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Photonic-Generated 256-Gbit/s Dual-Polarization 287-GHz Wireless Transmission over 56 m

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***Abstract*—We present a 56-m coherent dual-polarization wireless transmission experiment in the 300-GHz band employing photonic local-oscillator generation at the transmitter and an entirely electronic intradyne receiver. A single dual-polarized antenna aperture is deployed at each end of the link, thereby enabling polarization-division multiplexing without the need for parallel antenna pairs. Dual-polarization quadrature phase-shift keying (QPSK) signals are transmitted at symbol rates ranging from 30 to 64 Gbaud, achieving a maximum gross data rate of 256 Gbit/s at the highest baud rate. Over this symbol-rate range, the measured signal-to-noise and distortion ratio degrades from approximately 15 dB to 11 dB, with a polarization imbalance of less than 0.5 dB between the two orthogonal polarization channels.**

***Index Terms*—Terahertz communication, Coherent optical communication, Polarization-division multiplexing, Quadrature phase shift keying, Wireless communication.**

I. Introduction

Ultra-high-capacity wireless links will play a central role in future mobile communication infrastructures, supporting demanding applications such as extended reality, autonomous systems, and massive machine-type communications [1], [2]. In particular, wireless fronthaul and backhaul networks can benefit from sub-terahertz (sub-THz) transmission technologies, which offer fiber-like capacities while avoiding the installation costs and deployment constraints associated with optical fiber. Compared with free-space optical (FSO) systems, sub-THz links also exhibit lower sensitivity to adverse weather conditions such as rain, fog, and atmospheric turbulence, enabling more robust operation under a wider range of environmental conditions.

As spectrum resources below 100 GHz become increasingly congested, attention has shifted toward higher frequency bands. To facilitate the development of ultra-high-speed wireless systems, IEEE 802.15.3d in 2017 allocated the frequency range between 252.72 and 321.84 GHz for point-to-point communications [3]. Nevertheless, operation in this spectral region is challenging due to the large free-space propagation losses and the limited output power and sensitivity of currently available broadband electronic and optoelectronic devices [4]. These constraints necessitate the use of highly directive antennas, resulting in narrow-beam links that are particularly suited to fixed line-of-sight connections spanning tens to hundreds of meters [5]–[7]. Recent demonstrations have pushed the capacity of sub-THz wireless links well beyond 200 Gbit/s. Aggregate capacities beyond the terabit-per-second threshold have also been demonstrated, with 1.034 Tbit/s transmission over 100 m at 300 GHz through multidimensional frequency, polarization, and spatial-division multiplexing [8]. More recently, a photonics-aided THz-over-fiber system operating at 317 GHz achieved a record net rate of 374.4 Gbit/s per wavelength and polarization over 25 km of fiber and a 1 m wireless link [9]. In parallel, long-distance operation reached 0.2 Gbit/s over 3 km at 335 GHz [10].

Further capacity scaling can be achieved either by increasing the signal-to-noise ratio (SNR) or by transmitting multiple parallel data streams through spatial and/or polarization

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multiplexing. Owing to the logarithmic relationship between capacity and SNR, parallel transmission provides a more efficient path toward substantial throughput increases [11]. Spatial multiplexing based on multiple free-space beams has been extensively investigated [8], [12]. However, it generally requires either large antenna separations or non-orthogonal beam patterns, the latter introducing residual inter-channel interference. As a result, aggregate capacities beyond 1 Tbit/s have so far relied on multiple apertures and parallel transceiver chains [8], significantly increasing system complexity relative to single-aperture architectures.

Sub-THz signals can be generated through two principal approaches: electronic upconversion, in which baseband or intermediate-frequency signals are translated to the target carrier frequency using electronic frequency multipliers and mixers, and optoelectronic downconversion, where photonic techniques are employed to generate the wireless carrier directly from optical frequencies [13]. Electronic solutions generally provide compact and power-efficient receivers, whereas optoelectronic techniques offer high bandwidth and facilitate seamless integration with fiber optic links. Although quantum-cascade lasers (QCLs) can also directly generate sub-THz signals, their limited output power, modulation bandwidth and cooling requirements currently make them unattractive for short-range ultra-high-capacity communication links. In [13] it was shown that a hybrid architecture, combining optoelectronic transmission with electronic reception, offers superior performance for a high-capacity point-to-point sub-THz link.

In this paper, we experimentally demonstrate a single-aperture polarization-division-multiplexed wireless link operating at 287 GHz over a 56-m line-of-sight path. The transmitter employs photonic carrier generation, while reception is performed using a fully electronic dual-polarization intradyne architecture. Dual-polarization QPSK signals are transmitted at up to 64 Gbaud per polarization, corresponding to a line rate of 256 Gbit/s within the IEEE 802.15.3d frequency allocation.

II. Experimental Setup

Fig. 1 summarizes the link hardware. An external-cavity laser (ECL) at 193.1 THz, denoted L1, drives a dual-polarization IQ Mach–Zehnder modulator (MZM). The four electrical drive signals are generated by a 120-GSa/s arbitrary waveform generator (AWG). Each tributary carries a QPSK waveform shaped with a root-raised-cosine filter having a 5% spectral roll-off factor. The symbol rate is varied between 30 and 64 Gbaud.

After modulation, the optical signal is amplified by an erbium-doped fiber amplifier (EDFA), filtered with a 1-nm optical band-pass filter, and combined using a 3-dB coupler with a second ECL, L2 at 193.387 THz. The optical offset between L1 and L2 sets the sub-THz carrier frequency of 287 GHz, which was selected to remain within the IEEE 802.15.3d frequency allocation. A variable optical attenuator (VOA) adjusts the launch power before the polarization beam splitter (PBS). The outputs of the PBS are connected to two single-polarization uni-traveling-carrier (UTC) photodiodes (PDs), where optical heterodyning generates the sub-THz carrier. The resulting RF signals are combined by a WR-3.4 orthomode transducer (OMT) and radiated through a dual-polarized horn antenna equipped with cascaded lenses. The horn provides 26 dBi gain, while the lens assembly increases the total antenna gain to 51.1 dBi and reduces the beam divergence to 0.57° [14].

The receiver side mirrors the transmitter. A second identical cascaded-lens antenna system collects the signal, another OMT separates the orthogonal polarizations, and two synchronized intradyne IQ receiver chains recover the electrical quadratures. The receiver chains employ novel fully integrated 35-nm mHEMT front-end chips incorporating a fourfold LO multiplication stage, amplification, and a second-harmonic sub-THz IQ mixer. A shared 35.875-GHz electrical LO drives both branches, and the front-end LNA provides 28 dB small-signal gain with an approximately 7 dB noise figure from 220 GHz to 330 GHz. The four receiver outputs are further amplified by two microwave amplifiers, and then digitized by a four-channel real-time oscilloscope (RTO) with 80-GHz analog bandwidth and 256-GS/s sampling rate. The optical-spectrum inset in Fig. 1 shows the frequency offset that creates the wireless carrier, and the link remains within the IEEE 802.15.3d band at the highest-rate setting.

Digital signal processing (DSP) is performed offline using a fully blind receiver chain. The recorded waveforms are resampled to two samples per symbol, followed by Godard timing recovery. The two polarization tributaries are jointly equalized using a 2×2 constant-modulus-algorithm (CMA) MIMO equalizer to compensate for polarization mixing caused by the fiber section between the modulator and PBS. Frequency-offset estimation is then performed using a periodogram-based algorithm, followed by Viterbi–Viterbi carrier-phase recovery. Finally, the recovered symbols are compared with the transmitted sequence to estimate the signal-to-noise and distortion ratio (SNDR) and bit-error rate (BER), assuming a hard-decision decoder.

III. Experimental results

The transmit optical power was first optimized at a symbol rate of 30 Gbaud. Figure 2 shows the measured SNDR as a function of the optical power at the VOA output. An optimum operating point is observed around 18 – 18.5 dBm, corresponding to a trade-off between noise-limited performance at low power and nonlinear distortion at high power. The approximately 1-dB SNR difference between the two polarizations is attributed to receiver imbalance and residual polarization-dependent loss in the dual-polarization IQ modulator. The optical launch power was then fixed at 18.5 dBm, and the symbol rate was increased from 30 to 64 Gbaud. Figure 3 corresponds to a separate SNDR measurement campaign with improved link alignment, explaining the slightly higher SNDR at 30 Gbaud. The measured SNDR decreases from approximately 15 dB at 30 Gbaud to 11 dB at 64 Gbaud. This degradation

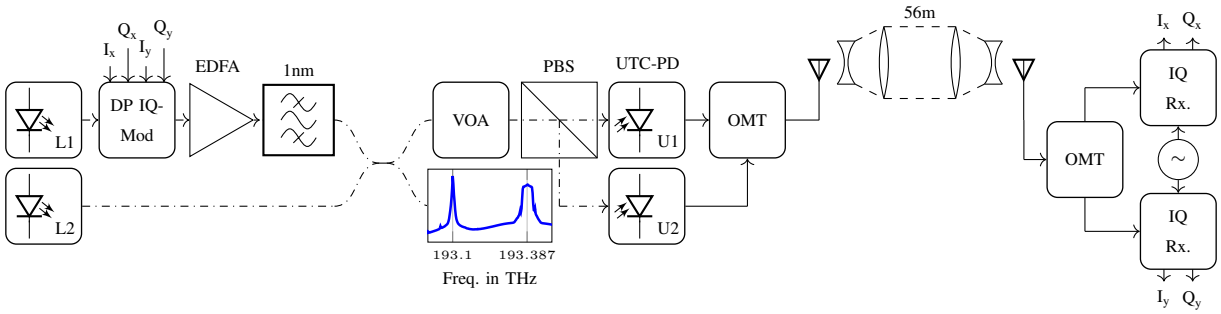


Fig. 1. Experimental setup of the 56-m dual-polarization sub-THz wireless link. The transmitter converts dual-polarization optical IQ signals to the wireless domain through two UTC photodiodes, an orthomode transducer (OMT), and a single dual-polarized cascaded-lens antenna. The receiver uses the same antenna concept in reverse, with a second OMT and two synchronized intradyne IQ receiver chains. The insets show the transmit optical spectrum.

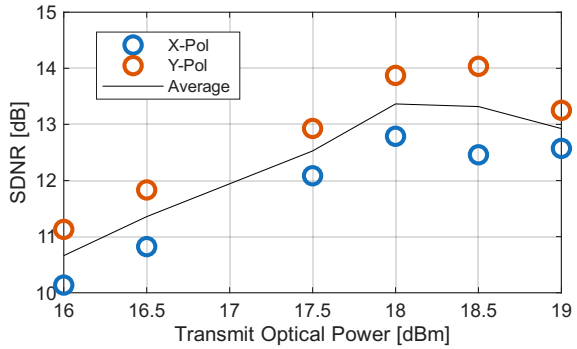


Fig. 2. Signal-to-noise and distortion ratio (SNDR) as a function of the transmit optical power, measured after the variable optical attenuator before the polarization beam splitter, of a dual-polarization QPSK transmission at 30 Gbaud after 56 m wireless transmission.

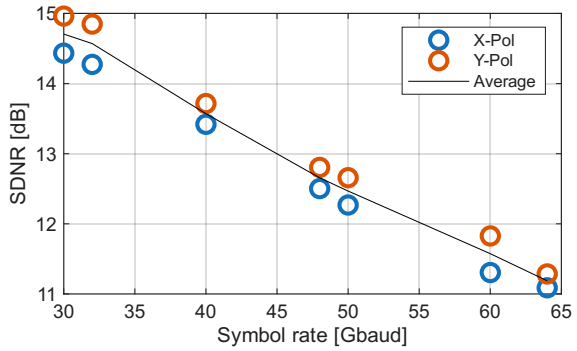


Fig. 3. Signal-to-noise and distortion ratio (SNDR) as a function of the symbol rate of a dual-polarization QPSK transmission after 56 m wireless transmission. The transmit optical power was set to 18.5 dBm.

is primarily attributed to the increased occupied bandwidth and the corresponding limitations of the transmitter, receiver, and acquisition hardware. At higher symbol rates, the SNDR imbalance between polarizations decreases to less than 0.5 dB. Representative received constellations are shown in Fig. 4. Error-free operation is achieved at 30 Gbaud, whereas the BER at 64 Gbaud is approximately 2×10^{-4}. This value remains below the threshold of the KP4 RS(544,514) hard-decision FEC, which provides a BER limit of approximately 2.2×10^{-4}

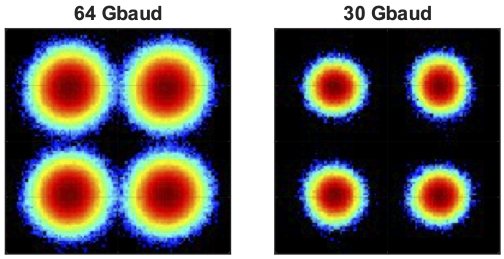


Fig. 4. Resulting constellations of the X-polarization at two different symbol rates, at the same 18.5 dBm transmit optical power.

with only 5.84% overhead. Consequently, all investigated operating points can achieve error-free transmission after FEC.

IV. Conclusion

We demonstrated a 56-m dual-polarization wireless link operating at 287 GHz using photonic carrier generation and a fully electronic dual-polarization intradyne receiver. By employing a single dual-polarized antenna aperture at each end of the link, polarization-division multiplexing was realized without duplicating the antenna hardware. Dual-polarization QPSK transmission at symbol rates up to 64 Gbaud achieved a gross line rate of 256 Gbit/s while remaining within the IEEE 802.15.3d allocation. Measured SNDR values ranged from approximately 15 dB to 11 dB, with less than 0.5 dB polarization imbalance. The results demonstrate that polarization-division multiplexing can significantly increase the capacity of sub-THz wireless links without requiring additional antenna apertures or parallel wireless paths.

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