In order to realize a real-time transmission system based on the multi-level modulation without using complicated DSP techniques, we have investigated the cause of phase instabilities in the optical frequency comb-based scheme, and solved the problem by introducing a phase stabilizer into the two optical paths after the optical filter such as an arrayed waveguide (AWG) filter as shown in Fig. 12. Phase instability between the two optical paths is caused by the change in the index of refraction due to temperature and acoustic noise in the optical fiber cables. Such a noise has a very low frequency component below several tens of hertz, and sometimes shows an unexpected burst-like behavior. To measure and control such a phase noise, we applied dither signals at frequencies around 10 kHz to each path with EOM, and compensated the phase fluctuation with Piezo phase shifters by the feedback circuits. The dither frequency should be chosen not to affect the data transmission.

To verify the importance of phase stabilization in the frequency comb-based transmitter, we conducted a coherent transmission experiment with a carrier frequency of 100 GHz as shown in Fig. 13(a). As for the receiver, we used a sub-harmonic mixer driven by a local oscillator (LO) signal at 50 GHz. In addition, we applied an FEC board to know whether the FEC is effective or not with or without the phase stabilizer. The FEC board is a standard one based on the Reed-Solomon codes [39].

Figure 13(b) shows an eye diagram after the receiver at a data rate of 10.3 Gbit/s with the phase stabilization. Without the stabilization, we could not observe clear eye diagrams at all. We measured BER characteristics with and without the FEC as shown in Fig. 13(c). It has been confirmed that the FEC properly works with our phase-stabilized transmitter. However, we could not measure BER without the phase stabilization; the bit error rate tester indicated "synchronous error". Thus, the phase stabilization is necessary to achieve a real-time data transmission even with the FEC.

4. Conclusion

To explore undeveloped THz-wave regions for wireless communications, photonic signal generation is the most powerful technique, and particularly, the approach with use of telecom-based components is not only a technology driver in the wireless communications, but also makes it easy to combine the wireless link with fiber-optic networks seamlessly.

In this paper, we have demonstrated real-time error-free transmission at a carrier frequency of 300 GHz with the highest data rate up to 40 Gbit/s and 48 Gbit/s for a single channel and polarization multiplexed channel, respectively, and 50 Gbit/s and 100 Gbit/s are feasible for each approach by improving the bandwidth of the baseband circuitry of the detector. We have also described a 600-GHz band system to show that available bandwidth can be doubled to ensure higher data rate, and a frequency-multiplied transmitter to increase the output power of the transmitter to 1 mW and higher. Finally, in order to apply multi-level modulation schemes to the real-time transmission with much higher data rate of over 100 Gbit/s, we have proposed the phase-stabilized transmitter based on the optical frequency comb, and a proof-of-concept experiment has been successfully conducted at a carrier frequency of 100 GHz.

Recently, THz amplifiers such as power amplifiers and pre-amplifiers for transmitters and receivers, respectively, have started to be developed even with Si technologies. Use of such amplifiers would make the photonics-based THz wireless technology more practical. One of the future directions of photonics-based approaches should be an integration of photonic devices as well as electronic devices using contemporary fabrication technologies such as silicon photonics to make THz transceivers more compact and cost-effective.

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