# THz Generation with Photoconductive Emitters with a Low-noise GHz Repetition Rate Laser

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***Abstract*— We demonstrate THz generation with state-of-the-art iron doped InGaAs photoconductive emitters using a low-noise GHz repetition rate amplified femtosecond laser operating at a central wavelength of 1560 nm. We measure a maximum dynamic range of 73 dB and a bandwidth of more than 3 THz. This unique laser source combining low-noise and high repetition rate is a promising alternative to the frequently used commercial fiber systems at 100 MHz.**

## I. Introduction

Photoconductive emitters and antennas are widely accepted as the best combination for applications requiring broadband and high dynamic range (DR) [1] and are nowadays deployed in most commercially available systems. The standard systems use fiber lasers with 100 MHz repetition rate, 90 fs pulse duration that can produce ca. 100 mW of average power as drivers. They achieve a DR of 90-95 dB (typically in measurement times in the few minutes range) while specialized antennas pushed the record to 105 dB and 6.5 THz bandwidth in 1 min measurement time [1]. In this context, whereas significant efforts have been placed on optimizing the emitters and detectors to push the emitter efficiency and detection sensitivity, the laser sources used have pretty much remained the same ones. Novel laser sources with higher repetition rate and higher power levels are a promising route towards further improvements in this area, however the SNR and DR figures in a TDS are complex and strongly dependent on a large variety of parameters including which measurement method is used, and a more thorough exploration is needed to make conclusions about the optimal laser system parameters.

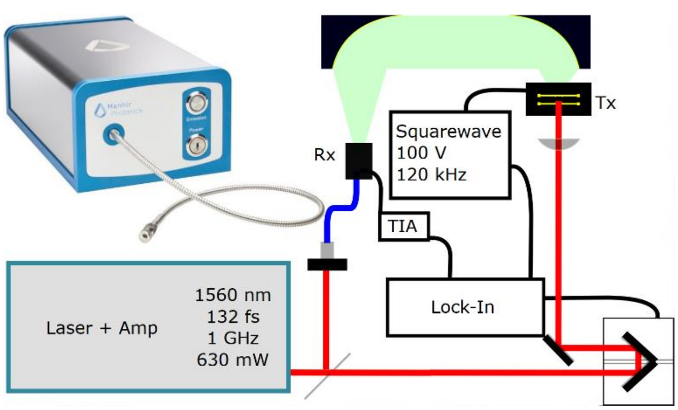


*Fig 1. Scheme of the THz TDS setup. After the beam splitter the probe beam (P = 20 mW) is coupled into the fiber of the Rx. The pump beam (P = 30 mW) passes through the delay stage and is focused in free space on Tx.*

Here, we present our first steps in this direction by combining state-of-the-art emitters and receivers with an ultra-stable femtosecond laser at 1 GHz repetition rate [2] as the optical source. We demonstrate a 1 GHz repetition rate THz-TDS system with a dynamic range of 73 dB and a bandwidth of 3.5 THz using state of the art THz photoconductive emitter and receiver with a measurement time of 60 s, and discuss current limitations in our setup. This first result is part of a larger effort to understand the compromises to be realized in terms of repetition rate and average power to take photoconductive emitters and receivers to the next step in SNR and DR.

## II. Experimental setup

As seen in Figure 1 the driving laser is a shoe box sized turnkey commercial fs laser (MENHIR-1550 SERIES) operating at 1550 nm wavelength with a repetition rate of 1 GHz, providing an output power of 30mW with a supported pulse duration of 250 fs, offering extremely low noise levels. The output of the laser is amplified and compressed by a commercial fiber amplifier and 54 cm of dispersion compensating fiber to 630 mW ($E_p$=630 pJ) and 132 fs. We us an uncoated pellicle beam splitter to separate the pump and probe beam and use a lambda half waveplate to adjust the polarization of the probe along the fast axis of another patch of polarization maintaining dispersion compensating fiber connected to the fiber coupled receiver to keep the pulse duration of the probe beam short. The pump beam is propagating in free space only. In this first experiment, we only use 20 mW as the probe beam and 30 mW as the pump beam, as these are the optimal operation points for the emitter and receiver available. In this way, we can easily compare our results to previous achievements at lower repetition rate, to later explore power scaling with larger area emitters.

We use a 200 mm lens to focus the pump beam on the emitter, which is based on iron doped InGaAs and structured as a stip-line antenna with an active region of 50 µm x 50 µm [3] while the fiber coupled receiver is based on low-temperature grown, beryllium doped InGaAs with a 10 µm wide dipole antenna. The generated THz radiation is collimated by a 2 inch off axis parabolic mirror (OAP) and focused on the receiver with a second OAP. The receiver’s output is fed to a transimpedance amplifier which is connected to a lock-in amplifier (Zurich Instruments, UHFLI 600 MHz Lock-in Amplifier).

To modulate the emitter, we use a commercial waveform generator that can provide an AC bias of up to 10 V peak to peak and a rectangular waveform up to 200 kHz. Since the emitter can be biased up to 100 V, we also use a voltage amplifier with a fixed amplification factor of 50, a maximum output voltage of 150 V and a maximum frequency of 200 kHz. To sample the THz pulse, the pump beam is delayed with respect to the probe using an oscillating delay line with a shaking frequency of up to 25 Hz and a maximum range of 50 ps.

## III. Results

After scanning the available parameter range in terms of modulation and shaking frequency and amplitude, the best spectrum could be achieved using a rectangular modulation with 100 V peak to peak amplitude, a modulation frequency of 120 kHz. The filter bandwidth of the Lock-in amplifier was 30 kHz at a shaking frequency of 20 Hz with a 30 ps range. The time trace and spectrum are shown in Figure 2 featuring a DR of 73 dB acquired in 60 seconds.

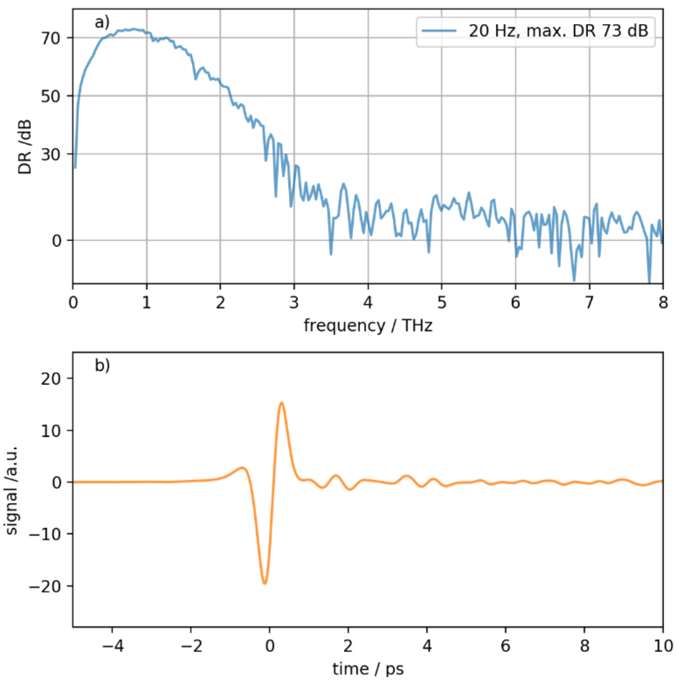


*Fig. 2. a) Measured THz TDS spectrum at 20 Hz shaking, 30ps range, 120 kHz electrical modulation at 100 V peak to peak voltage. The bandwidth is 3.5 THz with a peak frequency of 800 GHz and the DR is 73dB. b) Corresponding THz time trace. The total measurement time was 60 s, which results in 1200 averaged traces.*

In this first experiment, we identified the main limiting factor to achieve higher DR and benefit from the increase in repetition rate to be the accuracy of the oscillating time delay. As seen in Figure 3, the THz peak position fluctuates approximately in the range from -20 fs to +20 fs with a standard deviation of 7.5 fs, which corresponds to a displacement error of 2.2 µm. The influence of the timing jitter on the DR can be expressed as:

$$\mathrm{DR_{jit}} = -20\log\left(2\pi\nu_{THz}dt\right),$$

where $\nu_{THz} = 800$ GHz is the peak THz frequency of the signal and $dt$ is the timing jitter. Assuming a reduction of the time fluctuations to 1.3 fs as done by Vieweg et al. in [4] and keeping all other measurement parameters unchanged we can expect an increase of the DR of at least up to 15 dB which requires the displacement error to be around 400 nm. An increase of 15 dB in DR would lead to a peak DR approaching 90 dB, which approaches that of state of the art THz systems.

In the near future, we expect to reach significantly higher DR by using a more precise stage that has less than 400 nm displacement error, or by increasing the accuracy of the position measurement of a less precise stage like the current one used in this setup. A more accurate position signal could be achieved with the help of an interferometer which readily offer a resolution of less than 1 nm and additionally can follow the fast shaking of the oscillating delay line so there is no increase in measurement time.

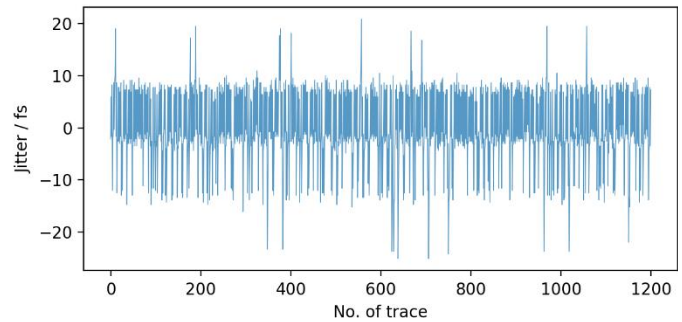


*Fig. 3. Timing jitter of the individual THz traces. The standard deviation is dt = 7.5 fs.*

## IV. Conclusion

In conclusion we present a first result using a GHz repetition rate, low-noise fs laser as the pump laser for state-of-the-art THz emitters and receivers and achieve a DR of 73 dB and a bandwidth of over 3 THz in 1 min measurement time. We could identify the main limiting factor in our system and suggested ways how to improve this result. This is a promising step in the direction of optimizing the DR and SNR of THz TDS by using higher repetition rate and higher average power lasers systems which are becoming more widely available.

## References

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