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Event: SPIE OPTO, 2023, San Francisco, California, United States

Purely Photonic Wireless Link at 120 GHz Carrier Frequency Enabled by Heterodyne Detection with a Photoconductive Antenna

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ABSTRACT

We demonstrate a fully photonic sub-THz communication link using a PIN photodiode (PD) emitter and an optimized photoconductive antenna (PCA) as a heterodyne receiver. The novel receiver comprises an iron-doped indium gallium (InGaAs) PCA on a silicon lens and passive radio frequency (RF) circuitry, all packaged into a fiber-coupled module. A 3-dB-bandwidth of 11 GHz for the intermediate frequency was measured. We analyzed the capabilities of the receiver in a wireless communication link over a distance of 1 m with a PIN photodiode as the emitter. At a carrier frequency of 120 GHz, we demonstrate error free transmission for net data rates up to 10 Gbit/s with quaternary quadrature amplitude modulation (4-QAM) modulation.

Keywords: Terahertz communications, Photoconductive antenna, Terahertz, Wireless communications

1. INTRODUCTION

The field of THz communications is continuing to grow and many options to access the unallocated channels and high bandwidths of the sub-THz frequency range are being explored [1]–[3]. Although electronic solutions are popular due to their high output powers, photomixers have also shown great potential as emitters (Tx) for millimeter-wave and sub-THz wireless communication applications [3]–[5]. However, only a few photonic receivers (Rx) have been used in communication links so far [6], [7], while electronic mixers remain the dominant technology [3], [8]. To fully exploit the advantages of THz photomixers, such as their high operating bandwidth and low phase noise, further development of respective photonic receivers is crucial. Here, we demonstrate a fully photonic communication link at a carrier frequency of 120 GHz, enabled by a PIN photodiode (PD) emitter and a photoconductive antenna (PCA) applied as a heterodyne receiver.

2. HETERODYNE THZ RECEIVER

We developed a photonic heterodyne THz receiver based on state-of-the-art PCAs using iron-doped InGaAs as the ultrafast absorber [9]. The PCA receives incoming THz fields through a silicon lens and a bow-tie antenna. The incident THz waves are downconverted to the baseband by photomixing with a photonic local oscillator (LO) that is generated by the superposition of two C band (1530 nm – 1570 nm) lasers with a certain frequency difference called LO beat frequency. The frequency of the output signal of the receiver is equal to the difference frequency of the LO beat frequency and the THz carrier frequency and will henceforth be called intermediate frequency (IF). To achieve gigabit data rates, the receiver has to be capable of handling signals of several GHz bandwidth. Therefore, we implemented radio frequency (RF) waveguide structures on the PCA chip and connected it to a ceramic comprising further RF waveguides and an RF coaxial connector in the package.

Terahertz, RF, Millimeter, and Submillimeter-Wave Technology and Applications XVI,
edited by Laurence P. Sadwick, Tianxin Yang, Proc. of SPIE Vol. 12420, 1242005

doi: 10.1117/12.2649256

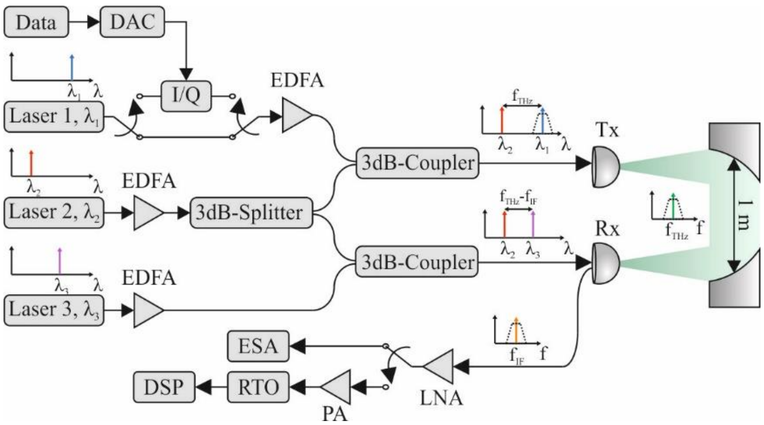

Figure 1. Setup for measuring the IF spectrum and data transmission. Two separate optical beatings with a frequency spacing of f_{IF} are created using three lasers and fed to the Tx and Rx, respectively. For the data transmission experiments, we added a digital-to-analog converter (DAC) and an in-phase quadrature (IQ) modulator to modulate 4-QAM data signals on laser 1, added a power amplifier in the electrical path, and replaced the ESA with a real-time oscilloscope (RTO). We recovered the transmitted data using offline digital signal processing.

To characterize the IF performance of the assembled module, we aligned the receiver to a commercially available PIN photodiode THz emitter [10] via parabolic mirrors over a distance of 1 m as shown in Figure 1. A low noise amplifier (LNA) with a gain of 26 dB and 21 GHz bandwidth and a 50 GHz electrical spectrum analyzer (ESA) served to measure the output power. The emitter was operated at an optical beat frequency of 120 GHz with an optical input power of 30 mW, generated by two independent continuous-wave (CW) lasers with fixed frequencies of 1556.91 nm and 1555.94 nm, respectively. The photonic LO at the receiver had an optical output power of 40 mW and was generated by using a third, tunable CW laser, in order to generate different IF frequencies. Figure 2 shows the output signal power as a function of the IF together with the finite element (FEM) simulation results obtained in Ansys High-Frequency Structure Simulator (HFSS). The receiver exhibits a 3-dB-bandwidth of 11 GHz, as expected by the simulation, which agrees very well with the measurement. From the simulation, we also determined the main limiting factors for the IF bandwidth to be package resonances and the transition from the RF waveguides to the connectors, which we intend to improve in future iterations of the package.

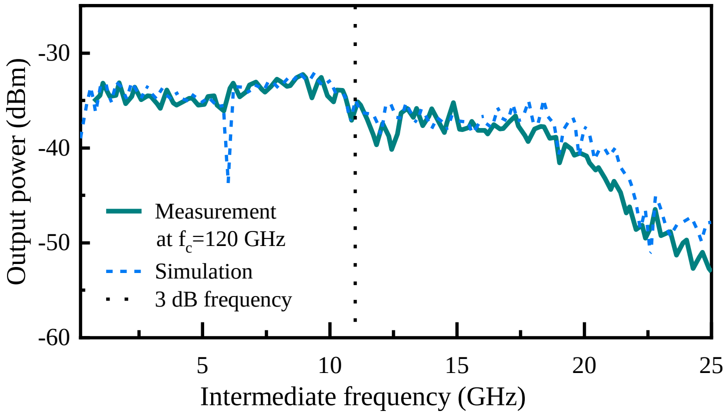

Figure 2. Simulation and measurement of the IF spectrum (output power as a function of intermediate frequency) of the heterodyne receiver after amplification by 26 dB. The carrier frequency was 120 GHz and the optical power at the emitter and receiver were 30 mW and 40 mW, respectively.

3. PHOTONIC THZ LINK

We used our novel receiver to set up a fully photonic data transmission link. For this, we used the 1 m transmission setup with parabolic mirrors and PIN PD emitter. Now, we modulated a 4-QAM signal onto one of the CW carriers of the optical beat signal at the transmit side using an IQ modulator. The emitter carrier frequency was set to 120 GHz, and the IF at the receiver was set to 8 GHz by setting the LO beat frequency to 112 GHz. At the receiver side, we added another power amplifier with a gain of 20 dB (35 GHz bandwidth) after the LNA and replaced the ESA with a real-time oscilloscope (20 GHz bandwidth, 50 GSa/s), from which we could sample the received and amplified signals. We used offline digital signal processing (DSP) [11] to reconstruct the data and measure the bit error rate (BER). Figure 3 shows the BER achieved for gross data rates between 4 and 12 Gbit/s. It can be seen that the BER increases for higher bit rates, which is expected. However, all values are below the forward error correction (FEC) threshold assuming an overhead of 20%. Therefore, the transmission can be assumed error free for up to 10 Gbit/s net data rate (corresponding to 12 Gbit/s gross data rate).

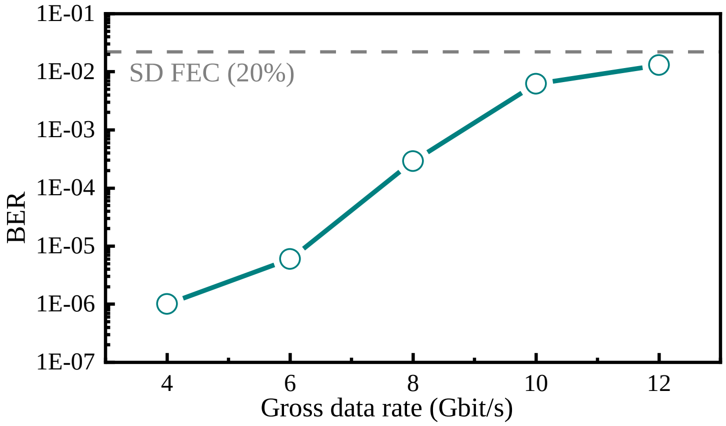

Figure 3. Measured BER as a function of data rate in our transmission link (distance = 1 m) at a carrier frequency of 120 GHz. The IF was 8 GHz. The dashed line indicates the soft decision FEC threshold for 20 % overhead.

4. CONCLUSION

In order to demonstrate a fully photonic sub-THz communication link with a PIN-photodiode as emitter, we developed a photonic heterodyne THz receiver based on state-of-the-art PCAs. It features RF waveguide structures, which we developed using high-frequency FEM simulations, to efficiently couple the IF signal from the chip to the external circuitry. The receiver exhibits a large IF 3-dB-bandwidth of 11 GHz, which enabled single channel net data rates up to 10 Gbit/s over a distance of 1 m at a carrier frequency of 120 GHz in this fully photonic sub-THz link. This is the highest reported single-channel data rate for a fully photonic sub-THz link and a significant step towards exploiting the full potential of photonics in THz communications.

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