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260 Gbit/s Photonic-Wireless Link in the THz Band

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***Abstract*— A single-transmitter/single-receiver THz link (0.3-0.5 THz) with a record net data rate of 260 Gbit/s is experimentally demonstrated. Spectrally efficient multi-channel signal transmission is enabled by a novel frequency-band-allocation scheme with pre-and-post- digital equalization.**

I. Introduction

The forecasted demand of wireless data rates has been driving the research progress of millimeter wave (MMW) and THz technologies in an accelerating pace from both the device and the system level. To date, extensive efforts have been put into converged research from both photonics and radio communities and significant progress has been achieved [1]. System demonstrations with wireless bitrates of the order of 100 Gbit/s have been demonstrated in different frequency bands in both real-time and offline experiments, including the sub-THz band (200-300 GHz) [2] and the THz band (>300 GHz) [3-6]. However, in order to reach the capacity limit of such channels, spectrally efficient modulation formats and optimal spectral arrangement of the used frequency bands are essential. The recent record of 160 Gbit/s using a single THz emitter was achieved with multi-channel Nyquist QPSK in the 0.3-0.5 THz band [7].

In this paper, we report on a record-high bit rate transmission in the THz regime that significantly exceeds the current record. We firstly use 16QAM modulation to double the spectral efficiency. Then we apply a novel spectral arrangement, where the channels are grouped in pairs instead of equally spaced to reduce the number of guard bands. Finally, we employ a tailored DSP routine with pre- and post-equalization to accurately reconstruct the channel response. Three configurations are demonstrated with 2-, 4- and 6-frequency channels, each modulated with 20, 16 and 12.5 Gbaud 16QAM signals, respectively. This results in pre-FEC line rates of up to 300 Gbit/s and a demonstration of post-FEC error-free bit rates of up to 260 Gbit/s. This result constitutes a new record bit rate for a single emitter in the THz band above 300 GHz.

II. Experimental setup

Figure 1a shows the experimental setup. We launch the output of an external cavity laser (ECL, <100 kHz linewidth) into two cascaded intensity and phase modulators, to generate an optical frequency comb. For 2- and 4-channel operations the line spacing is set to be 25 GHz, and 17 GHz for the 6-channel case. A programmable wavelength selective switch (WSS) is used to separate the even and odd channels, and to perform equalization. An arbitrary waveform generator (AWG, 64 GSa/s) is employed to map and modulate four shifted PRBS 2^{15}-1 sequences into 16QAM signals at two IQ modulators, whereafter adjacent channels are decorrelated and re-combined. The 16QAM signals are RRC pulse shaped with 0.15 roll-off factor and a pre-emphasis equalizer is used to pre-compensate the AWG output roll-off. The baseband optical signal is amplified and filtered before being coupled with a free-running local oscillator (LO) ECL. An ultra-broadband uni-travelling carrier photodiode (UTC-PD) [8] is used for heterodyne mixing. The corresponding optical spectra are shown in Fig.1b. At the output of the UTC-PD, multi-channel THz signals with carrier frequency centered around 400 GHz are generated. A pair of THz lenses is used to collimate the THz beam in a line-of-sight (LOS) link (shown in Fig.1a insets). In this proof-of-principle demonstration, we show transmission of 0.5 m, but it is well established that 0.3-0.5 THz beams can be used for 10-100 m indoor communication [1].

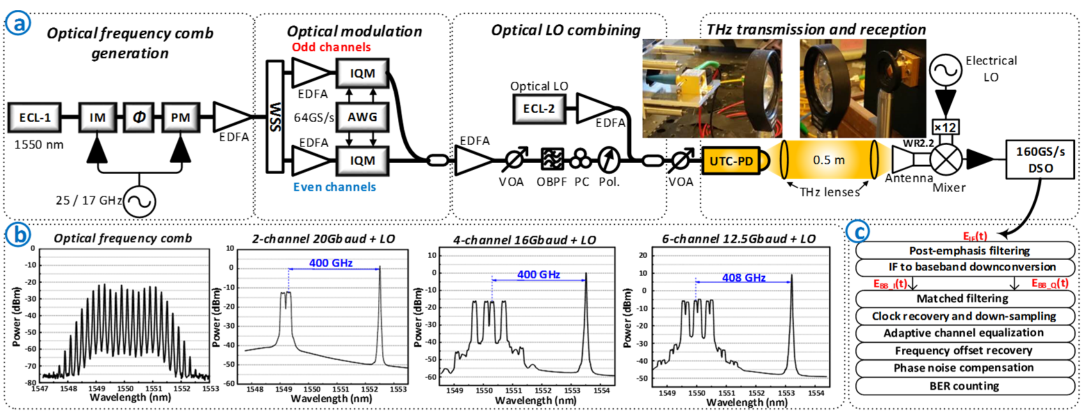

Fig. 1: a). Experimental setup of the 300-500 GHz link. IM: intensity modulator, PM: phase modulator, WSS: wavelength selective switch, AWG: arbitrary waveform generator, DSO: digital sampling oscilloscope. b). Optical spectra of generated optical frequency comb, and multichannel signals with LO. c). Structure of the DSP routine at the receiver.

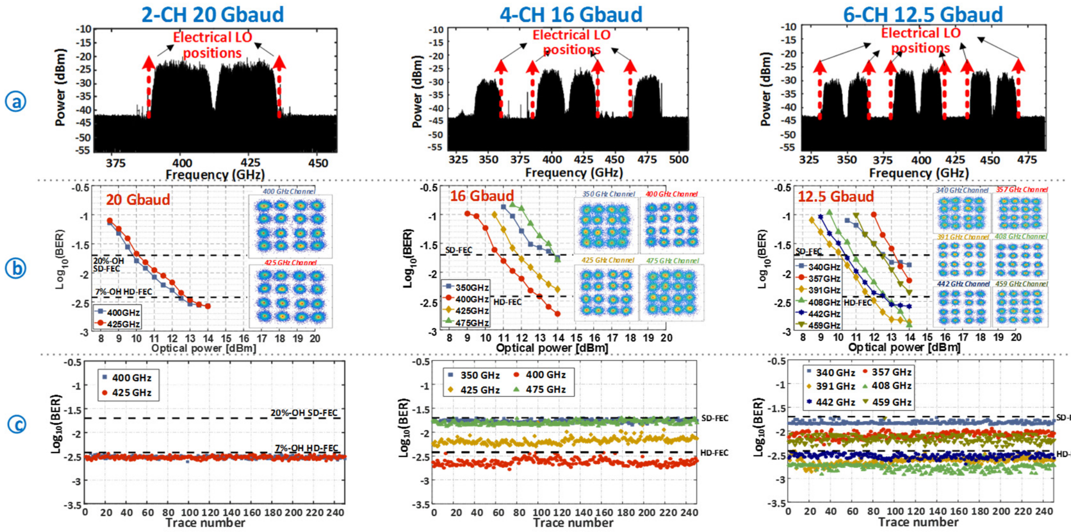

Fig. 2: a). Electrical spectra of the multichannel THz signals. b). BER vs. optical power into the UTC-PD. Constellations are shown for all channels at 14 dBm optical power. c). System stability tests for all configurations (250 traces (~25 min) per channel, 800 k Sa/Trace)

At the receiver, the signal is down-converted to an intermediate frequency (IF) signal using a 12-order harmonic THz Schottky mixer operating in the range of 300-500 GHz. The mixer is driven by a 27-39 GHz tunable electrical LO signal. Note that the frequency channels are arranged in pairs to further increase the overall spectral efficiency by reducing the number of guard bands, compared with the equal channel spacing arrangement reported previously [7]. The positions of the LO are shown in Fig. 2a. The IF signal is amplified and sampled at a 160 GSa/s digital storage oscilloscope (DSO) of 63 GHz analog bandwidth. The digital signals are processed and analyzed offline with a specifically designed DSP routine in a quasi-real-time manner with a loop probing the captured samples every ~6 seconds. The structure of the DSP chain is shown in Fig.1c. We firstly use a 2-tap static post-emphasis equalizer to compensate the receiver bandwidth limitation. After down-conversion, the baseband signal is processed through matched filtering, resampling and clock recovery, 29-tap multi-modulus algorithm (MMA) based adaptive channel equalization, blind phase search based 2-stage frequency and phase recovery, before differential decoding. The bit-error-rate (BER) is evaluated by counting errors with ~400k bits per trace.

III. Results

In this work, we successfully demonstrate three configurations, namely 2-ch 20 Gbaud, 4-ch 16 Gbaud and 6-ch 12.5 Gbaud 16QAM signals, corresponding to line rates of 160 Gbit/s, 256 Gbit/s and 300 Gbit/s, respectively. We measure BER as a function of launched optical power into the UTC-PD for all channels in all 3 configurations, as shown in Fig. 2b, and successfully show below-FEC threshold performance in all 3 cases. In the 2-ch 20 Gbaud case, both channels centered at 400 GHz and 425 GHz achieve BER performance below the 7% overhead hard-decision forward error correction (7%-OH HD-FEC) threshold, yielding an error-free post-FEC net bit rate of 150 Gbit/s. In the case of 4-ch 16 Gbaud, the channel centered at 400 GHz achieved BER below the7%-OH HD-FEC threshold, while the performances of the other 3 channels are below the 20% overhead soft-decision FEC (20%-OH SD-FEC) limit, resulting in an overall post-FEC error-free net bit rate of 220 Gbit/s. In the 6-ch 12.5 Gbaud configuration, the 3 channels at 391 GHz, 408 GHz and 442 GHz achieved BER performance below the 7%-OH HD-FEC and the other 3 channels are below the 20%-OH SD-FEC limit, resulting in a record-high post-FEC error-free net bit rate of 260 Gbit/s. Additionally, we evaluate the performance stability of the link and the DSP routine in the lab environment and show the results in Fig. 2c. For each case we run the system continuously over 25 minutes, collecting 250 traces of 800 k samples and counting errors. It is observed that for all cases the system could maintain the BER performance within a small fluctuation range, below the corresponding FEC limit. The results confirm the stability of the demonstrated high-speed THz link with a free-running optical LO for incoherent heterodyne mixing, operating with the specifically tailored DSP routine.

IV. Conclusion

We have experimentally demonstrated a record data-rate in a THz photonic-wireless link covering the 0.3-0.5 THz band using a single THz transmitter and a single receiver. By optimizing the frequency channel arrangement and employing specifically tailored DSP routines, a record 260 Gbit/s THz wireless transmission is achieved with high stability.

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