Integrated Dual-DFB Laser Chip-based PAM-4 Photonic-Wireless Transmission in W-band

Shi Jia[1,*], Mu-Chieh Lo[2, 3], Deming Kong[1], Robinson Guzman[2], Longsheng Li[1], Leif K. Oxenløwe[1], Guillermo Carpintero[2], Hao Hu[1,*]

[1] DTU Fotonik, Technical University of Denmark, DK-2800, Kgs. Lyngby, Denmark
[2]Universidad Carlos III de Madrid, 28911 Leganés, Madrid, Spain
[3]University College London, London, WC1E 7JE, UK
[*]shijai@fotonik.dtu.dk; huhao@fotonik.dtu.dk

Abstract: We experimentally demonstrate lens-free photonic-wireless transmission in the W-band using a monolithically integrated dual-DFB laser, which is injection-locked by a frequency comb to generate two 90-GHz-spacing phase-stabilized carriers and modulated with a 40-Gbit/s PAM-4 signal.

1. Introduction

The forecast demands for broadband wireless applications, such as smart city, in the coming 6G and Internet of Things (IoT) are driving the development of wireless communications. In this context, the ultrafast photonic-wireless network, with great advantages of being compatible with the optical fiber network and facilitating wireless-over-fiber technology for long-distance distribution of wireless signals, will play a key role to meet the demand of the future exponentially increasing global wireless traffic [1]. The historical evolution of wireless communications has shown that the wireless carrier frequencies for transmission have been increasing progressively to support the demand of larger bandwidth [2]. The present situation of the almost fully exploited frequency bands below 60 GHz, has driven the research of photonic-wireless communication to the millimeter wave (MMW) band to exploit the large available bandwidth [3]. The W-band (75-110 GHz), as a candidate of MMW band, is attracting lots of research interest to enable photonic-wireless links with higher data rate [4-8]. However, it is more desirable to further simplify and integrate the overall communication system, especially the transmitter. In terms of the modulation, pulse-amplitude-modulation with four levels (PAM-4), only requiring a 2-bit digital-to-analog converter (DAC), is able to enable intensity modulation and direct detection (IM-DD) photonic-wireless systems to simplify the configuration. On the other hand, the employment of on-chip light source can further integrate the transmitter. Hence, it is more desirable to employ the chip-based IM-DD photonic-wireless links, with low cost, small footprint and simple configuration, for practical broadband wireless applications and facing the trend of future photonic-wireless communication systems [9].

In this paper, we propose and experimentally demonstrate a PAM-4 IM photonic-wireless transmission system in the W-band based on a monolithically integrated dual-distributed feedback (DFB) laser chip, which is injection-locked by an optical frequency comb (OFC) emitted from a directly modulated laser (DML) driven by a RF sinusoidal signal. First, we generate a W-band wireless signal using an integrated dual-DFB laser chip attached to a photo-mixing broadband photodiode (PD) with an antenna. A DML driven by a RF sinusoidal signal emits an OFC and is used to injection-lock the two modes of the dual-DBF laser chip, for a phase-stabilized beat note. Second, we simultaneously modulate the two coherent optical carriers generated from the integrated dual-DFB laser chip after injection-locking to increase the signal-to-noise ratio (SNR) before beating in the PD, while saving an extra optical local oscillator (LO). Third, PAM-4 modulation is utilized to realize intensity modulation. Finally, the wireless link is lens-free to be more practical for actual applications. We have transmitted 10 GBaud and 20 GBaud PAM-4 W-band wireless signals and obtained a line data rate up to 40 Gbit/s. Such a lens-free photonic-wireless system based on an integrated dual-DFB laser chip, with low cost and simple configuration, is more suitable for the future practical broadband wireless applications. In addition, this scheme has potential for the realization of a fully integrated photonic-wireless transmitter, including the DML, intensity modulator, optical amplifier and PD.

2. Experimental setup

The overall experimental configuration is shown in Fig. 1. At the transmitter, an integrated dual-DFB laser chip is used to generate two continuous waves (CWs) [10], as shown in Fig. 1(d)-(e). The two freely tunable DFB lasers, each of which is controlled by a heater current and an injection current, are monolithically integrated with a 3-dB multimode interference coupler in a heterodyne configuration. The spacing between the two CWs is tunable within the range of 0-10.7 nm, corresponding to a continuous beat note up to around 1.4 THz. Then, an 18-GHz-spacing OFC emitted from a DML driven by an 18-GHz sinusoidal signal, is employed to injection-lock the two CW modes to make them phase coherent for a phase-stabilized beat note. In this experiment, the spacing between the two DFB lasers is tuned to be 90 GHz to generate the wireless carrier frequency in the W-band. Fig. 1(b) shows the optical spectra of the OFC before injection-locking (the black trace) and the two CW modes after injection-locked by the OFC (the red trace).

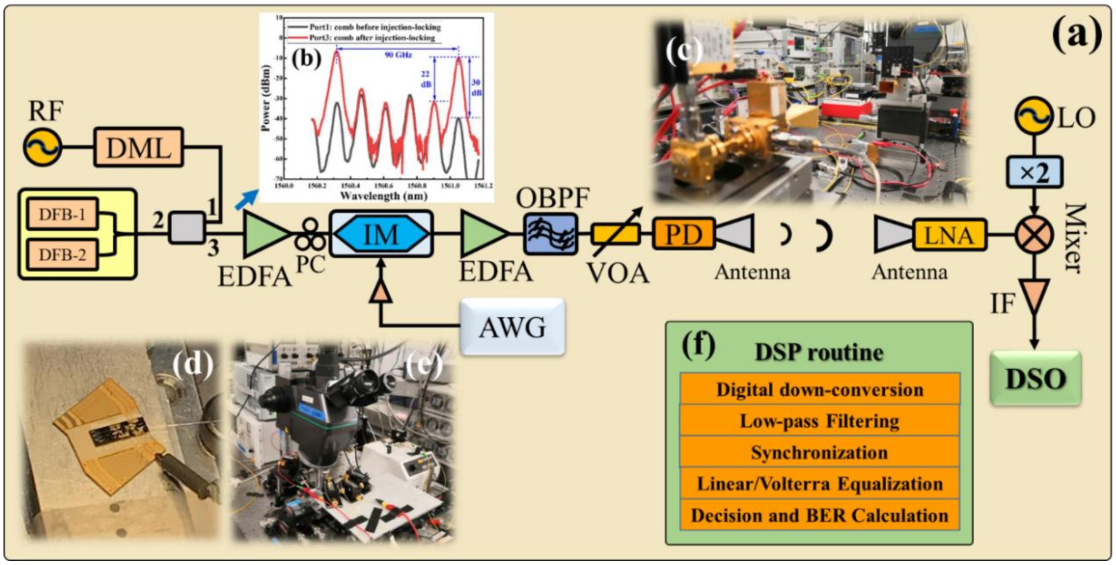

Fig. 1. Experimental configuration of the integrated Dual-DFB laser chip-based PAM-4 photonic-wireless transmission system in the W-Band: (a) The experimental setup of the overall system. (b) The optical spectrum of the injection-locking section. (c) The picture of the actual wireless link. (d)-(e) The pictures of the actual integrated Dual-DFB laser chip and the chip probe in the system. (f) The structure of the digital signal processing (DSP) routine at the receiver side. DFB: distributed feedback, RF: radio frequency, DML: directly modulated laser, EDFA: erbium-doped fiber amplifier, PC: polarization controller, IM: intensity modulator, AWG: arbitrary waveform generator, OBPF: optical band pass filter, VOA: variable optical attenuator, PD: photodiode, LNA: low noise amplifier, LO: local oscillator, DSO: digital sampling oscilloscope, IF: intermediate frequency.

The two coherent tones with 90 GHz spacing generated in the dual-DFB laser chip injection-locked by the OFC are amplified by an erbium-doped fiber amplifier (EDFA) and both fed into an intensity modulator for modulation. A 65 GSa/s arbitrary waveform generator (AWG) is used to generate the PAM-4 data. Here the two optical tones are modulated with same data simultaneously, to increase the SNR of the beating wireless signal and save an extra optical LO, compared to the traditional scheme of using one tone for modulation and the other tone for the LO [2]. The two optical carriers with same PAM-4 modulation are amplified by another EDFA followed by an optical band-pass filter (OBPF) to remove out-of-band amplified spontaneous emission (ASE) noise. A variable optical attenuator (VOA) is used to accurately control the optical power launched into the PD (XPDV 4120R, 3-dB bandwidth of 90 GHz) for photo-mixing. At the output of the PD followed by a horn antenna, a single-channel PAM-4 wireless signal centered at 90 GHz is generated and emitted into a 0.5-m lens-free wireless link, as shown in Fig. 1(c). Another horn antenna is used to receive the W-band wireless signal, and the received signal is first amplified by a low noise amplifier (LNA, 75-110 GHz) with a 40-dB gain. Then, the W-band signal after the LNA is down-converted to the intermediate frequency (IF) by a mixer operating in the W-band, driven by a 2-time frequency multiplied electrical LO. The IF output signal is amplified by a RF amplifier with 40 GHz bandwidth, and then fed into a broadband real-time digital sampling oscilloscope (DSO, Keysight DSOZ334A Infiniium Oscilloscope) with 80 GSa/s sampling rate and 33 GHz analog bandwidth, for analog-to-digital conversion, demodulation and communication performance analysis. The digital signals are processed and analyzed offline with a specifically designed digital signal processing (DSP) routine.

For the DSP routine at the transmitter side, the data is first mapped onto PAM-4 symbols and then the PAM-4 signal is shaped by a Raised-Cosine (RC) filer to shrink the signal bandwidth. The roll-off factor of the RC filter is set to 0.01. The shaped signal is then resampled to match the sampling rate of the AWG. At reception, the structure of the DSP routine at the receiver side is shown in Fig. 1(f). The captured waveform is firstly down-converted to the baseband domain. A digital down-conversion is performed with the LO at 16.5 GHz, which corresponds to the frequency of the IF output signal of the mixer. After the low-pass filtering and synchronization, a linear/Volterra equalizer is used to equalize the signal. Finally, the signal quality is evaluated for measuring the bit-error-rate (BER) performance.

3. Experimental results and discussions

The optical spectrum of injection-locking section is shown in Fig. 1(b), including the OFC generated from the DML driven by an 18-GHz RF signal before injection-locking (the black trace), and the two CW modes from the integrated dual-DFB laser chip injection-locked by the OFC (the red trace). The two CW modes injection-locked by the OFC are phase-stabilized. The single-channel W-band PAM-4 signals are evaluated after the wireless transmission. As shown in Fig. 2(a), the BER performance for two cases of 10 GBaud and 20 GBaud PAM-4 signals have been measured as a function of the optical power launched into the PD. It can be seen that for the 10 GBaud PAM-4 signal, the BER below the hard-decision forward error correction (HD-FEC) threshold of 3.8×10^{-3} with 7% overhead is successfully

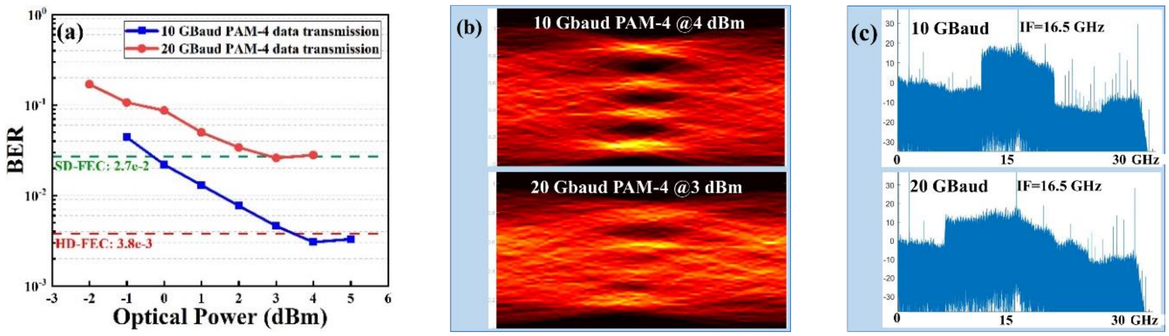

Fig. 2. (a) The BER performance for the 10- and 20 GBaud PAM-4 signals after wireless transmission. (b) Eye diagrams of 10 GBaud PAM-4 signal at 4 dBm optical power and 20 GBaud at 3 dBm. (c) The electrical spectra of the 10- and 20 GBaud PAM-4 signals after the down conversion.

achieved, resulting a line rate of 20 Gbit/s and a net rate of 18.7 Gbit/s. In terms of the 20 GBaud PAM-4 signal, it has achieved the BER performance below the soft-decision FEC threshold of 2.7×10^{-2} with 20% overhead (20%-OH SD-FEC) [11], resulting in a line rate of 40 Gbit/s and a net rate of 33.3 Gbit/s. It should be noted that with higher optical power launched into the PD than 4 dBm for the 10 GBaud case and 3 dBm for the 20 GBaud case, BER performances cannot be further improved, which is mainly attributed to the saturation of the mixer in the receiver. The PAM-4 signal eye diagrams measured at 4 dBm optical power for 10 GBaud and at 3 dBm for 20 GBaud case are shown in the inset of Fig. 2(b). Fig. 2(c) shows the electrical spectra of the 10-GBaud and 20-GBaud PAM-4 IF signals after the down conversion using the mixer. The IF frequencies for the two cases are both set to be around 16.5 GHz, and the mixer is driven by a 73.5 GHz electrical LO, which is generated by 2-time frequency multiplying a 36.75-GHz RF sinusoidal signal.

The overall performance of the photonic-wireless transmission system is mainly limited by the efficiency of the PD (0.5 A/W), the relatively high conversion loss (8-17 dB) of the mixer and free-space path loss (FSPL) without any lenses. In addition, the noise figure of the W-band and IF amplifiers and the layout of antennas are also relevant for the system performance. Since the DML generating the OFC could be potentially integrated with the dual-DFB laser, this scheme has the potential for realizing a fully integrated photonic-wireless transmitter. In addition to the integrated dual-DFB laser chip and the DML, optical coupler, intensity modulator, optical amplifiers, filter and PD could also be integrated on the InP platform [12].

4. Conclusions

We experimentally demonstrate a 20 Gbit/s and 40 Gbit/s PAM-4 photonic-wireless link in the W-band based on a monolithically integrated dual-DFB laser, with the BERs below the HD-FEC and SD-FEC limits, respectively. The phase-stabilized W-band wireless carrier is generated in a photo-mixing PD with the input of two phase-coherent optical carriers, which are generated by the integrated dual-DFB laser injection-locked to an OFC. The OFC is emitted from a DML driven by the 18-GHz RF sinusoidal signal. The two phase-coherent optical carriers from the dual-DFB laser are modulated with the PAM-4 signal simultaneously to increase the beating SNR, while saving an extra optical LO. This lens-free photonic-wireless link based on the integrated dual-DFB laser chip, with low cost and simple configuration, is suitable for the future broadband wireless applications. Such a scheme has the potential for the realization of a fully integrated photonic-wireless transmitter.

Acknowledgements

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