# 200 Hz Rapid Scan Fiber-coupled Terahertz Time Domain Spectroscopy System

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***Abstract*— A high speed optical delay line in combination with a fiber-coupled terahertz time domain spectroscopy system allows for scan rates up to 200 Hz, a spectral resolution of about 10 GHz and a bandwidth of 3 THz.**

## I. Introduction

MOST terahertz (THz) time domain spectroscopy (TDS) systems using femtosecond laser pulses for generating and detecting THz radiation in photoconductive switches [1] have two major disadvantages: In order to obtain a reasonable spectral resolution large temporal scans over the electric wave form have to be performed resulting in long data acquisition times. The scan rate can be increased by using shorter delay paths, however, in this case the spectral resolution will be reduced considerably. In addition, the free-space setup of most TDS systems does not allow for stable and flexible use of these systems, in particular, in industrial applications.

In order to overcome both problems a novel type of delay line was combined with a fiber-coupled THz TDS system with fiber lengths of up to 20 m. The delay line combines wide delay path lengths with high repetition rates thus allowing for fast data acquisition and high spectral resolution simultaneously.

## II. Experimental Set-Up

The layout of the fiber-coupled system is schematically shown in Fig. 1. The infrared light pulses generated by a frequency doubled fiber laser are guided in single mode fibers for 800 nm to ensure good beam quality and to keep pulse distortions low. Also the beam splitting into emitter and detector path as well as the 1 % monitor outputs are realized by special fiber couplers.

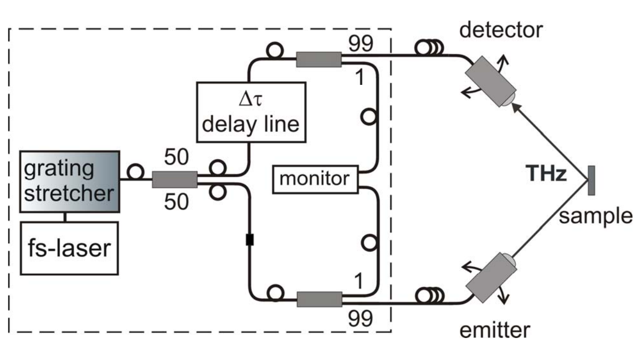


Fig. 1. Set-up of the fiber-coupled THz TDS system pumped by a fiber laser.

For these kinds of single mode fibers the chromatic dispersion at 800 nm is mostly affected by material dispersion and hence located in the normal dispersion regime. Thus the pulse is broadened while propagating through the fiber [2]. To obtain short pulses at the fiber end, they must be prechirped with a device in the abnormal dispersion regime. This is done by using a pair of refraction gratings. The negative dispersion of the grating stretcher can be tuned by changing the distance between the two gratings to compensate the net-dispersion of the complete fiber link [3]. Since the sign of the third order dispersion (TOD) of the fiber and the gratings are the same the overall TOD keeps uncompensated and is rising with fiber length (see Fig. 2). Hence TOD is one limiting factor of the maximum fiber length for a certain pulse width limit.

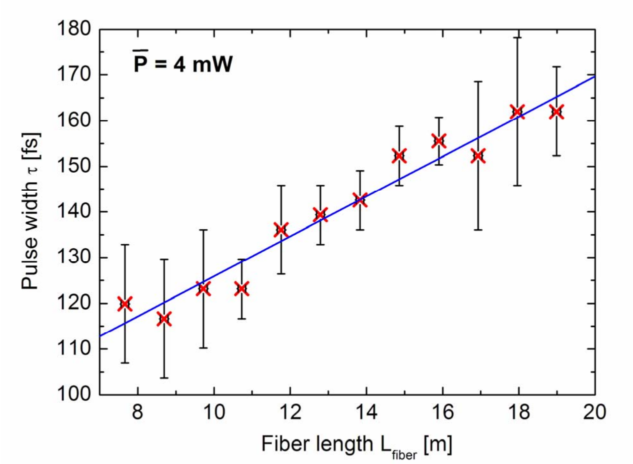


Fig. 2. Uncompensated TOD results in a rising pulse width (full width at half maximum: FWHM) with increasing fiber length.

Besides the linear dispersion also nonlinear effects in the fiber like self-phase modulation (SPM) are influencing the pulse propagation. The SPM leads to a pulse broadening with the same sign as the fiber dispersion but with a quadratic instead of linear phase [2]. Hence its impact on the pulse shape can be only slightly reduced by tuning the grating stretcher. Fig. 3 shows the pulse width at the end of a 20 m long fiber: The minimum pulse width is rising linearly with the average signal power [3].

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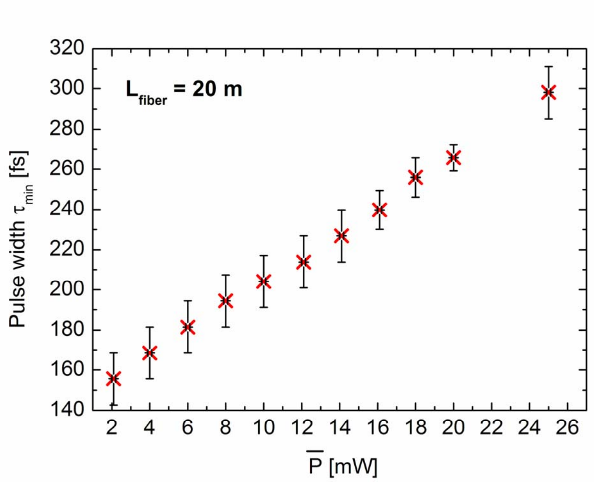


Fig. 3. The nonlinear effect of SPM leads to an increasing pulse width.

The optical delay line of the system is a mechanically operated device, which is in principle capable to scan its 40 mm delay path with a repetition rate of several kHz. The THz emitters and detectors are standard LT-GaAs photoconductive switches with a dipole structure to which the glass fibers are glued. As a consequence, no extra alignment of the optical beam in the THz heads is necessary. With the monitor outputs the optical power level is detected in the emitter and detector arm, respectively.

## III. Results And Discussions

Up to now we have propagated pulses as short as 160 fs full width at half maximum (FWHM) over 20 m fiber transmission lines using standard single mode fibers. The fiber-coupled THz system shows a bandwidth of about 3 THz with a signal to noise ratio of 60 dB (see Fig. 4).

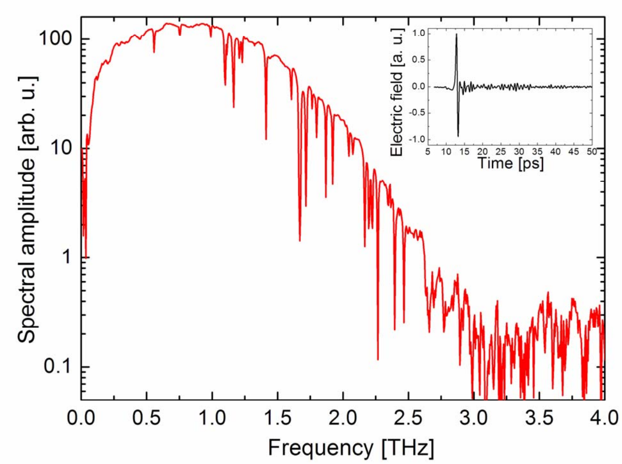


Fig. 4. Best performance of the fiber-coupled THz TDS system for slow scanning mode: Bandwidth 3 THz.

The THz-bandwidth is limited by the bandwidth of the femtosecond laser pulses and the THz optics used in the detector and emitter heads. Due to the effect of polarization mode dispersion low distortions of the fiber, e. g. by external stress while moving the THz heads, can lead to pulse broadening at the fiber end and, as a consequence, to a reduction of the bandwidth. This was avoided by using polarization maintaining fibers. No significant nonlinear effects except the SPM as shown above have been observed in the fiber as we have operated the system at very low powers sufficient to drive our LT-GaAs antennas. With this set-up real-time THz measurements have been performed at a repetition rate of more than 200 Hz (see Fig. 5). The bandwidth of our system still depends on the repetition rate and decreases with an increasing repetition rate: At 100 Hz a bandwidth of more than 2.5 THz was obtained.

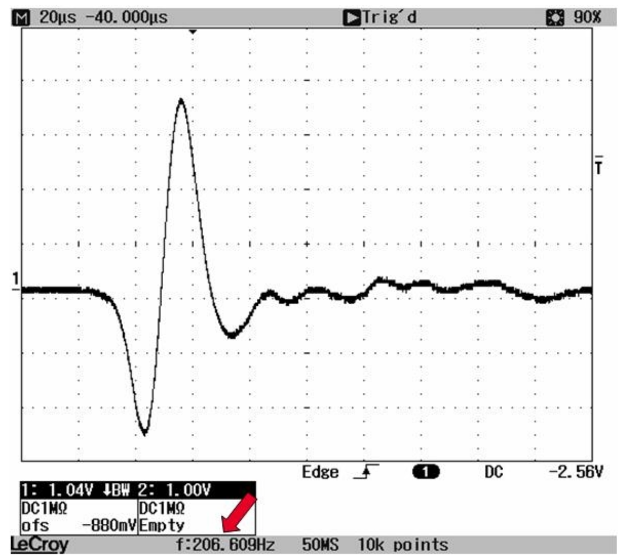


Fig. 5. Oscilloscope screenshot of the THz time signal at a scan rate of about 206 Hz (see bottom line in figure).

A limiting factor so far is the electronics we have used for data acquisition. In principle, scan rates well above 1 kHz are feasible with this delay line still allowing for high spectral resolution.

## References

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