32 Gbit/s QPSK Transmission at 385 GHz

Using Coherent Fiber-optic Technologies and THz Double Heterodyne Detection

Guillaume Ducournau, Klaus Engenhardt, Pascal Szriftgiser, Denis Bacquet, Mohammed Zaknoune, Rédha Kassi, Erwan Lecomte and Jean-François Lampin

We report on the first QPSK data link at 385 GHz, using a photonics based THz emission and a double heterodyne THz detection. The QPSK signalling is investigated up to 16 GBaud (32 Gbit/s) on short range distance, with 20 µW received power levels.

Introduction

Over the last 5 years, the continuously growing demand on data rates is pushing up the THz devices and systems performances. Such technologies are strongly envisaged for communications applications [1]. Among the different systems already reported, the highest performances have been obtained using a combination of photonics at emission and electronic receivers [2]. As the THz bandwidth is large, the use of simple amplitude signalling can easily lead to up to > 40 Gbit/s data rates [3,4]. However, such schemes are already challenged by higher spectral efficiency (bit/s/Hz) links using QPSK or PSK-8 modulation formats and also with a required compatibility of the THz links with other services [5]. In this work we present the first THz link using QPSK signalling in the sub-millimeter range with data rates of several 10 Gbit/s. Such link, associated with the development of coherent data optic fiber links in metro networks, could be used as a direct converter of a guided optical QPSK into a THz radio, for very high data rates indoor applications.

Description of the THz link: Figure 1 shows a general overview of the experimental setup, showing the details of the photonic-based THz emitter, THz link and electronic receiver.

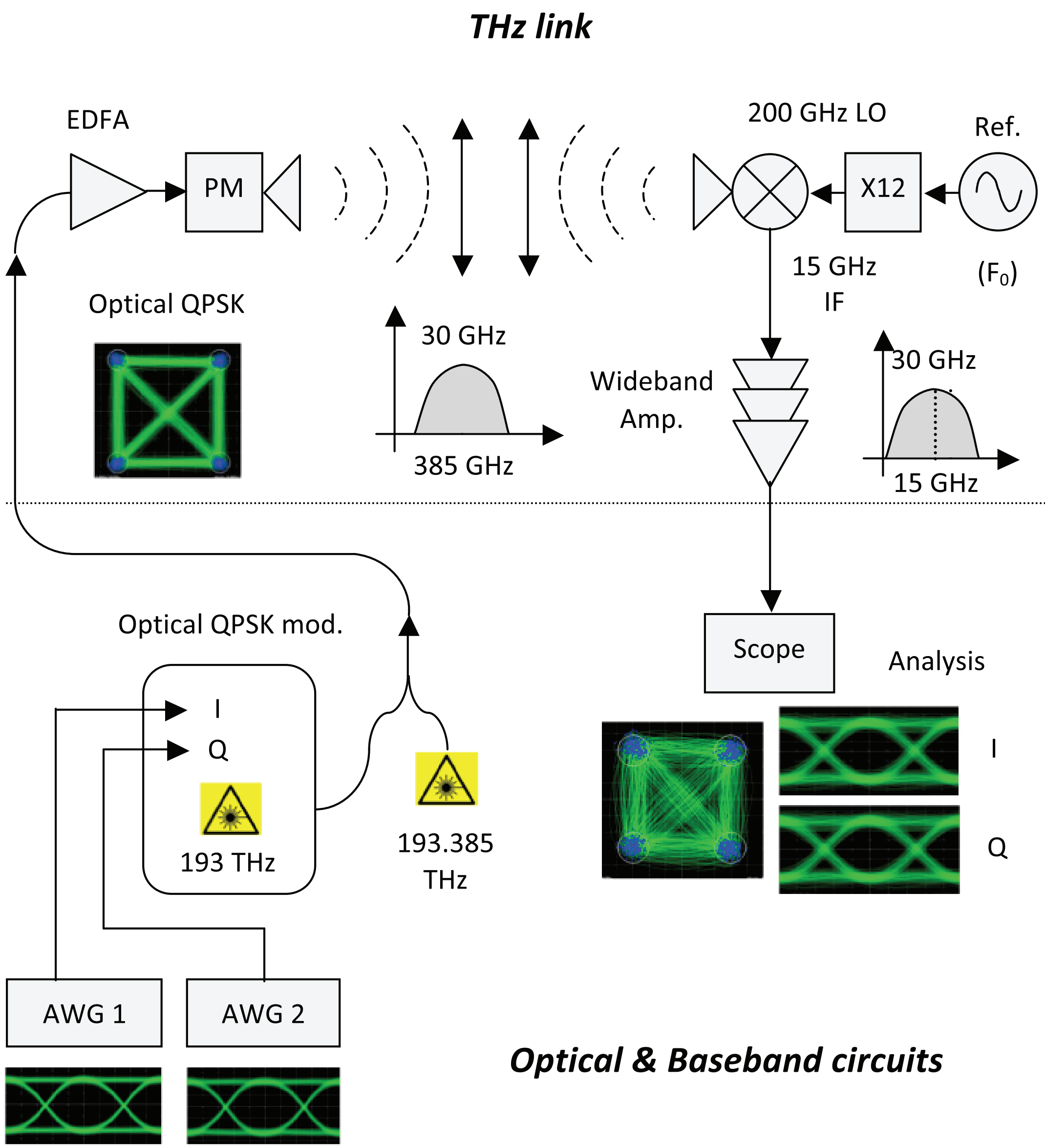

Figure 1: General overview of the THz link. PM = Photomixer.

The system is first composed of a fiber-optic based Tx designed for QPSK signalling over wavelength division multiplexing (WDM) optical carriers. One C-band channel (193 THz) was modulated in optical QPSK using a dual nested Mach-Zehnder configuration. Two arbitrary waveform generators (AWG) were used to create two baseband non return to zero (NRZ) data signals: the In-phase (I) and Quadrature-phase (Q) signal. These signals were generated using a digital Gaussian filtering of 0.65 with the AWG to optimize the spectrum size.

Once the QPSK is created in the optical domain, a second continuous wave (CW) optical tone is added, with a frequency separation of 385 GHz. These two optical signals are amplified using an erbium doped fiber amplifier (EDFA), and feed a uni-traveling carrier photodiode, integrated in waveguide. The D.C. response of the photomixer is 0.2 A/W, and the PM is operated within its linear regime as QPSK signalling is investigated rather than standard amplitude modulation schemes. Figure 2 plots the output power capability of the photomixer for a 7 mA current, showing that the carrier (385 GHz) power (without modulation) of -12 dBm at the transmitter output. The used bandwidth is indicated in the graph, showing the effective used bandwidth (~30 GHz) during experiment for the highest data rate tested.

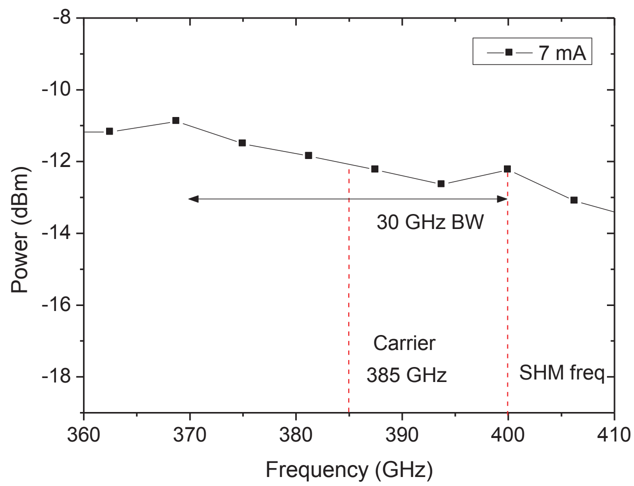

Figure 2: Output power (measured in waveguide) of the photomixer used in the experiment.

The THz signal is then collimated using a first 25 mm diameter polymer lens. After direct propagation over 0.4 m, a second lens focuses the radiation inside an electronic receiver composed of a sub-harmonic mixer, integrated in WR2.2 (325-500 GHz) waveguide, driven at 200 GHz (mW level source) to operate at 400 GHz. Assuming the 385 GHz carrier frequency, this produces an intermediate frequency (IF) signal at microwave frequencies (15 GHz). A wideband amplifier is then used to amplify the signal before real-time oscilloscope detection. The total gain used at the Rx side, including the SHM losses and the 'base band' wideband amplifier gain was 2 dB.

Figure 3 shows the THz channel response, measured with a CW THz tone, adjusted from 360 GHz to 400 GHz. The minimal losses found were around the IF minimum frequency due to SHM pumping (200 GHz). Around 10 dB differential losses are affecting the signal over the 30 GHz total modulation bandwidth (16 GBaud filtered QPSK signal).

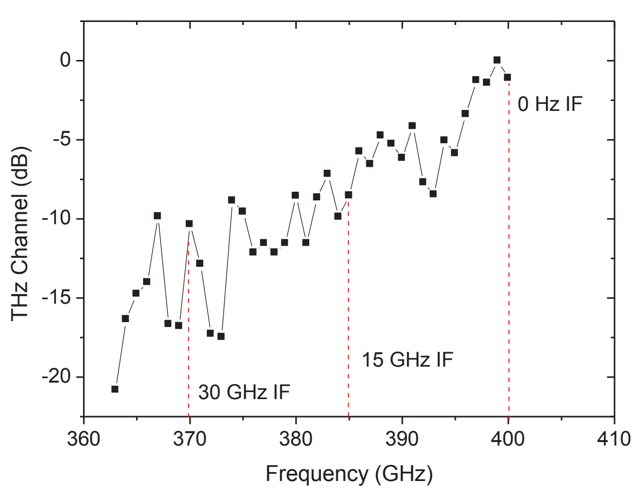

Figure 3: THz channel response around carrier frequency (The SHM receiver is pumped at 200 GHz in order to operate at 400 GHz).

This IF signal is then measured using a real-time scope (33 GHz bandwidth), and real-time analysis (second heterodyne detection) is processed on the data to plot constellations, eye diagrams and BER analysis using sufficient long time sequences. Different I and Q pseudo random binary sequences lengths were used (27-1 for I and 29-1 for Q) to keep the arbitrary behaviour between I and Q tributary channels and ensure a proper signal recovery at receiver.

The system was first operated using limited data symbol rates in order to optimize the modulation parameters and THz channel parameters. An example of constellation is given by figure 4 for a 2.5 GBaud QPSK, with a 7.7 mA at the Tx. In that case, ~ 70 µW output power was used at Tx side and around 20 µW at reception (input WR2.2 horn). This was obtained by measuring the losses of the quasi-optic link (S21) using a quasi-optic vector network analyzer in the 325-500 GHz range.

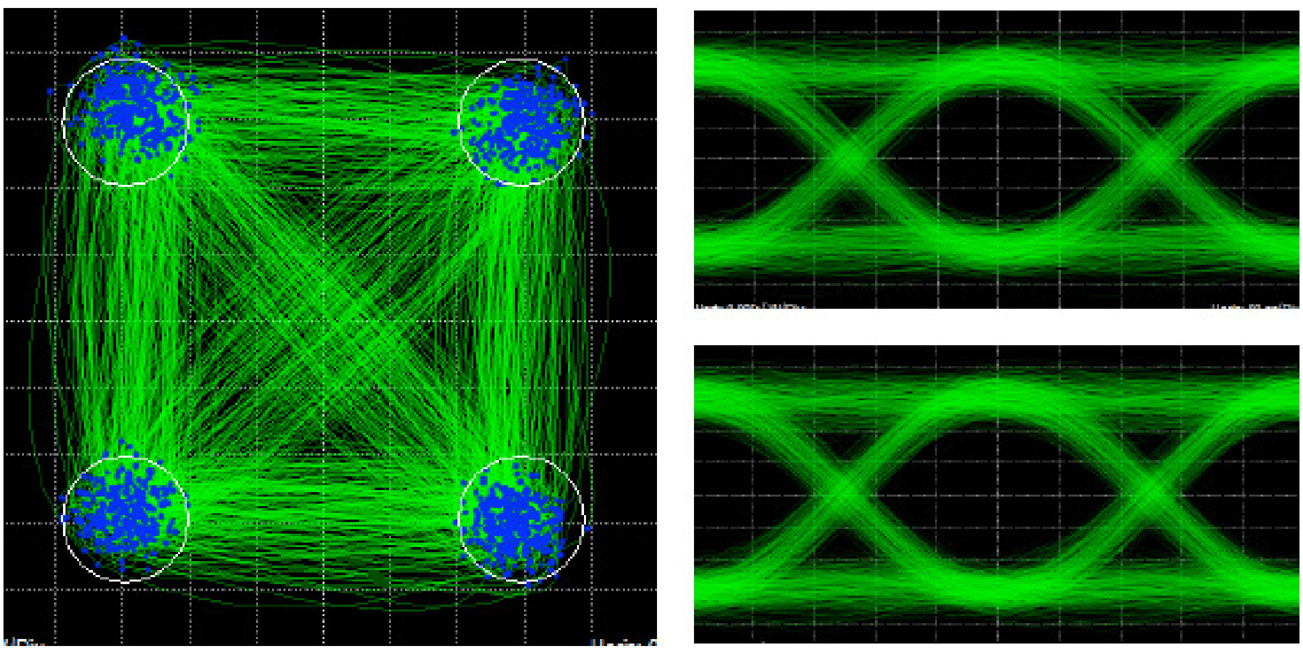

Figure 4: 385 GHz QPSK link evaluation at 2.5 GBaud (5 Gbit/s), using a raised-cosine filter (0.9 normalized bandwidth) and a 7.7 mA photocurrent in the Tx. In that case, the transmission is error-free.

Vectorial Transmission

After validation of QPSK error-free operation at 2.5 GBaud, the system has been driven up to 16 GBaud symbol rate. The highest data symbol rate tested was 16 GBaud (32 GBit/s), and the associated results are displayed in the figure 5. The detection was realized by analyzing time sequences long enough, in respect to the bit error rate (BER) performance, as given in table 1. The BER performances obtained are measured using long time sequences, depending of the BER level. The BER values found are compatible with forward error correction (FEC) processes [6] for I >5 mA photocurrents.

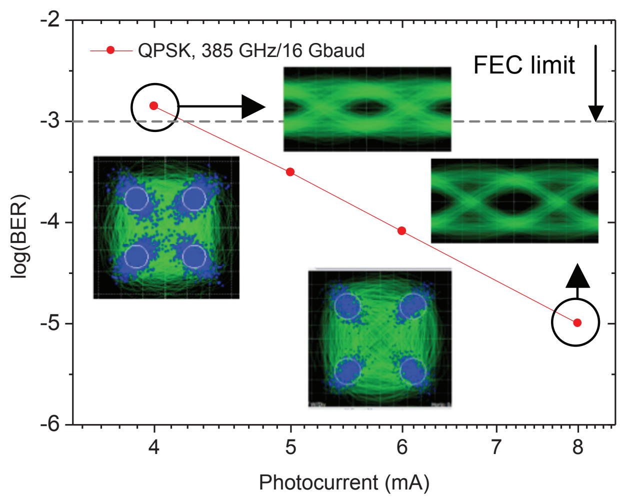

Figure 5: BER curves measured for the 16 Gbaud (32 Gbit/s) QPSK signal (0.65 Gaussian filtering). Insets show the constellation diagrams (blue points: sampling points) and eye diagrams.

I (mA)	BER	Nb of Bits analyzed	Time lenght (µs)
4	1.4E-3	101888	3.18
5	3.17E-4	324768	10.1
6	8.15E-5	503072	15.7
8	1.0E-5	1006144	31.4

Table 1: BER measurements, number of bits analyzed and corresponding time lengths for 16 GBaud (32 Gbit/s).

Analysis

The clear QPSK constellations results (blue points correspond to decision point) confirm that the vectorial QPSK nature is conserved in the optical to THz conversion, as expected. At 32 GBit/s, the detection gives a 10-5 BER value for the highest tested current (8 mA), corresponding to a -11 dBm THz power. Due to the wideband amplifier and limited available total gain at the Rx (2 dB), some noise is affecting the eye diagram. Further work will address the receiver optimization on noise and total gain to reach point to point links over higher distances.

Conclusions

A 385 GHz vectorial wireless link has been presented, using a combination of photonic and electronic THz devices, associated with coherent optical QPSK emission. Up to QPSK/16 Gbaud data signaling has been investigated, and 32 GBit/s data rates compatible with standard FEC limits. With the huge developments of coherent optical networks [7], such architectures could be very interesting to deploy optical-to-THz radio bridges for future access networks and network convergence.

Acknowledgments

This work has been realized within an IEMN/Tektronix academic collaboration. In particular, AWG70001A, OM5110 and DPO73304DX equipments were used to realize the setup. This work has been supported by the equipex program “FLUX”, ‘Fibre optics for high Fluxes’ and “COM’TONIQ” ANR project (grant ANR-13-INFR-0011-01). We thank the IEMN Nano-Microwave RF/MEMS characterization centre and the IEMN-IRCICA Telecom platform facilities. This work was partially funded by the RENATECH network.

G. Ducournau, M. Zaknoune, R. Kassi and J.F. Lampin are with the Institut d’Electronique, de Microélectronique et de Nanotechnologie (IEMN), UMR CNRS 8520, Université Lille 1. Avenue Poincaré, B.P. 60069, F-59652 Villeneuve d’Ascq, France.

D. Bacquet and P. Szriftgiser are with the Laboratoire de Physique des Lasers Atomes et Molécules (PhLAM), UMR CNRS 8523, Université Lille 1, F-59655 Villeneuve d’Ascq Cedex, France.

Klaus Engenhardt and Erwan Lecomte are with Tektronix GmbH, Heinrich-Pesch-Straße 9-11, 50739 Köln, Germany

E-mail : guillaume.ducournau@iemn.univ-lille1.fr,

References

1. J. Federici and L. Moeller, “Review of terahertz and subterahertz wireless communications”, J. Appl. Phys. 107, 111101, 2010.
2. S. Koenig, ,D.Lopez-Diaz , J. Antes, F. Boes ,R. Henneberger, A. Leuther, A. Tessmann, R. Schmogrow, D. Hillerkuss, R. Palmer, T. Zwick, C. Koos, W. Freude, O. Ambacher, J. Leuthold and I. Kallfass, “Wireless sub-THz communication system with high data rate”, Nature Photonics, DOI: 10.1038, Oct. 2013.
3. T. Nagatsuma, S. Horiguchi, Y. Minamikata, Y. Yoshimizu, S. Hisatake, S. Kuwano, N. Yoshimoto, J. Terada, H. Takahashi, “Terahertz wireless communications based on photonics technologies”, Opt. Exp., vol. 21, no. 20, 23736, 2013.
4. G. Ducournau, P. Szriftgiser, A. Beck, D. Bacquet, F. Pavanello, E. Peytavit, M. Zaknoune, T. Akalin, J.F. Lampin, "Ultrawide-Bandwidth Single-Channel 0.4-THz Wireless Link Combining Broadband Quasi-Optic Photomixer and Coherent Detection," IEEE Trans. THz Science and Tech. 4, pp. 328-337, (2014).
5. S. Priebe and T. Kuerner, “Interference between THz Communications and Spaceborne Earth Exploration Services”, IEEE IG THz Group Document, https://mentor.ieee.org/802.15/dcn/12/15-12-0324-00-0thz-interference-between-thz-communications-and-spaceborne-earth-exploration-services.pdf, accessed 29 april 2014.
6. F. Chang, K. Onohara, T. Mizuochi, “Forward error correction for 100 G transport networks”, IEEE Commun. Mag. 48, S48–S55, 2010.
7. Peter J. Winzer, "High-Spectral-Efficiency Optical Modulation Formats," J. Lightwave Technol. 30, pp. 3824-3835, (2012).

06/15 85W-60166-0