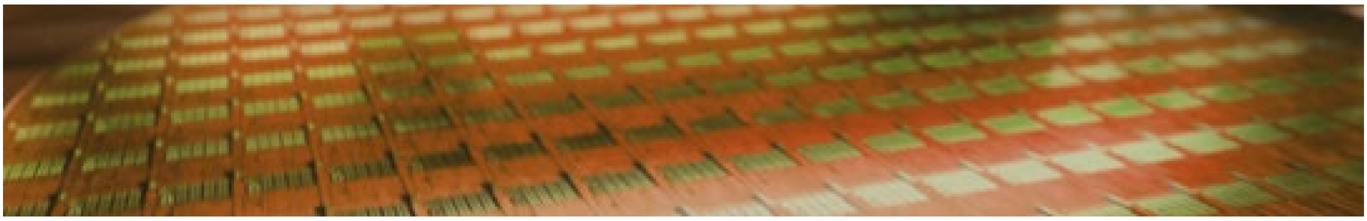

TERAHERTZ COMMUNICATION RESEARCH

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Wireless communication links strive for higher bandwidths, driven by an ever-increasing growth in data rates. Whilst present-day systems like Bluetooth or WLANs employ bandwidths between a few MHz and several GHz, it can already be foreseen that these frequency bands will not suffice in the long run, when transfer rates of several 10 to several 100 Gigabits/second will be needed. Since faster data transfer requires higher carrier frequencies, ongoing research now focuses on the use of "terahertz" (THz) systems, with carrier frequencies well above 100 GHz.
This application note summarizes some of the recent achievements in terahertz communication research, and presents systems and components that have proven beneficial in this field.

INTRODUCTION

At present, fully electronic and optoelectronic (i.e. laser-based) sources compete for the highest data rates and the lowest transmission errors. There are still technological questions that remain to be solved, one of them being the lack of seemingly simple components - for instance, no suitable transmission lines exist, i.e. no terahertz equivalents to fiber-optics. On the other hand, these very challenges make THz communication research such an active and vibrant field.

This application note focuses on optoelectronic systems, where so-called "photoconductive antennas" or "photomixers" convert near-infrared laser light into terahertz radiation. Depending on the utilized laser source, the terahertz light is either spectrally broad, or monochromatic. The latter is achieved with the help of single-frequency lasers, and it is the most common concept in optoelectronic THz communication research.

The following list of recent achievements is far from exhaustive, but it shows how dynamic the quest for ever-higher data rates has become.

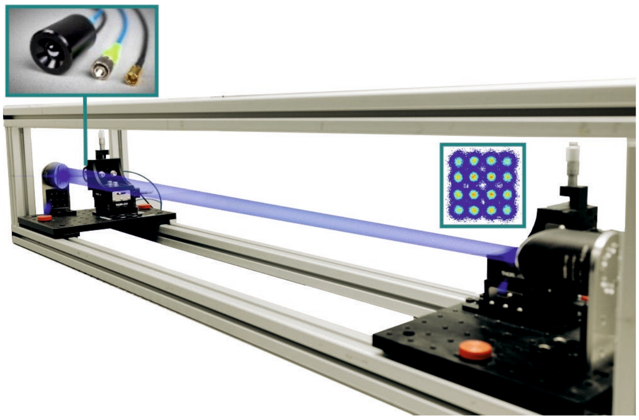

Fig. 1: Lab setup of a terahertz wireless link across a 1 m distance. The inset on the left-hand side depicts an optoelectronic terahertz emitter, the one on the right shows an example of a 16 quadrature amplitude modulation (QAM) constellation pattern.
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In 2022, researchers from Fraunhofer Heinrich Hertz-Institute (HHI, Berlin, Germany) and the Université de Lille (France) demonstrated a data rate of 160 Gbit/s with 32QAM modulation [1], using a fiber-coupled photodiode as transmitter (Fig. 1, inset) and a carrier frequency of 300 GHz. A year later, a collaboration between Karlsruhe Institute of Technology, the University of Duisburg-Essen and Nokia Bell Labs (all in Germany) pushed the limit to 200 Gbit/s over a 52-m-long indoor link [2], likewise at a carrier frequency of 300 GHz. In the same year, a French-Japanese consortium employed a multi-channel approach in the 600 GHz band and achieved a previously unmatched aggregated data rate of 1.04 Tbit/s [3].

TERASCAN 1550 : A FLEXIBLE TEST PLATFORM

Fig. 2: TeraScan 1550, with two DFB seed lasers operating at 1.5 µm, an emitter/receiver antenna pair, and the compact control unit DLC smart.

For researchers in the field of terahertz communication, TOPTICA's TeraScan 1550 (Fig. 2) offers a versatile testbed, as the emitted terahertz frequency can be flexibly chosen over a range of more than four octaves (50 GHz – 1200 GHz). Users can either select a constant frequency anywhere within the tuning range, or perform a frequency scan, e.g. in order to characterize the spectral response of components such as filters, reflectors or waveguides across a broader range.

Scientists new to the field will benefit from an instructive publication by a team of researchers at Polytechnique Montréal, Canada [4], who built a THz wireless link entirely from off-the-shelf commercial components. Their paper lists all the key components and their vendors, including the two-color laser platform from TOPTICA. For their work, the authors chose an operating frequency of 138 GHz.

The paper by the Montréal group also provides suggestions for additional components as needed for THz communication, such as the modulator, an Erbium-doped amplifier to compensate for the losses in the modulator and a fast, incoherent THz detector.

THE PHOTOMIXER

In any optoelectronic THz transmission link, the emitter module plays a key role. This device translates the beat signal of two cw lasers into THz radiation and is thus usually dubbed "photomixer". The two best-known designs are so-called uni-traveling carrier photodiodes (UTC-PDs), a concept pioneered by NTT in Japan [5], and waveguide-integrated PIN photodiodes (PIN-PDs), a design optimized by HHI in Berlin [6]. In 2020, a team of researchers from HHI, NTT and TOPTICA compared the output power of both emitter types [7]. They confirmed that each design has advantages within a certain spectral range, with the PIN-PDs reaching a higher output at low frequencies. Commercial PIN-PD modules, available from TOPTICA, meanwhile achieve power levels above 500 µW within the range of 50 .. 100 GHz.

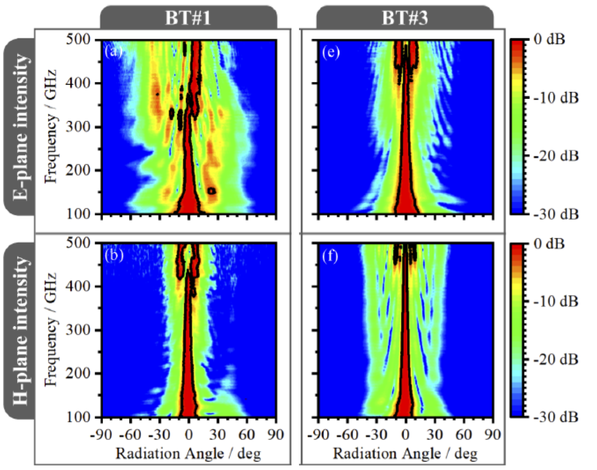

Fig. 3: Radiation patterns for two different PIN-PD photomixers as designed by Fraunhofer HHI. Each emitter is characterized between 100 GHz and 500 GHz, and the intensity of the emitted beam is plotted for angles between -90° and +90°. Top row: E-plane intensity, bottom row: H-Plane intensity. From ref. [8].

Besides the emitted power, the beam profile of the THz emitter also plays a crucial role in a wireless link. Researchers from HHI investigated the beam profile of their PIN-PD emitters in detail, and recently presented a new design with a more compact, more directional beam profile (Fig. 3) [8]. Both the standard design "BT #1" and the new type "BT #3" are now commercially available from TOPTICA.

THE MOST STABLE TERAHERTZ SIGNALS

For applications that require an ultimate stability of the frequency and phase of THz signals, it is advisable to lock the two lasers to a single frequency comb. TOPTICA Photonics pursued this approach in the German research project ADLANTIK, together with partners from Rohde & Schwarz, the Technical University of Berlin, and Fraunhofer Heinrich-Hertz Institute. The goal of the ADLANTIK project was to transfer the extraordinary phase-noise stability of optical oscillators into the microwave and THz region, maintaining a wide tunability of the THz carrier frequency. Whilst fixed-frequency operation remains possible, a key innovation is the "endless frequency shifter" concept [9] [10], where the output of a tunable laser remains precisely controlled even during a frequency scan.

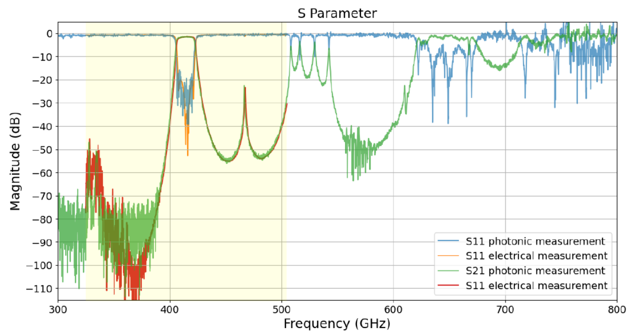

Fig. 4. S-parameter measurement of a 415 GHz waveguide bandpass filter. Reflection (S11) and transmission (S21) measurements obtained with an electric vector network analyzer (orange and yellow curves) agree well with spectra obtained with the TeraScan ultra (blue and green curves), which cover a much wider frequency range. © ADLANTIK project consortium.

The unique technique of the endless frequency shifter employs an electro-optic modulator, which adds a phase shift to the pulse train generated by the frequency comb. This, in turn, creates a frequency shift of the comb modes and hence, scans the wavelength of the tunable laser that remains locked to the comb. The technology has been implemented in TOPTICA's new TeraScan ultra. This system provides tunable cw-THz emission from 20 GHz to 5 THz, with a frequency accuracy and resolution down to 1 Hz. In the context of THz communication research, the system lends itself to channel sounding, spectrum analysis of external THz sources, or as a broadband vector network analyzer [11] (Fig.4). More results to be published soon!

BROADBAND SAMPLE CHARACTERIZATION

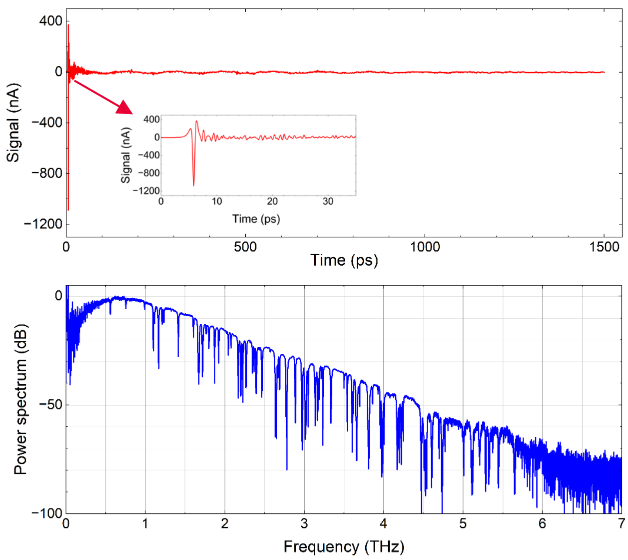

Fig. 5: 1500 ps time trace with corresponding spectrum, measured with TOPTICA's TeraFlash pro. Even for the long scan range, the useable bandwidth exceeds 5.5 THz. The dips are absorption lines of water vapor in the beam path. © TOPTICA Photonics.

Whilst THz wireless links generally work at a single frequency or several discrete frequencies, even pulsed THz systems have proven useful in communication research, for instance for the broadband characterization of components such as waveguides, reflectors, or filters.

The raw signal of a pulsed, or time-domain, THz system is the so-called pulse trace, which is created by scanning the THz pulse with precisely delayed laser pulses, akin to a sampling oscilloscope. A Fast Fourier Transform of the time trace then produces the THz spectrum. According to the principles of the Fourier transform, the attainable spectral resolution is given by the (inverse) length of the time trace. In order to achieve a high spectral resolution, one therefore needs to sample a long time trace – ideally several 100 ps – yet with utmost precision. TOPTICA's TeraFlash pro enables the acquisition of pulse traces of up to 3000 ps length, which translates into a spectral resolution as high as 300 MHz. Even for long sampling times, the dynamic range and thus, the signal quality remains very high. Fig. 5 shows a 1500 ps-long pulse trace (top panel) and the corresponding spectrum (bottom panel), with a useable bandwidth of more than 5.5 THz. At 4 THz and 5 THz, the dynamic range amounts to ~ 40 dB and ~ 25 dB, respectively, exceeding the bandwidth even of the best available cw-THz emitters and receivers.

CONCLUSION

Terahertz communication is a highly dynamic field of research. Over the last years, optimized emitters, receivers, lasers and modulation schemes have paved the way towards new records in data transmission rates. Spectrally narrow cw-lasers are best suited for THz wireless links, where photomixers efficiently convert the beat signal of the lasers to monochromatic, tunable THz radiation. For applications that require an exceptional phase-noise stability, the cw-lasers can be locked to optical frequency combs. Still, even pulsed THz systems have their merits in THz communication research, as they enable a broadband characterization of some of the relevant components.

ACKNOWLEDGEMENT

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