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Single-channel 100 Gbit/s transmission using III–V UTC-PDs for future IEEE 802.15.3d wireless links in the 300 GHz band

V.K. Chinni, P. Latzel, M. Zégaoui, C. Coinon, X. Wallart, E. Peytavit, J.F. Lampin, K. Engenhardt, P. Szriftgiser, M. Zaknoue and G. Ducournau

The achievement of single-channel 100 Gbit/s transmission, using linear untravelling carrier photodiodes and QAM-16 modulation format is reported. The wireless link has been done in the indoor case, considering the recent frequency standardised 300 GHz bands.

Introduction: From the connected society data usage, the market is pulling the wireless data rates. Since 10 years, researchers have made significant efforts to reach the required technological breakthrough toward wireless communications at high data rates. This continuously growing demand for data rates has driven the carrier frequencies to be extended up to the terahertz (THz) range, for front and backhaul in cellular communications. Recently, a new standard has been established by the IEEE [1], emerging from the THz wireless communications research that has been very intensive these past years [2]. Many technologies offer interesting features for THz communications, for example, III–V electronics can offer long-distance links [3], silicon germanium electronics are growing very fast for radar and communications applications [4]. Also, resonant tunnelling diodes devices have shown good performances for short-range links [5]. However, the increase of frequency is also associated with increased phase noise effects in electronic solutions, and the non-linear behaviour of circuits have deleterious effects. Photonics-based solutions, even less powerful than electronic-based, are intrinsic wideband and linear due to the photomixing process. Up to now, photonics used as THz emitter has shown to enable up to 100 Gbit/s around 240 GHz [6] (off-line detection), and also QPSK (real time) [7].

We demonstrate in this Letter the use of a linear photodiode (PD), operating at 280 GHz for up to 100 Gbit/s data rates, combined with a single sub-harmonic mixer (SHM) and off-line detection. Achieved BERs are lower than 10^{-6} , in the 69th channel of the new IEEE 802.15.3d standard.

Description of the THz link: Fig. 1 shows a general overview of the 100 Gbit/s link. It is composed of an optical transmitter, an optical to THz down-converter [resonant cavity enhanced (RCE) untravelling carrier PD (UTC-PD) [8]], and THz receiver composed of an SHM, combined with a broadband microwave amplifier. The detection is realised using a wide bandwidth real-time oscilloscope.

The system is first composed of an optical QAM-16 transmitter in C-band (1535–1565 nm), driven by two arbitrary waveform generators (AWGs). To create the THz data signal, an optical carrier (193.4 THz) is modulated using a dual-nested Mach–Zehnder configuration. The AWG was used to create two baseband pulsed amplitude modulation with four levels, filtered by a root-raised cosine filter, with 0.35 roll-off factor for spectral shaping, corresponding to the typical input eyes of Fig. 1. The corresponding spectra are 36 GHz wide in the optical domain. A second optical continuous wave tone (193.12 THz, e.g. 280 GHz separation between the two optical lines) is combined before injection in an erbium-doped fibre amplifier, to drive the photomixer (RCE UTC-PD). The UTC-PD is directly on-wafer probed using coplanar probes in the range 220–330 GHz (inset of Fig. 2). A waveguide-based horn antenna is then used to radiate the 280 GHz signal in the free space. This transmitter configuration enables to leave the THz signal inside the 69th channel of the new IEEE 802.15.3d standard for 100 Gbit/s wireless links [1].

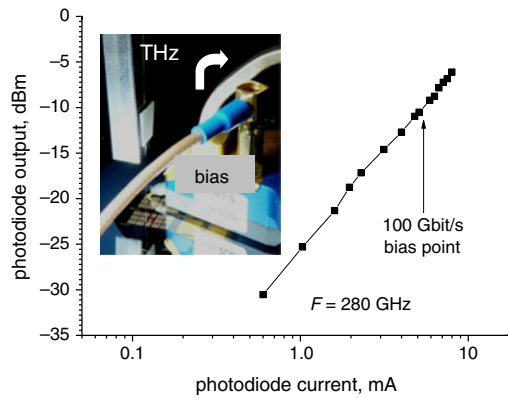


Fig. 2 Output power of RCE UTC-PD at carrier frequency (280 GHz). Inset: view of probed device. Left: fibre holder to illuminate device and right: coplanar probe in 220–325 GHz range

The 280 GHz signal is first collimated using a teflon lens, and further focused to feed the SHM at the receiver. The distance used in this experiment was 0.5 m as the main target was to evaluate the linearity of the system, in a short-range link. The receiver is composed of an SHM, pumped to operate at 298 GHz, to downconvert the THz QAM-16 signal into an intermediate frequency of 18 GHz, amplified and detected by a wideband real-time oscilloscope. Off-line processing is used to display constellations, eye diagrams as well as BER estimation.

The structure and topology of the UTC-PD used in this experiment have been reported recently [8]. This PD uses a semi-transparent top contact utilising subwavelength apertures for enhanced optical transmission, front-side illumination of the PD (1.55 μm wavelength). The responsivity of the device is increased by introducing a metallic mirror below the diode mesa through wafer bonding. The DC response of the UTC-PD (4 μm diameter) used here is 0.1 A/W.

Transmitter power and bandwidth measurement: The available power at RCE UTC-PD output is given by Fig. 2.

To optimise the QAM-16 operation, a linear behaviour is required for the transmitter. No saturation effects were observed up to 8 mA. By taking a 3.5 dB margin, the operating point was chosen to be around 5.3 mA. In addition, the carrier frequency was determined to obtain the flattest response of the transmitter as well as lowest conversion losses of the SHM at the receiver to limit the residual dispersion of the THz link. Fig. 3 gives the transmitter frequency evolution of the output power, in the range 220–330 GHz. Considering the spectral extension of the QAM-16 signal (36 GHz centred at 280 GHz), ~-10 dBm power was obtained (taking into account probe losses) for 5.3 mA.

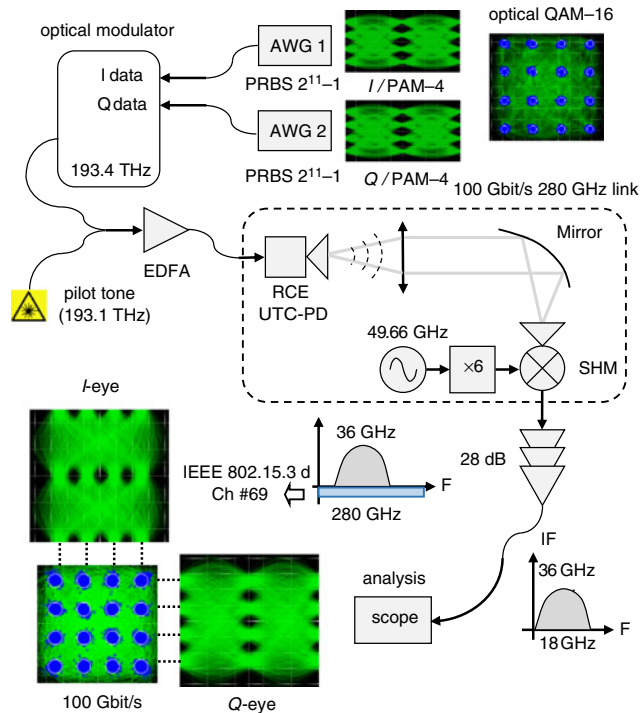


Fig. 1 100 Gbit/s wireless link. Carrier frequency 280 GHz, up to 25 GBaud QAM-16 modulation scheme. Emitter: RCE UTC-PD and receiver: SHM. The THz modulated 100 Gbit/s signal falls in channel 69 (252.72–321.4 GHz) of IEEE standard 802.15.3d [1]

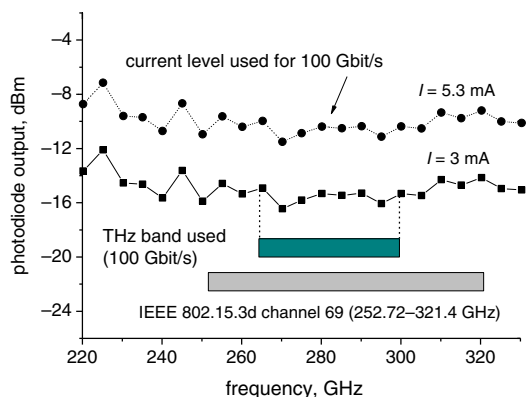


Fig. 3 Output power of RCE UTC-PD in range 220–330 GHz. Identification of occupied bandwidth for QAM-16/100 Gbit/s signal. Grey zone: 69th channel of IEEE 802.15.3d [1]

As can be shown, the RCE UTC-PD output power was measured to be -10 dBm ($I = 5.3$ mA, optical power 50 mW). Taking into account the coplanar probe (3 dB), THz path losses (6 dB), the total received power at the SHM input was -19 dBm. The signal-to-noise ratio of the detected spectrum was estimated to 25 dB. Owing to an increase in the conversion losses of the SHM around 20 GHz and amplifier frequency-dependent gain (few dBs), the modulated signal spectra was not flat at the end of the link. However, this deterministic effect was taken into account in the off-line detection by a linear equalisation of the channel.

Constellation analysis: The constellations of THz transmissions at 56, 80, and 100 Gbit/s data rate are shown in Fig. 4. A very linear QAM-16 is detected, up to 100 Gbit/s data rates. In this figure, the blue points correspond to the decision instants and the green curves behind are the signal path between two decision instants.

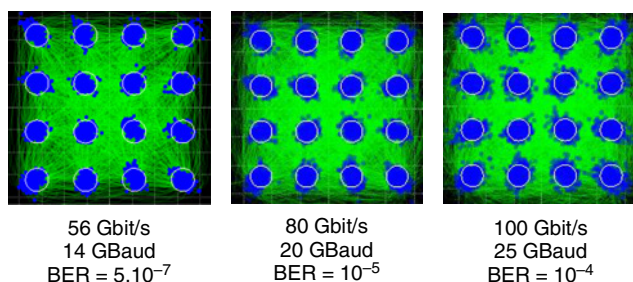


Fig. 4 Constellations examples obtained at end of THz link. PD (-1 V bias) current level was 4.9 mA for 56 Gbit/s, 5.1 mA for 80 Gbit/s and 5.3 mA for 100 Gbit/s, using 23 taps for digital equalisation

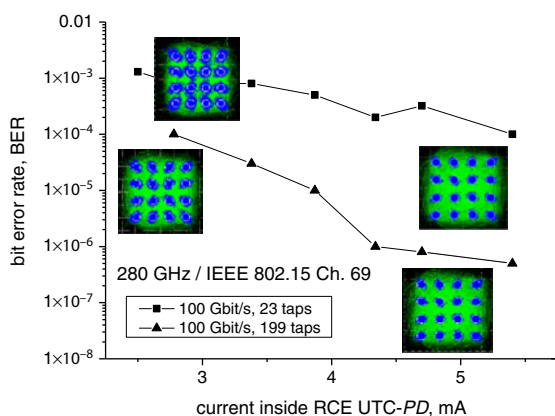


Fig. 5 BER curves obtained for single-channel 100 Gbit/s at 280 GHz, using 23 (squares) and 199 taps (triangles) for equalisation

Fig. 5 presents the evolution of the BER performance with current level inside the RCE UTC-PD. In this case, 23 and 199 taps were tested: this shows that for 23 taps (which can be achieved with

state-of-the-art application specific integrated circuits, ASICs), the achievable BER is lower than forward error correction usual threshold ($\sim 4 \times 10^{-3}$). Assuming that future ultra-high-performance ASICs could handle higher tap numbers, it is shown that 199 taps lead to BER values lower than 10^{-6} at 100 Gbit/s.

We believe that the proposed approach could be further extended to dual channel operation to go beyond 100 Gbit/s data rate as well as increased transmission distance by increasing the UTC-PD bias current.

Conclusions: We have reported the first demonstration of a single 100 Gbit/s THz channel using QAM-16 signalling, compliant to the new IEEE standard for 100 Gbit/s wireless communications in the 300 GHz bands.

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One or more of the Figures in this Letter are available in colour online.

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