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# Photonics-enabled 1.04 Tbit/s aggregated data-rate in the 600 GHz band

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**Abstract**—We demonstrate in this work the use of a waveguide-integrated THz photodiode in the 600 GHz band, combined with a waveguide-based receiver. Leveraging on the wide available bandwidth of this association, beyond 1 terabit per second aggregated data-rate is reached with a bit-error-rate performance compliant to the standard error-correction techniques limits, setting a new milestone for THz communications.

**Keywords**—THz communications, photomixers, Tbit/s wireless links.

## I. INTRODUCTION

Following the demand of wireless data consumption, supporting mobile connectivity is inducing an ever increasing demand for future back-hauling solutions that are usually fixed point-to-point links. Beyond the E-band (71-76 GHz & 81-86 GHz), the 'D-band' (140-170 GHz) is expected to take-off after 2025, and '300 GHz' band, after 2030. While most of the research projects have targeted these frequency windows, only few work has been carried out beyond 400 GHz. In addition, the '300 GHz' band is offering around 120 GHz bandwidth, making challenging to reach Tbit/s systems. Considering the atmospheric response, there are several interests in the '600 GHz band', where large bandwidth is available from 625 to 725 GHz. Among technological solutions to cover the 600 GHz band, the photonics approach is very appealing thanks to the intrinsic wideband nature of photomixers. In this work, we consider the association of a photonics-based THz source and an electronic receiver, showing an aggregated data-rate beyond 1 Tbit/s. To the best of our knowledge this is the first-ever reported experiment for a Tbit/s THz system with FEC compliant performances.

## II. DESCRIPTION OF THE SYSTEM

### A. Transmitter and receiver description

The THz transmitter used here is based on a unitravelling carrier (UTC) photodiode integrated for the 600 GHz band [1]. The structure of the photomixer was previously reported in

[2]. Fig. 1 shows typical performance of this photomixer, measured with a waveguide power-meter (PM5 from VDI [3]) and associated with a waveguide taper from WR1.5 to WR10. This photomixer has a 3 dB bandwidth beyond 250 GHz. The receiver part is composed of a sub-harmonic mixer using GaAs schottky technology, with typical conversion losses of 10-12 dB. Fig. 1 shows the conversion losses of the mixer used in the receiver that shows a large overlap with the intrinsic bandwidth of the UTC-PD based transmitter.

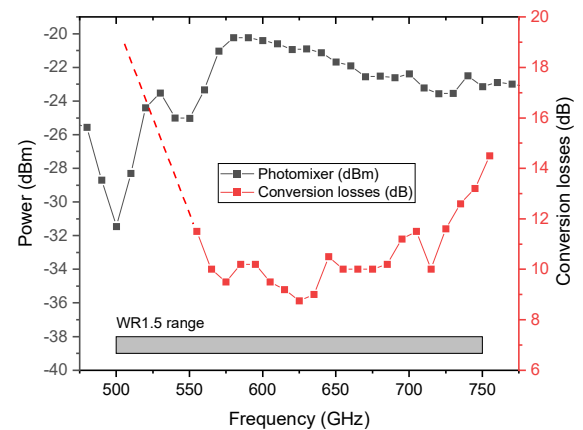


Fig. 1. Output power of the transmitter (6.5 mA, and 0.8V reverse bias) and conversion losses of the mixer stage of the receiver. The frequency range of the WR1.5 (WM380) waveguide is shown for reference.

### B. Testbed

The system tested is described in this section. A pair of optical C-band (1530-1560 nm) tunable laser source enables the generation of each carrier frequency, one by one. One laser is modulated using a wideband IQ modulator, to imprint complex data signals from arbitrary waveform generator (AWG) on the optical carrier. In all measurements, the baseband data from AWG is filtered using 0.1 root raised cosine. The second laser (not modulated) is mixed with the modulated one before optical amplification by an erbium-doped fiber amplifier (EDFA). The optical part of the testbed

is similar to the one used in [4], adapted here for the 600 GHz band (lasers and SHM). The optical signal is injected to the UTC-PD WR1.5 module. In this study, a back-to-back (B2B) configuration is used, corresponding to a direct waveguide connection of the UTC-PD to the WR1.5 subharmonic mixer (SHM, receiver side, pumped by a 300 GHz local oscillator (LO). After down-conversion of the THz signal, an IF amplification stage (SHF-810 [5]) is used before fast-real-time oscilloscope (70 GHz bandwidth) detection of the modulated signal, while the detection of modulated signal is accomplished by the VSA software [6].

### III. DESCRIPTION OF THE SYSTEM PERFORMANCES

#### A. Frequency allocation plan and spectrum measurement

In this section, the performance of the overall association is tested. In this configuration, a back-to-back configuration (transmitter and receiver directly connected each other) is tested to assess the maximum performance of the association. As per the results shown on Fig. 1, a frequency allocation plan is proposed to use the full bandwidth of the system, described in the Tab. 1, with the carrier frequencies (Freq.), baud-rate (BR) and occupied bandwidth (OBW).

TABLE I. 600 GHz-BAND FREQUENCY ALLOCATION PLAN

Carrier	Frequency, GHz		OBW	BR	Carrier	Frequency, GHz		OBW	BR
GHz	Min	Max	GHz	GB	GHz	Min	Max	GHz	GB
500	496.5	503.5	7	3.5	610	600	620	20	18.5
508	504	512	8	3.5	632	620.5	643.5	23	20
520	513.75	526.25	12.5	12	655	645	665	20	18
535	528.75	541.25	12.5	12	675	665	685	20	19
550	541.75	558.25	16.5	15	695	685.5	704.5	19	19
569	559	579	20	19	712	704.5	719.5	15	14
590	580	600	20	19	724	720.5	727.5	7	6

Fig. 2 presents the measured spectrum, measured each carrier at a time, the overall spectrum is then aggregated to check the isolation between channels.

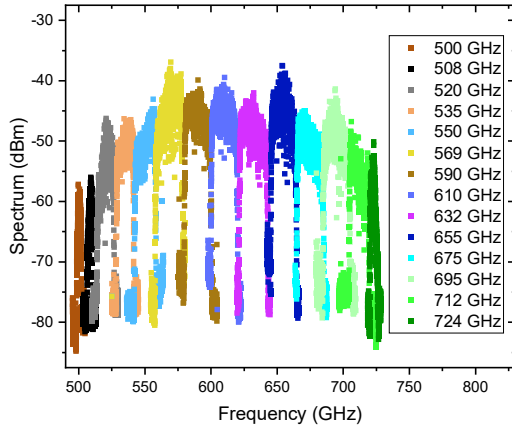


Fig. 2. Measured spectrum, from IF analysis, at oscilloscope input.

#### B. BER/EVM performances

Each channel was tested with different modulation formats. Considering the bit error-rate limits for soft-decision forward-error correction (SD-FEC) of  $2E-2$ , and hard-decision (HD) FEC of  $2E-3$ , the system was settled to reach a performance below SD-FEC and HD-FEC. The results are shown in the Tab. 2 and 3, respectively. The overall data-rate of the system is 1.04 Tbit/s (SD-FEC compatible) and 887.5 Gbit/s (HD-FEC compatible). These figures are corresponding to the Fig. 3 and 4, respectively.

TABLE II. BER/EVM PERFORMANCE, SD-FEC COMPATIBLE

F	Case 1	BER	Mod. Type	EVM
GHz	DR	SD-FEC comp.	-	%
500	14	0.0042	QAM-16	12
508	14	0.0069	QAM-16	12.3
520	48	0.00049	QAM-16	10
535	72	0.0083	QAM-64	5.8
550	75	0.0008	QAM-32	6
569	95	0.00068	QAM-32	5.9
590	114	0.006	QAM-64	5.5
610	111	0.008	QAM-64	5.7
632	120	0.0076	QAM-64	5.7
655	108	0.0073	QAM-64	5.8
675	95	0.001	QAM-32	6.2
695	95	0.0029	QAM-32	6.8
712	56	0.0007	QAM-16	10.2
724	24	0.000303	QAM-16	9.5
1.041 Tbit/s aggregated data-rate				

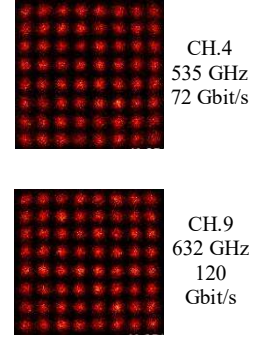


TABLE III. BER/EVM PERFORMANCE, HD-FEC COMPATIBLE

F	Case 2	BER	Mod. Type	EVM
GHz	DR	HD-FEC comp.	-	%
500	-	-	-	-
508	-	-	-	-
520	48	0.00049	QAM-16	10.0
535	60	0.00037	QAM-32	5.7
550	75	0.0008	QAM-32	6.0
569	95	0.00068	QAM-32	5.9
590	95	0.00026	QAM-32	5.5
610	92.5	0.00056	QAM-32	5.6
632	100	0.00045	QAM-32	5.7
655	90	0.00039	QAM-32	5.8
675	76	0.000035	QAM-16	6.8
695	76	0.000018	QAM-16	7.9
712	56	0.0007	QAM-16	10.2
724	24	0.000303	QAM-16	9.5
887.5 Gbit/s aggregated data-rate				

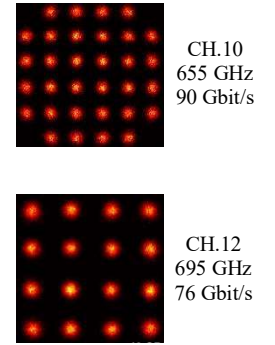


Fig. 3 presents the plots of the system IQ maps obtained from the aggregated data-rate of 1.041 Tbit/s.

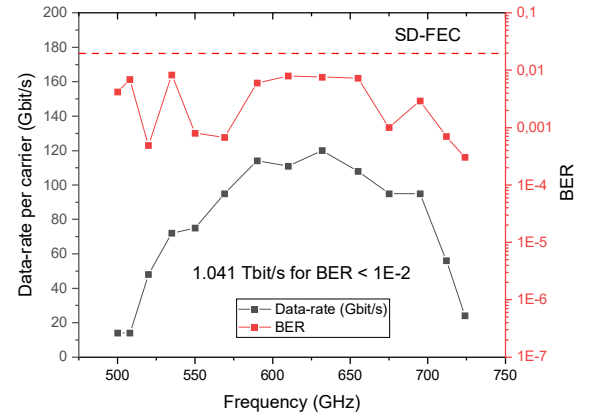


Fig. 3. System performance, with a SD-FEC compliance (ie all BER  $< 1E-2$ ) and aggregated data-rate of 1.041 Tbit/s.

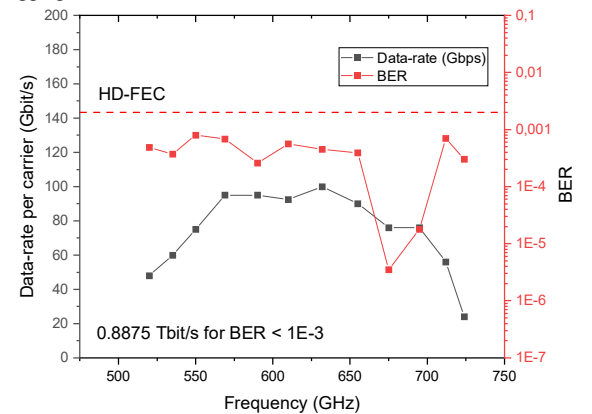


Fig. 4. System performance, with a HD-FEC compliance (ie all BER  $< 1E-3$ ) and aggregated data-rate of 0.8875 Tbit/s.

### C. Single channel analysis at 632 GHz

From the measurement shown on Fig. 1, the best carrier frequency of the association of the UTC-PD and the SHM receiver was 632 GHz. For this channel, a single carrier analysis, with ultra-wideband modulation was tested. Thanks to the widebandwidth of the testbed, the system was tested up to 185 Gbit/s (46.25 GBaud, QAM-16) and 200 Gbit/s (40 GBaud, QAM-32). Corresponding BER values are shown by the Fig. 5. Fig. 6 shows the I/Q map of fastest QAM-32 tested.

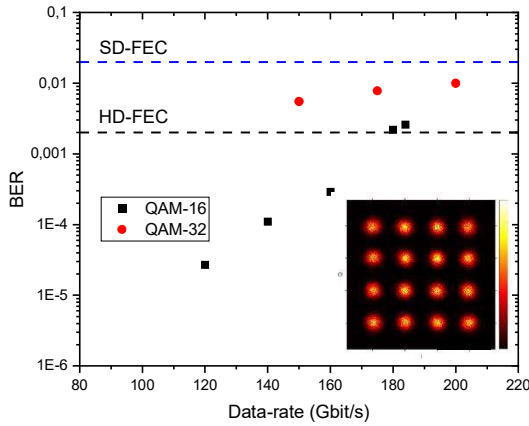


Fig. 5. Ultra-wideband single channel performance in the 600 GHz band: HD-FEC 180 Gbit/s using QAM-16, and SD-FEC compliant 200 Gbit/s. UTC-PD current is in that case 7.5 mA for all measurements. Inset shows 160 Gbit/s QAM-16,  $2.9E-4$  BER.

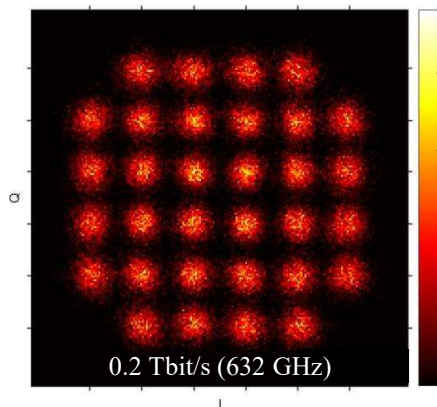


Fig. 6. I/Q map of single channel 0.2 Tbit/s at 632 GHz. BER is  $1E-2$ , below SD-FEC limit.

### CONCLUSION

The combination of a wideband optical testbed optimized for THz communications, a  $> 250$  GHz bandwidth UTC-PD in the 600 GHz band and state-of-the-art electronic receiver is proposed. Leveraging the linear and wideband nature of the whole testbed, we demonstrated a multi-channels approach to open new research opportunities for THz communications beyond 300 GHz band. This is, to the best of author's knowledge, the highest ever reported data-rate in the 600 GHz band, and the first aggregated data-rate beyond 1 Tbit/s using a THz system while maintaining a FEC compliant performance. The use of photonics approach also enabled here to showcase the highest ever reported single channel data, as high as 0.2 Tbit/s for a carrier frequency of 632 GHz. The perspective of this work is to use of this system within a wireless link.

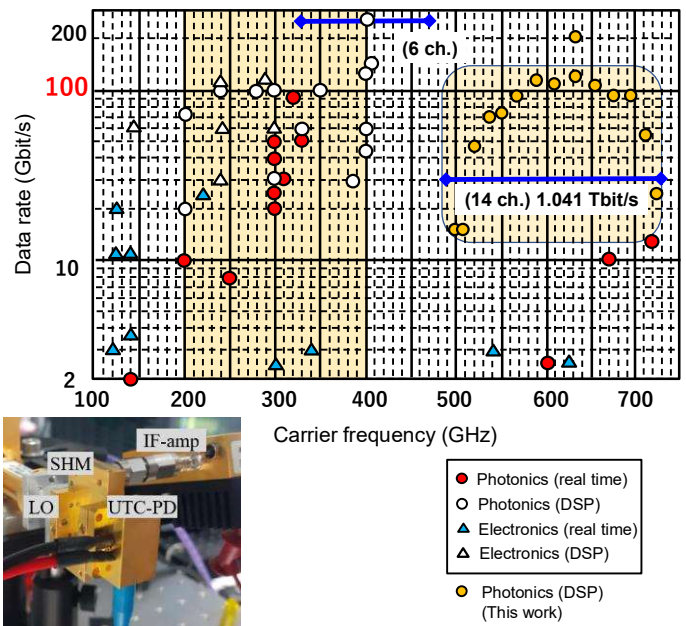


Fig. 7. Benchmark of the data-rate demonstrated using single carrier frequencies in the range 100-750 GHz. The photonics-electronics association in the WR1.5 shown here open new research routes for the use of the 600 GHz band. Inset: view of the UTC-PD module connected to the SHM.

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