300-GHz-band Wireless Link Using Photonics-based Ultralow-noise Transmitter and Receiver

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Abstract: We present a THz wireless link using photonics-based signal generators using ultralow amplitude- and phase-noise Brillouin laser sources for both the transmitter and receiver, and demonstrate successful transmission of over-100-Gbit/s signals at 300 GHz with on-line signal processing.

OCIS codes: (060.5625)Radio frequency photonics; (060.1660)Coherent communications

1. Introduction

In recent years, terahertz (THz) communications have been intensively studied as enabling technologies towards the 6th generation (6G) mobile communication systems, to meet the anticipated demand for the data rate of over 100 Gbit/s [1-3].

Photonics- as well as electronics-based systems have been developed mostly in the sub-THz region from 100 GHz to 300 GHz (D-band, G-band and J-band). In particular, the photonics-based system is considered to be more suitable not only for achieving higher data rates but also for combining fiber-optic networks and wireless networks seamlessly. One of the practical limitations of the recent photonics-based systems is the phase noise of carrier frequencies in the transmitter and/or local signal frequencies in the receiver. Most photonics-based systems employ two free-running lasers with different wavelength/frequencies, and a large phase noise must be often compensated by "off-line" digital signal processing to achieve a record data rate [4]. Optical frequency comb-signal generators using electro-optic modulators are effective to stabilize the frequency and phase, but they are essentially based on the frequency multiplication process, which results in the increase of the phase noise.

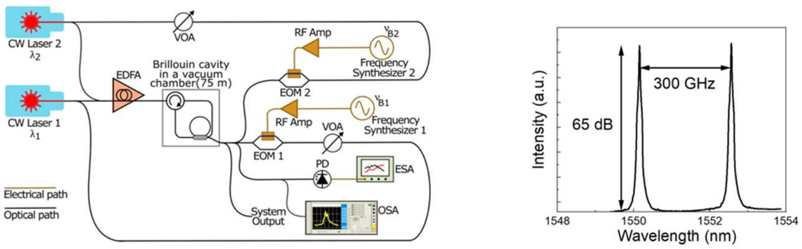
Against this background, we proposed to use a low phase noise photonic source based on the stimulated Brillouin scattering (SBS) optical fiber cavity for a 300-GHz-band QPSK wireless communication link [5]. In the system, however, the data rate was still limited by the phase noise of the receiver, where an electronic sub-harmonic mixer was pumped by the frequency multiplier.

In this paper, we present a 300-GHz-band wireless link by using improved SBS laser systems [6] for both the transmitter and receiver. First, we demonstrate low-amplitude noise properties of the SBS laser system in the coherent link, where 23-Gbaud 32QAM data signal upconverted to the IF frequency is transmitted via 300-GHz carrier, and demodulated by coherent homodyne detection using the same laser system. Next, we demonstrate low-phase noise properties of the laser system in the coherent link, where the transmitter and receiver are controlled by individual laser systems. 20-Gbaud 16QAM data signal is directly upconverted to 300-GHz carrier frequency, and it is demodulated by heterodyne detection using the on-line digital signal processing installed in the commercial real-time oscilloscope.

2. Experimental Setups

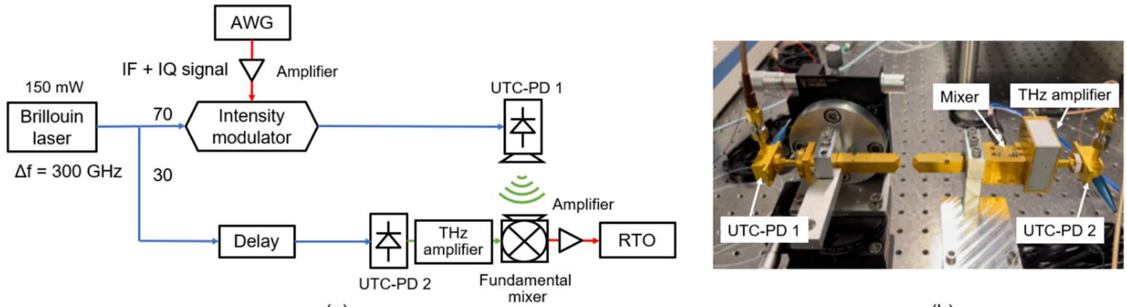
Figures 1(a) depicts a schematic diagram of the SBS laser system used in the experiment. An optical spectrum is shown in Fig. 1(b), where two optical carriers are generated with a frequency difference of 300 GHz. The output power of 150 mW with a carrier-to-noise ratio (CNR) of 65 dB was obtained with the phase noise as low as -130 dBc/Hz at 100 kHz. The details of the phase noise performance will be reported elsewhere.

Figure 2 shows the coherent homodyne link system to study the effect of the wireless transmission performance by changing the CNR of the laser source. The output of the laser source is divided into two paths; 70% of the output is used for the transmitter, and 30% for the receiver. In the transmitter, the QAM data signal is upconverted to the IF frequency (15 GHz) with the arbitrary waveform generator (AWG), and it is applied to the optical intensity modulator. The IQ signal is filtered by a root-raised cosine filter with a roll-off factor of 0.35. The modulated optical signal is input to the photodiode (UTC-PD 1) to generate and radiate the 300-GHz signal from the horn antenna. In the receiver, the same horn antenna receives the RF signal followed by Schottky-barrier-diode fundamental mixer. The mixer is pumped by the IF signal with the same frequency, which is generated with the photodiode (UTC-PD 2) and amplified with the RF amplifier. The down-converted IF signal is once amplified with the baseband amplifier and it is finally demodulated and analyzed with the real time oscilloscope (RTO).



(a) (b)

Fig. 1. (a) Block diagram of the laser system. (b) Optical spectrum showing two tones separated at 300 GHz.



(a) (b)

Fig. 2. Block diagram (a) and photo (b) of the experimental setup for the coherent homodyne link system.

Figure 3 illustrates the second experimental setup, where the transmitter and receiver are separated and controlled by individual laser systems, to demonstrate the low-phase noise properties of the laser systems. The RF frequency of the transmitter is set to 300 GHz, while that of LO signal applied to the mixer is 285 GHz, to perform the coherent heterodyne detection with the IF frequency of 15 GHz. Both laser systems generate 150-mW output power with CNR of 65 dB. It must be noted that there is no synchronization processing between two laser systems. Optical filters are used to separate two laser tones; one is directly IQ modulated, and the other is unmodulated.

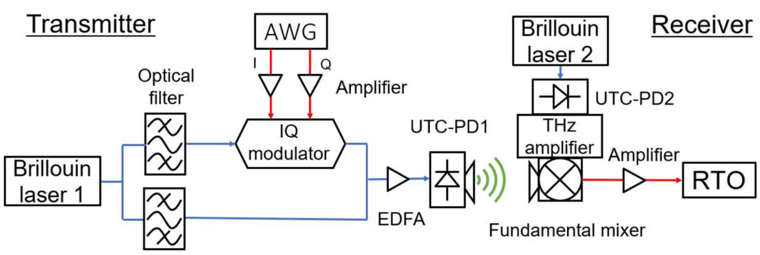


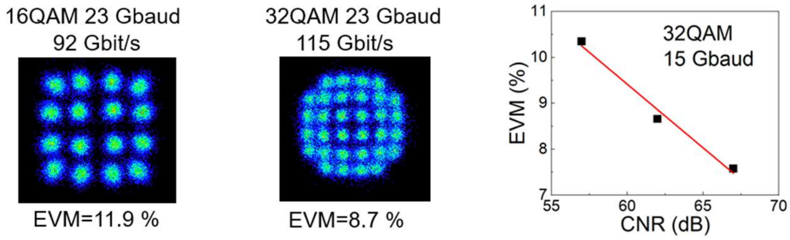
Fig. 3. Block diagram of the coherent heterodyne THz wireless link using two Brillouin laser sources.

3. Experimental Results

All the results are obtained by on-line signal processing installed in the RTO (Keysight UXR1002A), and we define that the transmission test is successful when the bit-error ration (BER) reaches below the forward error correction threshold of 2.17E-3, referred to as the HD-FEC limit.

Figure 4 (a) shows constellation diagrams obtained with the coherent homodyne link system (Fig. 2) for 16QAM and 32QAM modulation. The symbol rate is 23 Gbaud for both cases, and corresponding values of the error vector magnitude (EVM) are below the HD-FEC limit. The highest net data rate is 115 Gbit/s with 32QAM modulation. The limitation is caused by the IF bandwidth of the fundamental mixer (3-dB bandwidth: ~ 25 GHz). Figure 4 (b) shows the plot of the relationship between CNR and EVM values. It is concluded that use of laser systems with higher CNR ensures better EVM values particularly for increased number of multi-modulation levels.

Figure 5 shows constellation diagrams obtained with the coherent heterodyne link system (Fig. 3) for 16QAM and 32QAM modulation. The highest HD-FEC limited symbol rates are 20 Gbaud and 12 Gbaud with 16QAM and 32QAM, respectively. Even though the two laser systems are not locked each other in the experiment, the observed constellation diagrams are stable without any rotational behavior in constellation maps, thanks to the unprecedented phase stability of the Brillouin laser systems. The main reason for the decrease of symbol rates compared with the coherent homodyne link was due to degraded CNR (~45 dB) in the transmitter caused in the separation process of two-tone optical signals to two paths. This issue should be solved in our future work.



(a) (b)

Fig. 4. (a) Constellation diagrams of 16QAM and 32QAM with the coherent homodyne link system. (b) CNR vs. EVM values.

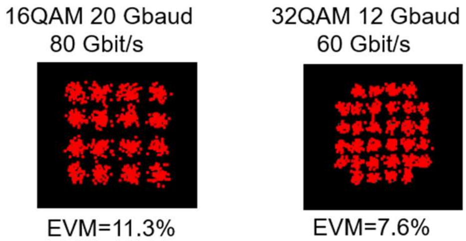


Fig. 5. Constellation diagrams of 16QAM and 32QAM with the coherent heterodyne link system.

4. Conclusion

We have demonstrated photonics-based THz wireless links by using ultralow-noise laser sources for both the transmitter and receiver at 300 GHz, for the first time, and have achieved the maximum HD-FEC limited data rate of 115 Gbit/s. Dynamic behavior of constellation diagrams observed by on-line signal processing is quite stable, which proved a low-phase noise performance of the Brillouin laser systems.

Further development of laser systems should address small size and low cost by introducing, for example, optical micro-comb technologies [7] to make the photonics-based transceiver more practical in THz wireless communications.

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