Photonic Frequency Hopping Driven by High-Speed Wavelength Tunable Laser for Secure Terahertz-wave Communication

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Abstract: We proposed a photonic frequency-hopping physical-secure Terahertz-wave communication system driven by a high-speed wavelength tunable laser and a photomixer, and experimentally demonstrated a frequency-hopping time of less than 25 ns at 300-GHz band.

1. Introduction

Although high-frequency and narrow-beam terahertz wave is considered as a secure wireless communication solution in line-of-sight scenarios, eavesdroppers still can obtain scattered terahertz wave by placing obstructions in the transmission path [1]. For this reason, physical-layer security in Terahertz-wave wireless networks is required to be developed. Recent studies focused on two terahertz beams encryption, intelligent reflective surface, etc. [2-3]. Another attractive solution is the frequency-hopping spread spectrum (FHSS) which is widely applied in secure microwave communications. Figs. 1(a) and (b) show the carrier frequency with rapid pseudo-random change and expected advantages at the FHSS. In terahertz frequency band, it has yet to be developed because of the difficulty in frequency hopping by electronics. At the FHSS, even if the signal can be jammed by unauthorized users in a single hopping period, they do not know the carrier frequency at the subsequent period and the complete information cannot be eavesdropped by scattered terahertz waves. However, the FHSS requires a large bandwidth, which, conversely, is advantageous in the vast bandwidth-rich terahertz domain. The frequency hopping range of the electronics-based terahertz technology is a few tens of GHz which is limited by frequency multipliers [4]. In contrast, the photonics-based terahertz-wave generation method provides over 100 GHz tuning range, which enables more carrier frequency channels to increase the complexity and security of the FHSS system. However, the information transmission efficiency of the conventional Wavelength Tunable distributed feedback laser-based terahertz FHSS system is degraded by a carrier frequency hopping time due to the thermal tunning time of a few seconds [5].

This study aims to develop a practical terahertz FHSS system using an electro-optically wavelength tunable laser that can achieve a small transition time as well as a wide frequency hopping range in the terahertz band rendering it difficult for eavesdroppers to detect.

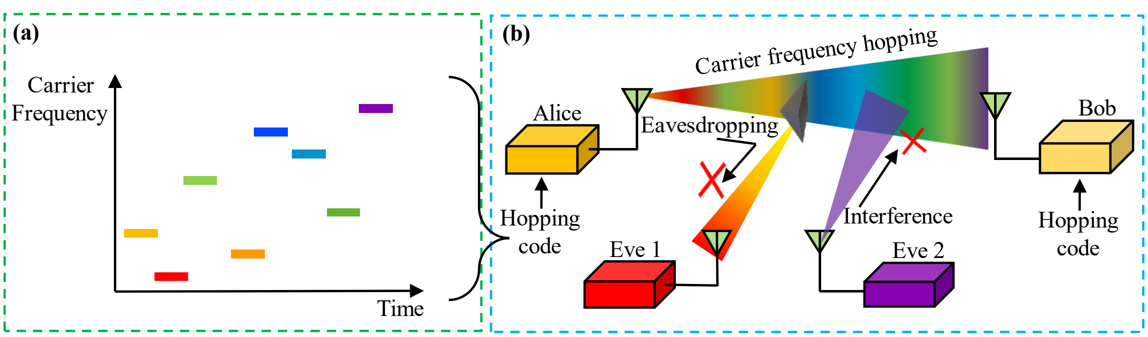

Fig. 1. (a) Carrier frequency hopping at the FHSS. (b) Conceptual diagram of the FHSS system.

2. Photonic THz FHSS system by electro-optically wavelength tunable laser

The photonics-based terahertz-wave generation by mixing two lightwaves with different optical frequencies is easy to change the frequency as described below. The electric field of the terahertz wave is given as

$$E_{THz} \propto \cos(2\pi(f_1 - f_2 - \Delta f)t)$$

where f_1 and f_2 are the optical frequencies of two lightwaves from different lasers, that are coupled and introduced into a photomixer for generating the terahertz wave. In this study, the electro-optically wavelength tunable laser with a reflection-type transversal filter (RTF) [6] (Fig. 2(a)) is used for a high-speed optical frequency shift Δf. Here, a current is injected into the ACT electrode for lasing while the fine and phase electrodes control lasing frequency. At the fine and phase electrodes, the electro-optic (EO) effect is utilized as the fast optical frequency tuning. Δf is described as

$$\Delta f \propto \Delta n L \propto \Delta V L$$

where Δn, L, and ΔV are a refractive index shift due to the EO effect at the RTF delay-line waveguide, the length of the tuning electrode, and an applied voltage at the electrode, respectively. It has been demonstrated in Ref [6] that a large tunability over the C band can be obtained by using a long L. As shown in Fig. 2(b), The fine and phase electrodes are used for selecting one longitudinal mode in the cavity and continuously shifting the laser frequency, respectively. The fine electrode has a lasing frequency tuning range of about 400-GHz while the phase electrode has an over 15-GHz tuning range as shown in Fig. 2(c). According to the lookup table of the voltages-frequency relationship, rapid lasing frequency hop can be achieved by quickly changing the applied voltage at each electrode. Fig. 2(d) shows the experimental setup for rapid lasing frequency hop. Two lightwaves are coupled to the uni-traveling carrier photodiode (UTC-PD) to generate a frequency-hopping wave at the 300-GHz band which is outputted to a WR3 waveguide. Fig. 2(e) shows a configuration for observing the terahertz hopping process in the time domain directly by an oscilloscope in which a terahertz-wave signal is down-converted to an intermediate frequency (IF) signal using a sub-harmonic mixer (SHM) with a local oscillation (LO).

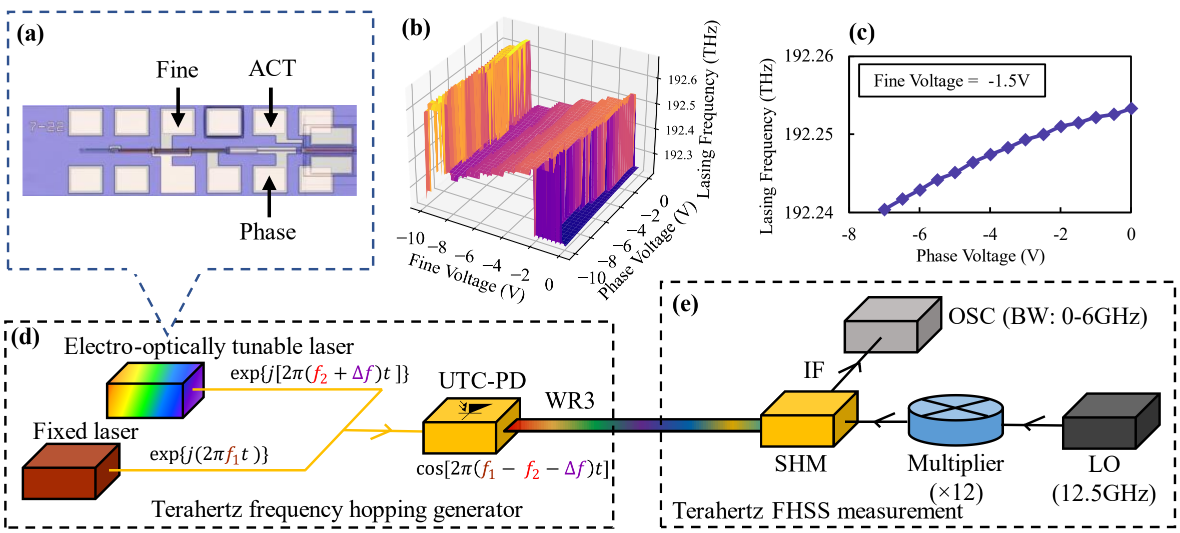

Fig. 2. (a) Photograph of the electro-optically wavelength tunable laser with the RTF. (b) Relationship among the control voltage at the fine electrode, the control voltage at the phase electrode, and the lasing frequency. (c) Relationship between the control voltage at the phase electrode and the lasing frequency. (d) Configuration of the terahertz FHSS generator. (e) Configuration of the terahertz FHSS measurement.

3. Experiment of frequency hopping in the 300-GHz band

With a period of 400 ns, a control voltage signal that randomly hops at eight levels is applied to the phase electrode as shown in Fig. 3(a) so that the lasing frequency of the RTF laser hops among eight channels between 192.2465 and 192.2510 THz. The lasing frequency of the other laser is fixed at 192.5520 THz so that the beat frequency hops in the range of 301.0 GHz to 305.5 GHz. In a future practical system, the frequency hopping range can be enlarged up to 400 GHz, but the bandwidth of this experiment is limited by the oscilloscope bandwidth (<6 GHz). On the terahertz FHSS measurement side, the 12.5 GHz LO signal is multiplied twelve times and sub-harmonically mixed with the 300-GHz band signal in the SHM. As a result, a hopping IF signal from 1 GHz to 5.5 GHz is generated and displayed on the oscilloscope as shown in Fig. 3(b). Fig. 3(c) shows the result of the short-time Fourier transform (STFT) of the waveform of Fig. 3(b). It can be seen that the frequency hop is completed within 25 ns, which demonstrates the feasibility of the photonic terahertz FHSS system based on the electro-optically wavelength tunable laser. Furthermore, since Fig. 3(a) and Fig. 3(c) show the same waveform, the frequency hopping speed is not limited by the tuning speed of the RTF laser and a much faster response can be observed by a larger bandwidth oscilloscope.

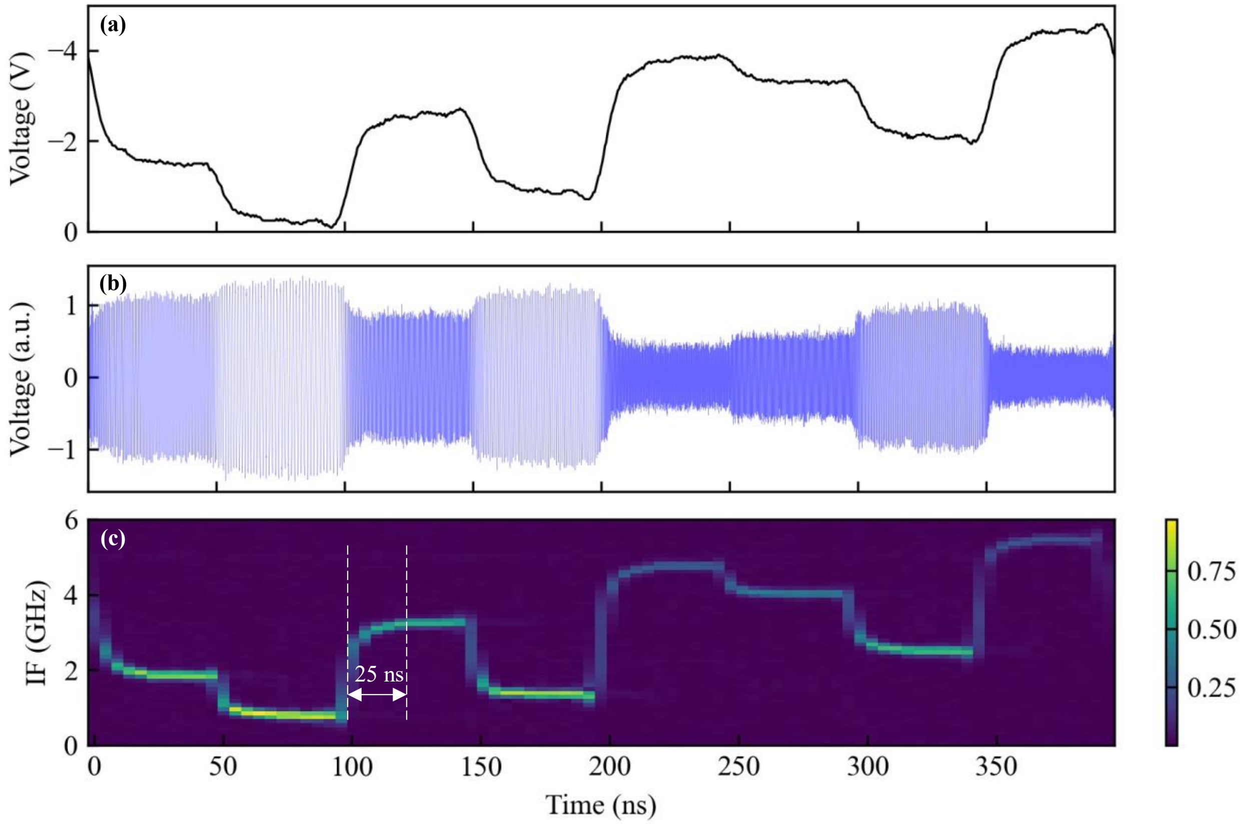

Fig. 3. (a) Voltage pattern to the Phase electrode, (b) the observed IF signal, (c) the STFT of the IF signal.

4. Conclusion

We proposed a terahertz FHSS system based on the electro-optically wavelength tunable laser to improve security at a terahertz-wave communication. By taking advantage of its high-speed wavelength tuning characteristic, a practical carrier hopping time of less than 25 ns in the 300-GHz band has been demonstrated.

Acknowledgments

This work was supported by the commissioned research by the National Institute of Information and Communications Technology (NICT) #02801, #00901, the MIC/SCOPE #195010002, JSPS KAKENHI Grant Number: JP20H00253, JP21K18730, JP23K17751, and the Grant of Graduate School of ISEE of Kyushu University for Supporting Students' Participation in International Conferences.

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