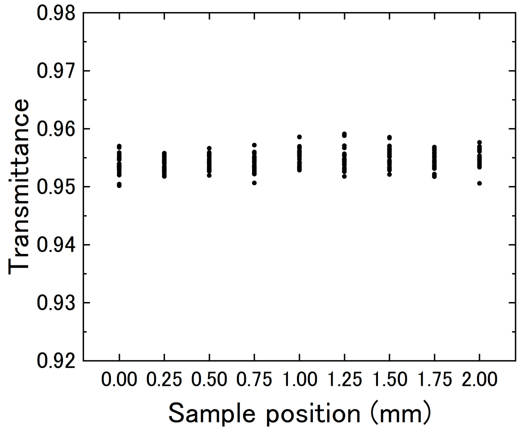

Figure 4. Measured transmittance of the PET sample at each sample position

5. Conclusion

In this study, we addressed the problem of interference in transmission measurements using sub-terahertz continuous wave radiation. We derived interference equations for both reference and sample measurements and proposed a method to eliminate interference effects by analyzing maximum and minimum voltage values. Notably, we found that using oblique incidence simplifies the interference pattern, allowing for more accurate and reproducible transmittance measurements. Experimental validation using a 1 mm PET plate and a 95 GHz oscillator confirmed that our method provides stable transmittance results, independent of sample position. These findings contribute to improving the reliability of CW-based terahertz and sub-terahertz inspection technologies and hold potential for broader application in material inspection, especially for non-destructive testing and plastic recycling.

Author Contributions: Con-ceptualization, T.D.; methodology, T.D.; software, T.D. and S.M; validation, T.D.; formal analysis, T.D.; investigation, T.D.; resources, T.D.; data curation, T.D.; writing—original draft preparation, T.D.; writing—review and editing, T.D. and T.T.; visualization, T.D.; supervision, T.D.;

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Dataset available on request from authors.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Okubo, K.; Manago, G.; Tanabe, T.; Yu, J.; Liu, X.; Sasaki, T. Identifying plastic materials in post-consumer food containers and packaging waste using terahertz spectroscopy and machine learning. *Waste Manage.* **2025**, *196*, 32–41. https://doi.org/10.1016/j.wasman.2025.02.018
2. Li, C.; Zhao, C.; Ren, Y.; He, X.; Yu, X.; Song, Q. Microwave traveling-standing wave method for density-independent detection of grain moisture content. *Measurement* **2022**, *198*, 111373. https://doi.org/10.1016/j.measurement.2022.111373
3. van de Stadt, H.; Muller, J. M. Multimirror Fabry–Perot interferometers. J. Opt. Soc. Am. A 1985, 2, 1363–1370. https://doi.org/10.1364/JOSAA.2.001363
4. L. Wang; R. Zhou; M. Li; M. -Y. Li; X. Wen; H. Lu Asymmetric Reflection Spectrum of Fabry-Perot Interferometer and the Application in Pressure Sensing. *Journal of Lightwave Technology* **2022**, *40*, 4011–4019. 10.1109/JLT.2022.3153517