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High-definition television transmission at 600 GHz combining THz photonics hotspot and high-sensitivity heterodyne receiver

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A 600 GHz data transmission using the combination of a photonic emission using a uni-travelling carrier photodiode and an electronic detection is investigated. A high-definition television transmission at this carrier frequency with a very low power at the receiver is reported. Only 10 nW of terahertz (THz) power at 600 GHz was sufficient to ensure a successful high-definition video transmission. This combination of photonics at emission and heterodyne detection lead to achieving THz wireless links with a safe level of electromagnetic exposure.

Introduction: The demand on bandwidth to serve increasing services such as video on mobile terminals is growing every year according to Edholm’s law of bandwidth [1]. As nowadays almost all the radio bands are allocated, new ways for wireless data transmissions are currently being investigated. The physical layer for wireless links will thus be strongly developed within coming years as the traffic in the wireless regime is supposed to become larger than the wired networks lines. The terahertz (THz) communications are very promising as they open a huge space for the new services using the frequencies in the submillimetre region, i.e. above 300 GHz. The THz frequency range is very attractive as it provides more data bandwidths in accordance with the increase of the carrier frequency. Several systems have already been reported, for example based on photonics [2] or electronic devices such as multiplication chains [3] or resonant tunnelling diodes [4]. In addition, combined systems using photonics at the emission and heterodyne reception [5, 6] have been demonstrated for frequencies below 250 GHz. Above 600 GHz, one demonstration of wireless transmission has already been reported with the data rate > 1 Gbit/s. It used an electronic source (20 μ W at reception) and a low-sensitivity electronic envelope detection at the receiver, leading to a 2.5 Gbit/s capability at 625 GHz [7]. Here, we report for the first time the combination of a photonics-based emitter and a heterodyne receiver to achieve a very high sensitivity 600 GHz data link.

Experimental setup: The data link is described in Fig. 1 with indications of the transmitter and the receiver part. Fig. 2 is a photographic view of the transmitter (Tx), the THz path and the receiver (Rx).

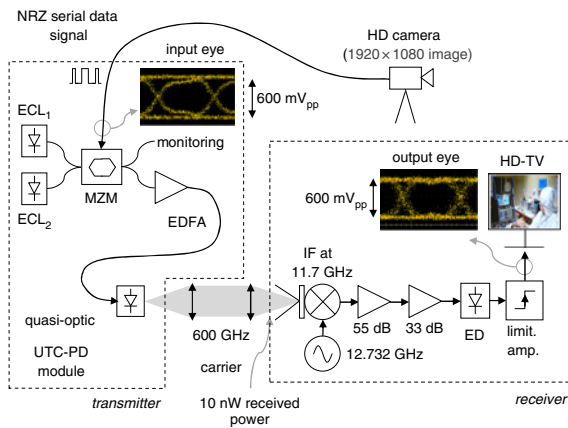


Fig. 1 Experimental setup of 600 GHz data link
Displayed eye diagrams were obtained during HD-TV test (1.7 Gbit/s data flow)

Transmitter description: Two external cavity lasers (ECLs) were combined to generate a dual-tone optical signal with a 600 GHz separation (4.8 nm at 1550 nm). These two wavelengths were amplitude modulated by the data signal by using a LiNbO₃ Mach-Zehnder modulator driven around the 50% power transmission, thus ensuring a standard non-return-to-zero (NRZ) data signal. These two wavelengths were amplified by an erbium doped fibre amplifier, feeding the uni-travelling carrier photodiode (UTC-PD) device, which realises the

photonic-to-THz conversion. No bias is required at the UTC-PD, thus this hotspot could be plugged directly after the existing optical fibre networks. The photomixer is integrated with a wideband transverse electromagnetic horn antenna (TEM-HA) [8]. The THz path is composed of two polymer lenses: the first one collects the signal from the emission antenna and the second one focuses on the THz beam inside the receiver. The transmission distance is 50 cm (limited by the configuration of the laboratory).

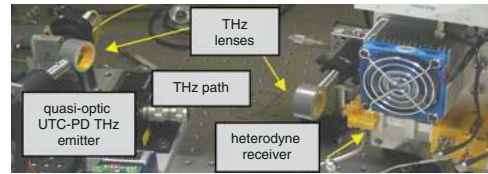


Fig. 2 600 GHz transmission system over distance of 50 cm

Receiver description: The THz signal is focused inside a WR1.5 waveguide diagonal horn (25 dB gain, 2.4 mm aperture diameter). This signal feeds a subharmonic mixer (SHM) featuring 15 dB conversion losses at the carrier frequency (600 GHz). The SHM is pumped at half operating frequency, i.e. 305.85 GHz, using a commercial electronic multiplication chain, in order to operate at 611.7 GHz. The mixing of the 611.7 GHz signal in the SHM with the THz carrier at 600 GHz thus creates an intermediate frequency (IF) at 11.7 GHz, corresponding to the centre of the available bandwidth of the first output amplifier. At the mixer output, a first 50 Ω low-noise amplifier (55 dB gain) and a second 50 Ω amplifier (33 dB gain) amplify the modulated data signal. Finally, this IF signal is detected by an envelope detector (ED), which rectifies the 11.7 GHz modulated signal to recover the data signal in the baseband. This scheme suppresses the residual frequency jitter and the phase noise present at the mixer output, originated from the ECL frequency jittering converted into the THz domain inside the UTC-PD. This enables us to take benefit from the heterodyne receiver sensitivity without being limited by the residual THz carrier phase noise. Lastly, a limiting amplifier is used to recover a clean eye shape, which is required to drive the serial data receiver.

Baseband bandwidth detection analysis: The ED was tested in terms of video bandwidth capability, for an 11.7 GHz carrier frequency. To this end, an analysis was conducted on the modulating system using a microwave mixer to produce an amplitude shift keying (ASK) signal to feed the ED, as shown in Fig. 3.

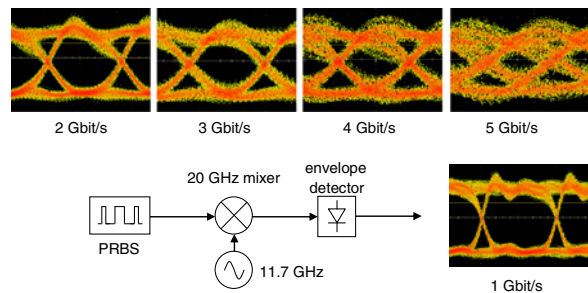


Fig. 3 Bandwidth test of modulation system + ED

A pseudorandom binary sequence data source is mixed with an 11.7 GHz microwave source, to produce a radio frequency ASK signal at the same IF frequency that was used during the data experiment. This signal is directly injected in the ED at various data rates, up to 5 Gbit/s. It appeared that the achievable bandwidth of this system was ~ 3 GHz, which was corresponding to the combination of the available IF bandwidth at the emission mixer and the video bandwidth of the ED. Indeed, eye diagrams and a long-term stability were obtained with a very good eye opening up to 3 Gbit/s. The higher data rates suffer from degradations due to the mixer limited bandwidth.

Results: The photocurrent used in the UTC-PD during the data experiments was only 0.38 mA, corresponding to a ~ 10 dBm optical power injected in the UTC-PD. Fig. 4 shows the received relative IF electrical spectrum at 11.7 GHz (a 100 kHz resolution bandwidth (RBW)),

showing the NRZ received ASK data after the two amplification stages. We assume that the residual carrier at 1.7 and 3.4 GHz, respectively, was coming from the direct coupling between the serial data at 1.7 Gbit/s (video source) and the spectrum analyser. The peak power value was found to be 16 dBm, and the signal-to-noise ratio was >50 dB. Thus, by taking into account the 15 dB conversion losses of the receiving mixer, the 55 + 33 dB gains of the two amplifiers and the additional 4.2 dB losses for the cables and 2 dB for all the coaxial transitions at 11.7 GHz, we have estimated that <-50 dBm (10 nW) were feeding the mixer. To take into account the THz path losses, we have measured the THz path using a quasi-optic setup based on a vector network analyser in the range of 325–500 GHz. The THz losses found were <5 dB. We assume that at 600 GHz the THz losses should be of the same order of magnitude (5 dB). Thus, the THz emitted power from the photomixer used with this very low photo current was ~ -45 dBm (30 nW) at 600 GHz.

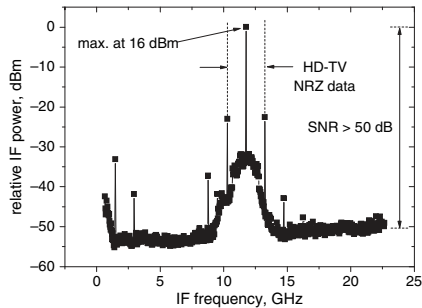


Fig. 4 IF received spectra at 11.7 GHz, RBW = 100 kHz

From the baseband bandwidth analysis, the ED was shown to be compatible with up to 3 Gbit/s data signals, thus compatible with the standard high-definition television (HD-TV) required data rates (1.7 Gbit/s). As no bit error rate tester was available at the time of the measurements, the transmission was validated using a real HD-TV serial data flow (Fig. 5). Indeed, we succeeded in transferring the HD-TV during several tens of minutes, highlighting the fact that the BER should be well below 10^{-9} over the long time periods.



Fig. 5 Photograph of HD-TV transmission working, showing video transmission in laboratory during experiment

Above 600 GHz, the sole reported system was at 625 GHz [7], showing an ASK transmission using an ED (Schottky rectifier). In this system, the estimated received THz power was ~ 20 μ W, and an error-free operation was obtained up to 2.5 Gbit/s. In that case, the number of the THz photons per bit of this data transmission was 2×10^7 . In our experiment, the number of the THz photons per bit was reduced to 1.5×10^4 . The combination of heterodyne detection and envelope detection leads to a $1000 \times$ reduction in the required number of THz photons per bit. This enables us to release the link budget and enables a safe (ultra-low) free-space radiated power requirement, resulting in a safe level of exposure. With the recent results of the photomixing devices [9, 10] with the mW-level reported capabilities, along with the recent advances in the dual-tone low phase-noise lasers [11], the combination of these devices with heterodyne receivers may open the way for non-directive THz links for indoor uses.

Conclusions: In this Letter, the first high-sensitivity communication system using the UTC-PD at emission and heterodyne detection at

600 GHz is reported. Moreover, the photomixer used here is directly fed by the optical signal (no bias is applied); enabling a direct optical to THz transceiver operation using the already deployed fibre networks. The combination of THz photonics and the electronic receiver in the heterodyne configuration leads, thanks to an ED, to the highest sensitivities at the reception stage. Here, the HD-TV signal was handled at 600 GHz with only 10 nW of received power. The realisation of this kind of system is also possible with standard laser lines such as distributed feedback sources, widely deployed in fibre core networks.

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

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