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Demonstration of DSM-OFDM-1024QAM transmission over 400 m at 335 GHz

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The terahertz (THz) band has received extensive attention and is considered a potential band for future mobile communications [1]. Up to now, 1024QAM and 2048QAM have been adopted in practical applications. For such high-order QAM (quadrature amplitude modulation) signal transmission, the current THz system is difficult to support. Considering the abundant bandwidth resources of the THz band, the delta-sigma modulator (DSM) with oversampling could be a good solution. Usually, low-resolution DSMs with oversampling are used to quantize the baseband signal, and the in-band noises are reduced by the noise shaping technique [2].

In such a system, the high-order signals can be converted into low-order ones so that a high receiver sensitivity can be obtained. Moreover, the receiver can use an ADC (analog-to-digital converter) with a lower resolution for low-order signal reception. In this study, we proposed and demonstrated a DSM-based THz-over-fiber system for high-order orthogonal frequency division multiplex (OFDM) signal transmission. 1.25 Gbaud OFDM-256QAM 1024QAM signals can be successfully transmitted over 20 km SMF (single-mode fiber) and 400 m wireless link at the terahertz band. The BER (bit error rate) of the OFDM-256QAM and OFDM-1024QAM after the transmission can satisfy the SD-FEC (soft-decision forward error correction) threshold of 4.0 $\times 10^{-2}$ and HD-FEC (hard-decision FEC) threshold of 3.8 $\times 10^{-3}$, respectively.

The experimental setup is demonstrated in Figure 1(a). At the transmitter (Tx) side, the external cavity laser-1 (ECL1) with the 100 kHz linewidth is employed as the optical carrier source. The baseband electric signal, delivered by the 10-Gsa/s arbitrary waveform generator (AWG), is modulated via the I/Q modulator with 30-GHz bandwidth. After the polarization-maintaining erbium-doped optical fiber amplifier (PM-EDFA), the modulated signal is coupled with the optical oscillator signal generated by ECL2. The frequency space between two signals is set as 335 GHz. Heterodyne beaten by the uni-traveling-carrier photodiode (UTC-PD) and amplified by the 25-dB gain low-noise amplifier (LNA), the wireless 335 GHz signal at −10 dBm is delivered by the 25-dBi gain antenna [3, 4].

At the transmitter, the 1.25 Gbaud OFDM signal is used as the baseband signal for transmission. We use two 1-bit fourth-order DSMs with an OSR (oversampling rate) of 8 to quantize the real and imaginary parts of the baseband OFDM signal. The two 1-bit DSMs can generate two OOK (on-off keying) signals, which can be combined as an 8 Gbaud single carrier (SC) quad-phase shift keyed (QPSK) signal and then used to drive the I/Q modulator for optical modulation. A pair of polytetrafluoroethylene lenses are deployed for the signal beam aggregation to support a 400-m wireless link. Two tripod heads are deployed to adjust the elevation, azimuth, and height of the Tx and receiver (Rx) for better performance. At the Rx side, the signal down-conversion is realized via an integrated mixer/amplifier/multiplier chain consisting of a 20.625-GHz radio frequency (RF) source, a × 16 frequency multiplier, and a mixer [5]. The 5 GHz intermediate-frequency (IF) signal is captured by a 50 GSa/s oscilloscope (OSC) for following offline digital signal processing.

The DSP (digital signal processing) in the receiver includes two parts: the equalization for QPSK and the DSM demodulation. The sampled signals are firstly down-converted to the baseband for the following DSP. A 73-tap CMA (constant modulus algorithm) equalizer and a decision-directly least-mean-square (DD-LMS) equalizer with 133 taps is adopted. Before DSM demodulation, the equalized signals are decided into the standard QPSK constellations. After LPF (low-pass filter) and down-sampling operation, the baseband OFDM signal can be recovered. Fi-

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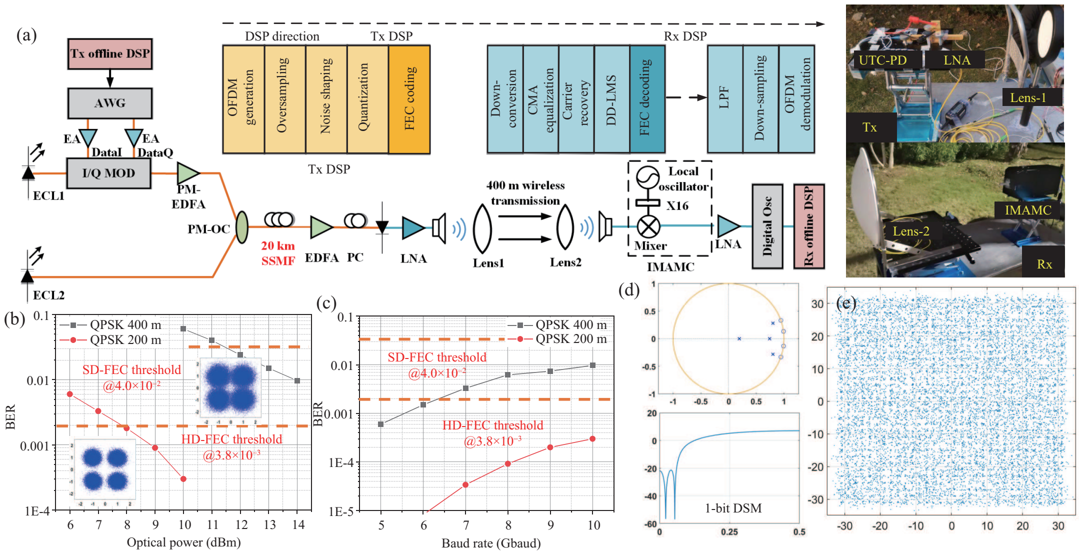

Figure 1 (Color online) The experimental setup of the DSM-based THz-over-fiber transmission system (a) and the experimental results: measured BER of the DSM-QPSK with (b) different optical power and (c) different baud rates; (d) zero-poles and magnitude-frequency response of the 1-bit DSM; (e) constellations of the recovered OFDM-1024QAM.

nally, we can simply recover the original high-order QAM signals by reversing the operations of the OFDM generation at the transmitter. Here, the FFT (fast Fourier transform) size of the OFDM signal is 1024 and the CP (cyclic prefix) length is 16.

Even a small number of misjudgments of constellation points can lead to performance degradation of the recovered signal. We can use the commonly used FEC threshold. Usually, FEC coding can reduce the BER of the DSM-QPSK signal to 1E−6 or even lower so that the original OFDM-QAM can be recovered. Figure 1(b) shows the measured BER of the 10 Gbaud DSM-QPSK signals with different optical power. Figure 1(c) presents the measured BER of DSM-QPSK signals with different baud rates. The constellations of the recovered OFDM-1024QAM are also given in Figure 1(d). The corresponding BER is 0.028. Generally, high-order QAM signals are hard to be transmitted due to the nonlinearities and low SNR (signal to noise ratio). The DSM-QPSK signals can overcome these limitations and can be a promising solution in future mobile networks, such as mobile fronthaul and indoor scenarios.

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