Electric Field Visualization System for Antenna Characterization at Terahertz Frequency Based on a Nonpolarimetric Self-heterodyne EO Technique

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Abstract

We demonstrate a nonpolarimetric self-heterodyne electrooptic (EO) field visualization system at terahertz (THz) frequency based on a 1.55 μm telecom technology. An optical intensity beat generated by mixing two frequency-detuned free-running lasers is used for both the generation and the detection of the RF signal. The frequency of the beat for the detection is shifted by an optical frequency shifter to realize coherent heterodyne measurement using free-running lasers. The amplitude and the phase of the RF signal is read out through the beat signal between the probe beam and the sideband generated by the RF signal to be detected. In our nonpolarimetric technique, the polarization state of the probe beam is maintained, therefore the sensitivity of the system is stable compared to the conventional system in which the RF signal is read out through the polarization state of the probe beam which easily fluctuates in the optical fiber and the EO crystal. Stable sensitivity improves the repeatability of the measurement which enables us to visualize the phase evolution of the radiated field. The phase evolution of the propagating THz field (126 GHz) radiated from a horn antenna is visualized.

1. Introduction

There has been an increasing interest in the application of terahertz (THz) waves (0.1 THz - 10 THz) to broadband wireless communications [1, 2]. For these applications, an antenna is one of the key components. A cassegrain antenna was used for an error-free transmission of a 10-Gbit/s signal over a distance of 800 m at 120-GHz-band [3]. An error-free transmission of a 10-Gbit/s for short-distance (2.5 m) has been demonstrated using a plate laminated waveguide slot array antenna [4]. Several antenna integration techniques such as integration in a plastic package based on a flip chip interconnect [5] have also been developed in the 120-GHz-band. Electric field visualization technique in this frequency range has attracted a great deal of attention not only for the antenna characterization, but also for the integrated circuit inspection.

Recently, we proposed and demonstrated electrooptic (EO) field visualization system based on a self-heterodyne technique [6] in which free-running lasers can be used both for the THz wave generation and the EO detection [7]. In this proof-of-concept, the THz signal was read out through the polarization state of the probe beam. One of the problems in this conventional poralimatric technique is that the deviations of birefringence within the EO crystal and/or optical fiber strongly influence the detection sensitivity because these effects reduce the optical polarization coherence in the probe beam. This degrades the system stability and the repeatability of the measurements. Because of the low repeatability of the measurement, visualization of the phase evolution of the RF signal based on the 1.55 μm telecom technology has not been demonstrated so far.

In this paper, we demonstrate a stable self-heterodyne EO field visualization system in which THz signal is read out based on a nonpolarimetric technique [8]. The phase of the probe beam is modulated by the THz electric field in the EO crystal and modulation sidebands are generated. Coherent detection of the generated sideband in the optical domain results in a down conversion of the THz signal for the lock-in detection. In this system, the polarization of the probe beam was set to be parallel to the optical axis of an EO crystal (ZnTe) and also aligned to the slow-axis of the polarization maintaining fiber (PMF). The polarization state of the probe beam maintains in the system, and this solves previous problems. Stable sensitivity improves the repeatability of the measurement which enables us to visualize the phase evolution of the radiated field. Our system has improved not only the system stability, but also simplicity because it is not necessary to adjust the polarization state of the probe beam.

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2. System configuration

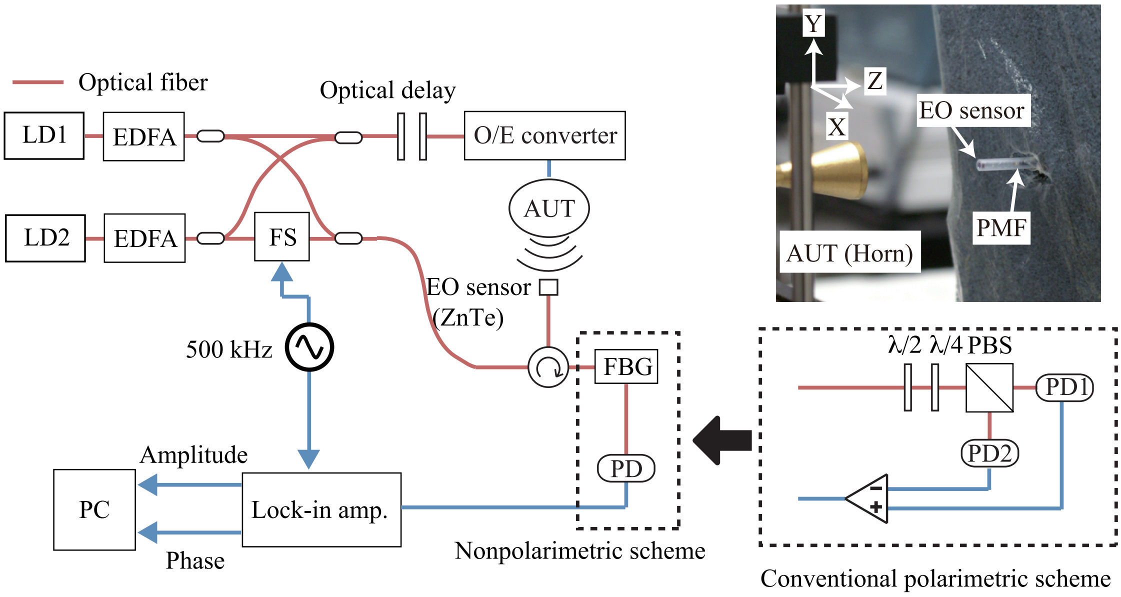

Fig. 1. Experiment schematic. LD; laser diode, EDFA; erbium-doped fiber amplifier, FS; frequency shifter, UTC-PD; uni-traveling-carrier photodiode, AUT; antenna under test, FBG; fiber Bragg grating, PBS; polarization beam splitter, PMF; polarization maintaing fiber. The sensor was scanned in the x-y, x-z, and y-z planes.

Figure 1 shows the schematic of our new system. Two free-running 1.55 μm laser diodes (LDs) were used as optical sources. The RF signal was generated by an optical-to-electrical (O/E) converter and radiated from an antenna under test (AUE). A ZnTe EO crystal (1 mm x 1 mm x 1 mm) was used as a sensor. An EO frequency shifter (FS) was used to shift the frequency of the LD2 by 500 kHz to realize self-heterodyning. In the EO crystal, the probe beam (optical LO signal) was interacted with the RF signal radiated from the AUT. Each laser component was modulated in the EO crystal and sidebands were generated. The modulated probe is filtered by the fiber Bragg grating (FBG) to have only one heterodyne pair and beat signal (IF signal) is detected by the PD. The amplitude and the phase of the IF signal is demodulated with the lock-in amplifier. In the conventional polarimetric technique, the deviation of the polarization state of the probe beam from its initial state is converted to the intensity modulated signal by the analyzer and detected by the PD.

We applied this system to visualize the THz wave radiated from a horn antenna. The configuration of the EO sensor and the horn antenna is also shown in Fig. 1. The origin coordinates was set at the center of the antenna surface. The frequency of the THz wave was 126.4 GHz, which was calculated using laser frequencies measured with optical wave meter. The W-band uni-travelling-carrier PD (UTC-PD) was used as the O/E converter. The polarization of the LO beam was set in the slow-axis of the PMF, therefore bending of the fiber does not influence the detection sensitivity. In contrast with the previous work [1], the fiber mounted EO sensor instead of the AUT was scanned in the x- y, y-z, and x- z planes (50 mm x 50 mm for each imaging). The sampling step in each direction was 0.2 mm.

3. Results

Figure 3 (a) shows the detected amplitude signal at the center of the antenna surface (x-y plane). The signal detected by the conventional polarimetric technique fluctuates due to the sensitivity fluctuation mainly caused by the fluctuation of the birefringence of the EO crystal. Moreover, when scanning the EO sensor, the polarization state of the probe beam in the sensor-mounted-fiber is drastically changed and as a result the field distribution measured by the conventional polarimetric technique has been distorted as shown in the Fig. 3(b). Contrary, the signal detected by the

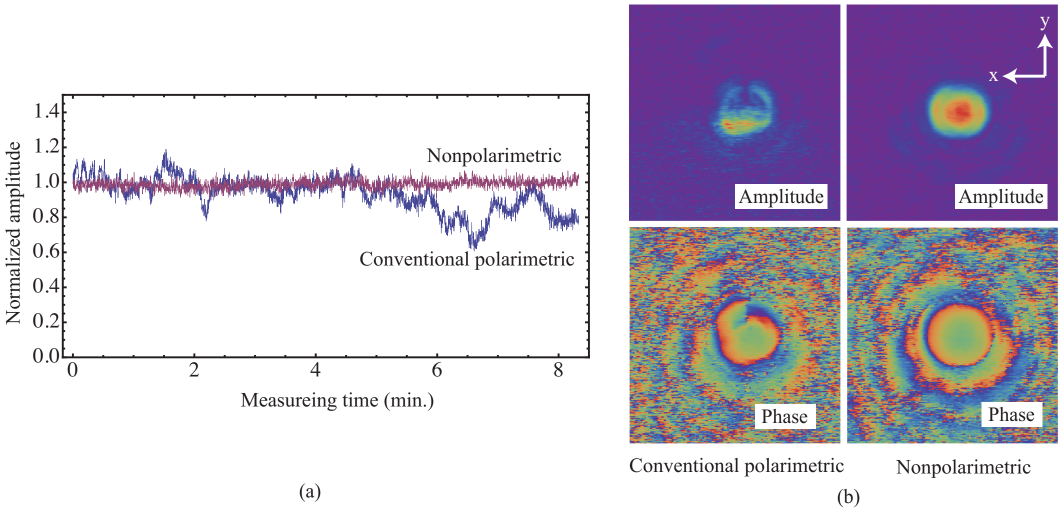

Fig. 3. (a) Detected amplitude signal at the center of the antenna surface (x-y plane). (b) The amplitude and the phase distribution at the antenna surface measured by scanning EO sensor.

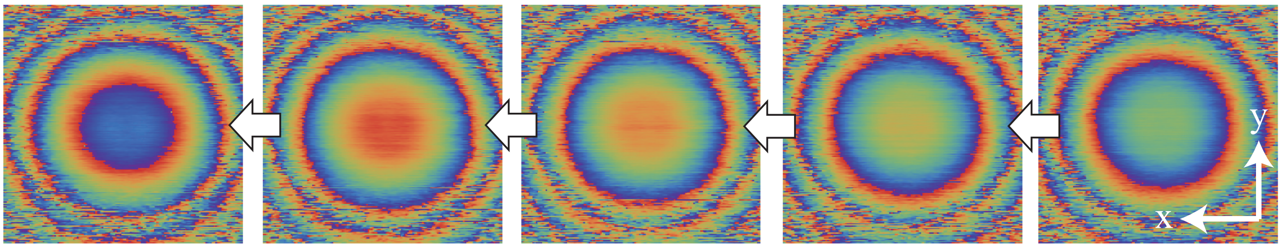

Fig. 4. Measured phase evolution in the x-y plane at z = 20 mm.

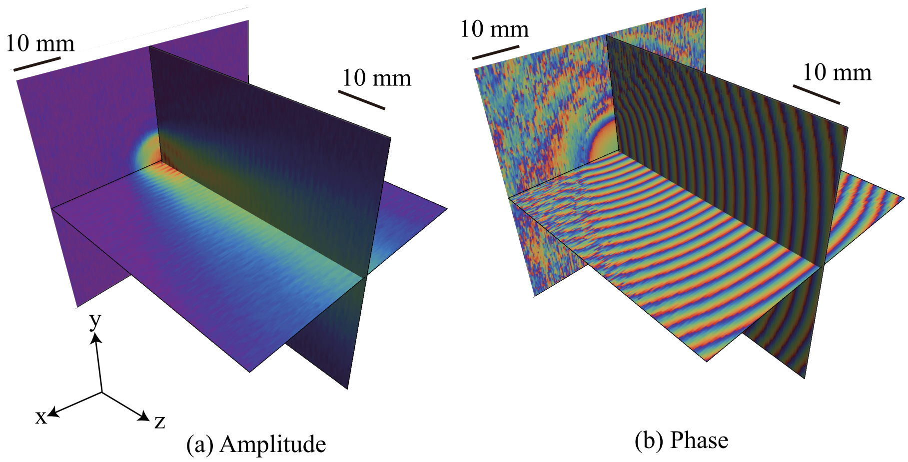

Fig. 5 Measured field distribution radiated the horn antenna (126 GHz).

nonpolarimetric technique is stable. Not only the signal-to-noise ratio (SNR), but also the repeatability of the measurement has been improved. This enables us to visualize the phase evolution of the THz wave propagating in the free space.

Figure 4 shows the phase evolution of the THz wave in the x-y plane measured at z = 20 mm. Each image contains 250 x 250 points. It took about 5 min to scan one plane with lock-in time constant of τ=3 ms. The initial phase of the THz wave was adjusted by changing the optical delay line. The relative phase was changed by $2\pi/5$ rad step. The spherical feature of the phase front has been clearly visualized.

Figure 5(a) and (b) show the amplitude and phase distribution images respectively, which contain 250 x 250 points. The lock-in time constant was τ=3 ms. The deviation of the phase measurement is reduced to about 1/3 compared with the previous result obtaiend based on the conventional polarimetric technique [7].

4. Conclusion

We demonstrated the visualization of the continuous THz wave based on the nonpolarimetric self-heterodyne EO detection technique. The amplitude and the phase of the THz field (126 GHz) radiated from the horn antenna were simultaneously visualized. Improved sensitivity-stability and the repeatability of the measurement enables us to visualize the phase evolution of the radiated field. Thanks to the self-heterodyne technique, the target frequency can easily be tuned by tuning the frequency of the "free-running" laser. Tuning bandwidth is limited by the bandwidth of the O/E converter, which exceeds 2 THz [9]. Our technique is applicable to antenna characterization not only for high-gain antennas such as phased array antenna, but also for wideband antennas such as tapered slot antenna.

5. Acknowledgments

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6. References

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