[EN-A-081] Bistatic Radar System in Terahertz Bands Based on Radio Over Fiber Network

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Abstract: We demonstrated 300-GHz bistatic radar system connected via a frequency-modulated continuous-wave signal feeder network configured with optical fiber cables. The probability of the detection will be enhanced by the detection by multi-receiver system synchronized by the optical fiber network.

Keywords: bistatic radar, terahertz band, FM-CW.

1. INTRODUCTION

Enhancement of civil security and safety desperately requires non-destructive imaging technology with high preciseness. The high-frequency radar system is attractive for detection of small objects as well as surveillance of surface structure. However, shorter-wavelength radio signal has relatively large transmission losses due to propagation and large atmospheric attenuation coefficient. Thus, received signal power is smaller than that in the microwave band. The multistatic radar system has great advantages on collecting the radio signals by several receivers to enhance the signal-to-noise power ratio as well as enhancement of preciseness of the radiolocation [1], [2]. In addition, a high-precision radar system requires a high-precision radar signal source: a costly configuration in high-frequency radio bands such as terahertz bands.

Radio over fiber (RoF) technology is a promising solution to deliver the radio signal generated at a central office via an optical fiber network; one ultra-high precision radar source will be equipped with the central office to reduce total costs [3], [4]. Moreover, a low-loss feature of an optical fiber cable with <1 dB/km enables a long-distance remote radar heads configuration can be realized. A foreign object debris detection system in airport runway surfaces at a frequency of 96 GHz is configured with a combination of an optical fiber network and remote radar heads, whose transmission distance is longer than 5 km [5], [6]. In principle, frequency-modulated continuous-wave (FM-CW) radar requires a broad bandwidth for improvement of the range resolution. Therefore, for precise ranging, terahertz-band radio is a promising solution [7].

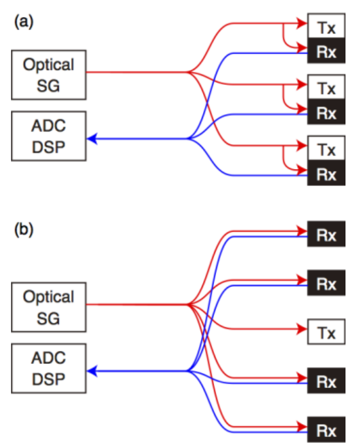

Figure 1 Concept of terahertz-band multistatic radar system under (a) TRx and (b) Tx-Rx separation configurations. Red and blue arrows denote an LO and RF signal lines and IF lines, respectively.

In the study, a 300-GHz FM-CW-based bistatic radar system is evaluated using photonics technologies [8]. An FM-CW feeder network configured by the optical fiber cables provide the simultaneous signal distribution to each radar head including transmitter and receivers with considerable losses.

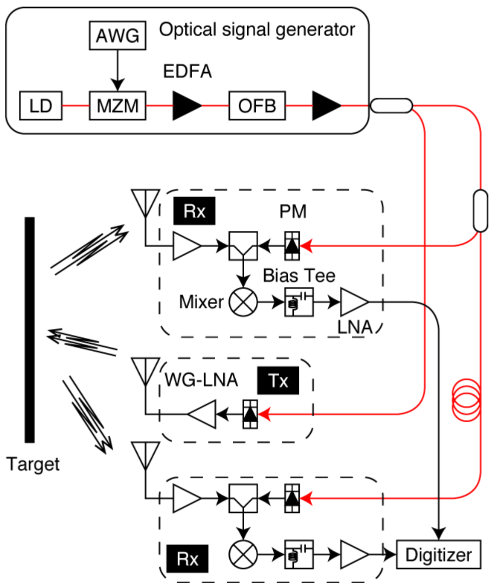

Figure 3 Experimental setup

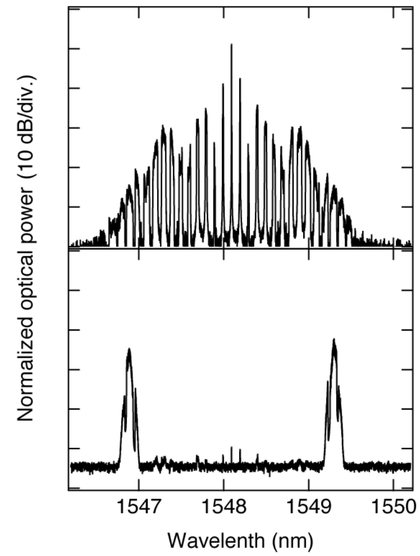

Figure 2 Obtained optical spectra of (top) FM-CW-signal-launched optical frequency comb and (bottom) two-tone signals passed after the OFB.

2. CONCEPT OF TERAHERTZ MULTISTATIC RADAR SYSTEM

Figure 1 shows a conceptual schematic of multistatic radar systems. In principle, an optically driven transmitter (Tx) and receiver (Rx) should be configured by launching the radar signal via an optical fiber network. The Tx is comprised of a photomixer (PM) and radio front-ends including an amplifier and multipliers. On the other hand, particularly in FM-CW configuration, the Rx should also have a local oscillator (LO) signal input for an intermediate frequency (IF) downconversion with the radio front-end. In a sense, an optical LO port, whose signal waveform is just same as the signal launching into the Tx. For configuration of a multistatic radar system, in case of use of conventional radar transceiver (TRx), both Tx and Rx should be connected to an optical signal generator (SG) for delivery of the RoF signal. Downconverted IF signals are transmitted over the optical fiber cable to an analog-to-digital converter (ADC) and a digital signal processor (DSP) set in a central office. In this configuration, each TRx can be operated independently, and thus, functionality based a multistatic configuration, such as enhancement of the ranging and increase of probability, is performed by the DSP.

On the other hand, a configuration of separation of Tx and Rxs are a promising solution to the enhancement of the detection probability as well as reduction of the complexity of the optical fiber network configuration. The Tx should have only one input port of the optical LO/RF signal from the optical SG. Distributed Rxs configuration has a network topology of a passive double star. In the configuration, of course, the DSP can improve the preciseness of ranging. Moreover, a beamforming detection by tuning the LO transmission line distance to each Rx is also realized in the receiver side. A coherent summation of the IF signals in the ADC/DSP domain is also available when the optical fiber length is same enough within the phase differences in the radar section. Therefore, the multistatic radar system under a Tx-Rx separation configuration has advantages for enhancement of the function by optimization of the optical network domain. In the study, one Tx and two Rxs configuration in the terahertz bands is evaluated.

3. EXPERIMENTAL SETUP

For proof-of-concept experiments of a bistatic radar system in 300 GHz band, an experimental setup is configured as shown in Fig. 2. In the system, a Tx and two Rxs were set under quasi-coaxial configuration for evaluation of improvement of detection probability. In an optical signal generator, a laser diode (LD) provided a CW lightwave signal at a wavelength of 1548.5 nm. A Mach-Zehnder interferometer-type intensity modulator (MZM) operated by an arbitrary waveform generator (AWG) modulates the CW light to produce an optical frequency comb signal. The AWG generate a saw-type FM-CW electrical signal at a center frequency of 12.5 GHz with a chirp bandwidth of 0.8 GHz and a pulse duration of 10 μs. An erbium-doped fiber amplifier (EDFA) boosts up an optical power level output from the MZM for launching to an optical filter bank (OFB). The OFB picks up two optical components from the optical frequency comb signal with a frequency separation of 300 GHz, and then, the EDFA set after the OFB optimizes the

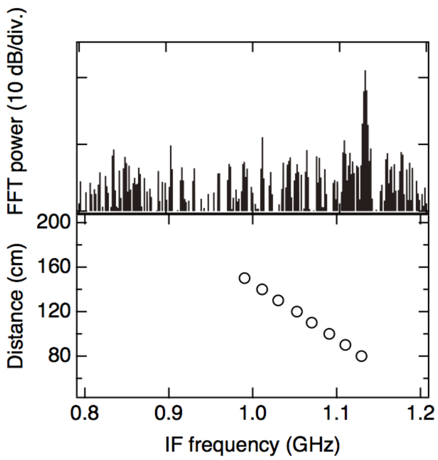

Figure 4 (top) IF spectrum obtained by FFT of digitized Rx signal and (bottom) ranging results with various target distances.

optical power for distribution. First optical coupler splits two components: one is for a Tx, and the other is for the Rxs. In the Tx, a photomixer (PM) receives the 300-GHz-separated two-tone optical signal and converts into the 300-GHz signal. A waveguide-type low-noise amplifier (WG-LNA) optimizes the power level of the signal at 300 GHz to –10 dBm. On the other hand, the Rx is configured in the PM, a directional coupler, a WG-LNA, a 300-GHz fundamental mixer, a bias-tee and a low noise amplifier (LNA) for the IF component. A reflected 300-GHz signal captured by an antenna is input to the coupler as combined with an LO component converted by the PM. The mixer performs a frequency downconversion to the IF component. It should be noted that the mixer is operated with a bias voltage, the bias-tee is inserted at the IF port of the mixer. The IF signal is amplified by the LNA, and finally, a digitizer acquires the time-evolution data of the IF signal. For easy identification of the IF signal, two Rxs has a different fiber length of the LO signals. Insertion of the fiber can shift the IF beat frequency of the received FM-CW signal. In the proof-of-concept experiments, the fiber length difference is set 5 m. All the antenna has an antenna gain of approximately 23 dBi with a pyramidal horn structure. A metal plate is used as a target under test.

4. EXPERIMENTAL RESULTS

In optical domain evaluation, Figure 3 shows optical spectra of generated optical frequency comb signals. In the system, we obtained ±14th order components by over-driven MZM modulation. However, at the order of the harmonic component less than 12th, the separation between adjacent channels is observed; however, the separation is gradually disappeared by overlapping with neighbor channels. This is because the bandwidth of the FM-CW signal of 0.8 GHz provides 11.2-GHz bandwidth

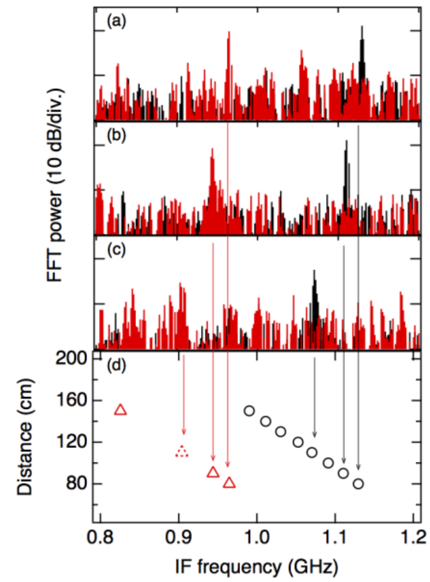

Figure 5 (a-c) (a-c) IF spectra obtained by FFT of digitized Rx signal with several target distances and (d) ranging results with various target distances. Red and black lines and circles show obtained signals from different Rxs.

at 14th-order harmonics, which would be come close to a comb separation of 12.5 GHz. For the 300-GHz signal generation, ±12th-order components are suitable for generation of two-tone components with a separation of 12.5 GHz × 12 × 2=300 GHz: 24th-order multiplication in the frequency domain. The passband of the OFB is approximately 15 GHz, and then, the 300±7.5-GHz signal could be converted by the PM. It should be noted that leaked components from adjacent channels also converted by the PM; however, the suppression ratio of the unwanted components is larger than 10 dB, and therefore, they could not affect significant degradation of the radar configuration.

Figure 4 shows an obtained IF spectrum and ranging results with various target distance from the Tx under one Tx and one Rx configuration. In the received signal, an IF peak structure has a signal to noise ratio of greater than 10 dB. There is no significant spurious component in the obtained signals. Also, the IF peak frequencies with the various target distances has linear relationships, and thus, the FM-CW ranging is successfully demonstrated in 300-GHz band using a fundamental-mixer-based Rx.

For bistatic radar evaluation, we used two Rxs for the same target detection. Figure 5 shows observed intermediate frequency spectra in the Rxs. In these two Rxs configuration with a metal plate as a target, small misalignment of the reflection angle cannot reflect the signal to Rxs; for instance, IF signal from the Rx can detect the signal at the target distance of 100 cm, but the other Rx cannot (red colored signals in the Fig. 5). In principle, an increase of Rxs directly improves the preciseness of the ranging results because the FFT-based

IF frequency estimation limits the range resolution by a bin of the FFT size. Resulting ambiguity will be reduced by statistical techniques. In the case, a detectable Rx helps to estimate the undetected signals in the other Rx. Therefore, it also helps to enhance the precise ranging system. Therefore, the bistatic configuration in 300-GHz bands can configure probability-optimized radar systems.

5. CONCLUSION

The optical-fiber-based bistatic radar system in 300 GHz is discussed, configured and demonstrated experimentally. Optical frequency comb source with a simple power splitting network easily enhance the probability of the detection of the target in the radar system. WDM and the other network configuration can enhance the functions of the multistatic radar system, and therefore, the concept is capable of the high-probability radar system as well as a detection of a complex-surface-structured target.

6. ACKNOWLEDGMENTS

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