Absolute Distance Measurement with Asynchronous-Optical-Sampling Terahertz Impulse Radar

Takeshi Yasui,[*] Yoshiyuki Ohgi, Yasuhiro Kabetani, Shuko Yokoyama, and Tsutomu Araki
Graduate School of Engineering Science, Osaka University, 1-3, Machikaneyama-cho, Toyonaka, Osaka 560-8531, Japan
[*]E-mail: t-yasui@me.es.osaka-u.ac.jp

Abstract: We proposed a method to determine the absolute distance of a distant target using asynchronous-optical-sampling terahertz impulse radar. The determined distance was good agreement with the actual distance measured by a scale.

OCIS codes: (280.3400) Laser range finder; (280.5600) Radar.

1. Introduction

Radar (radio detection and ranging) technique has a wide variety of applications in military and commercial fields. Recently, commercial radar plays an important role in the field of automobile driving such as adaptive cruise control systems for driving assistant and collision mitigation systems for safe driving support. Automobile radar using an infrared laser light provides precise distance measurement, however, this method is sensitive to light scattering caused by bad weathers (rain, snow, and fog) and contaminated surface of a target. On the other hand, automobile radar using millimeter wave can be used under bad weathers and applied to contaminated surface of the target whereas the precision of distance measurement is relatively low. In this way, the conventional methods of automobile radar have their own merits and demerits. If merits of both methods are combined with each other, ideal automobile radar will be achieved. One possibility to combine merits of both methods is use of THz wave as a radar wave because THz wave lies at a boundary between infrared light and millimeter wave, and possesses both characteristics of them.

Recently, we have proposed real-time THz impulse radar by combination of time-of-flight measurement of THz pulse [1] and asynchronous optical sampling technique [2], namely AOS-THz-IR [3], and demonstrated displacement measurement of a moving object at a precision of 354 μm. However, repetition rate of the THz pulse used in the AOS-THz-IR is too high for ranging of a distant target, typically several tens MHz. In this paper, we propose a method to determine the absolute distance of a distant target using the high-repetition-rate THz pulse.

2. Principle of absolute distance measurement

In the AOS-THz-IR, an SFG (sum-frequency-generation) cross-correlation signal between two asynchronously locked laser lights is used as a time origin independent of a target distance. Figure 1(a) shows a timing chart of the SFG signal and a THz echo signal returned form a target, where ϕ and T are time delay and time period of the THz pulse, respectively. When the target distance (d) is shorter than a half spatial period of the THz pulse ($=cT/2$, where c is velocity of light), the d is simply determined by $c\phi/2$. Conversely, if the d exceeds the half spatial period, we have to apply a modified equation $d=c(nT+\phi)/2$, where n is the order of the measured THz pulse. Therefore, we have to determine the n for absolute distance measurement of a target at a distance over $cT/2$. To this end, the T is shifted by ΔT with the laser control system as shown in Fig. 1(b). This results in change of the time delay by $\Delta\phi$.

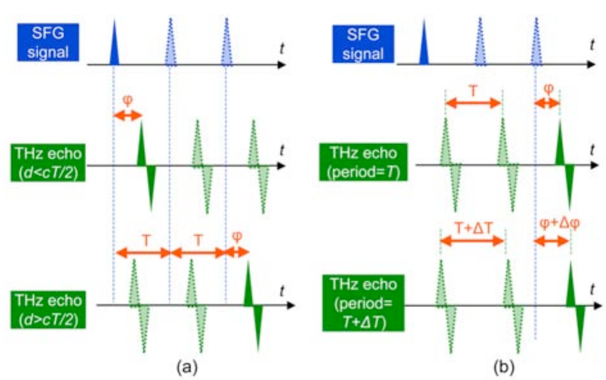

Fig.1. Principle of absolute distance measurement.

978-1-55752-890-2/10/$26.00 ©2010 IEEE

Since ΔT and $\Delta\phi$ must satisfy that $\Delta\phi = -n\Delta T$, we can determined the order of n by measuring the ΔT and $\Delta\phi$.

3. Experimental setup

The experimental setup is shown in Fig. 1. We used two mode-locked Ti:Sapphire lasers for generation and detection of THz pulse. The mode-locked frequencies of the two lasers (f_1 = 81.8 MHz, f_2 = 81.8 MHz + 10 Hz) and the difference frequency between them ($\Delta f = f_2 - f_1$ =10Hz) are well stabilized by a laser control system. Portions of the two laser lights are fed into a SFG cross-correlator using a nonlinear optical crystal, and the resulting SFG signal is used for time origin for the AOS measurement. Residual of the two laser lights are incident on to photoconductive antennas (PCA) for THz generation and detection, respectively. The THz pulse radiating from a THz-PCA emitter is collimated by an off-axis parabolic mirror, and then directed to a target object at a distance of 1 m by a mirror. Reflected and/or scattered THz pulse at surface of the object is collected and focused onto a THz-PCA detector by another off-axis parabolic mirror. After passing through a high-gain current preamplifier, the signal is measured at a scan rate of Δf with a fast digitizer triggered by the time origin signal from the SFG cross-correlator.

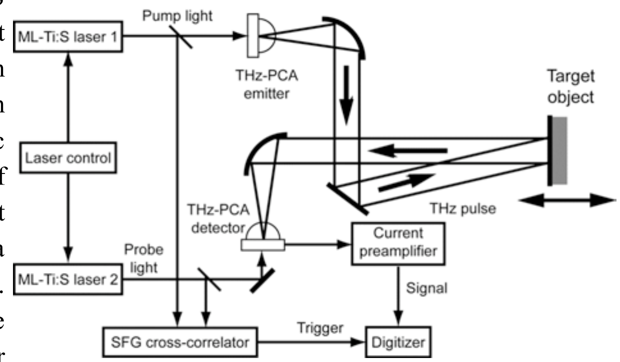

Fig.2. Experimental setup

4. Results

To confirm the above concept, we determine the absolute distance of a metal plate at a distance over a half spatial period of the THz pulse (= $cT/2$ = 1.835 m). When the initial T was set to 12.2351 ns, the temporal waveform of the THz echo pulse was observed as a blue curve in Fig. 3. Here, the time position of the SFG signal and the THz pulse is temporally overlaped, indicating ϕ = 0 ps. And then, the T was shifted by ΔT = 14.9 ps as shown in a red curve in Fig. 3. The resuting change of the time delay $\Delta\phi$ was -14.9 ps. The order of n was calculated to be 1 based on the above principle. Finally, we determined the taget distance to be 1.835 m. This value is good agreement with the actual distance measured by a scale.

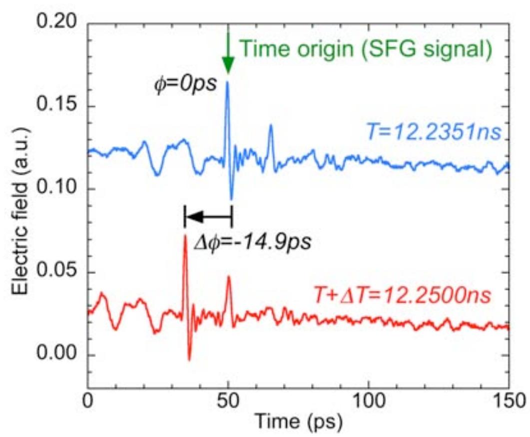

Fig.3. Result

5. Conclusion

We applied the AOS-THz-IR for determination of the absolute distance of a target. The proposed method has the potential to become a powerful tool for automobile radar.

This work was supported by Grants-in-Aid for Scientific Research Nos. 20560036 and 21650111 from the Ministry of Education, Culture, Sports, Science, and Technology of Japan.

References

[1] R. A. Cheville and D. Grischkowsky, "Time domain terahertz impulse ranging studies," Appl. Phys. Lett. **67**, pp. 1960-1962 (1995).

[2] T. Yasui, E. Saneyoshi, and T. Araki, "Asynchronous optical sampling terahertz time-domain spectroscopy for ultrahigh spectral resolution and rapid data acquisition," Appl. Phys. Lett. **87**, 061101 (2005).

[3] Y. Ohgi, Y. Kabetani, T. Yasui, S. Yokoyama, and T. Araki, "Asynchronous Optical Sampling, Terahertz Impulse Radar," in *Conference on Lasers and Electro-Optics/Pacific Rim (CLEO-PR) 2009*, Technical Digest (CD) (Optical Society of America, 2009), paper TuP7-09.