NOISE AND DRIFT CHARACTERIZATION OF CRITICAL COMPONENENTS FOR THE LASER BASED SYNCHRONIZATION SYSTEM AT FLASH

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Abstract

At FLASH, a new synchronization system based on distributing streams of short laser pulses through optical fibers will be installed and commissioned in 2007. At several end stations, a low drift- and low noise conversion of the optical signal into RF signals is needed. In this paper, we present the influence of photodiodes on the phase stability of the optical pulse streams and investigate the drift performance of the photo-detection scheme for the extraction of the RF signal.

INTRODUCTION

A novel optical synchronisation system based on the generation and distribution of laser pulses in the Free Electron LASer facility in Hamburg (FLASH) at DESY is currently under development [1] and a candidate to overcome the short and long term stability limits given by a conventional RF distribution system [2].

The tight synchronisation requirements at distant tap points for experiments performed with the coherent FEL radiation can be met by locking a Fiber Master Laser to a microwave Master Oscillator (M.O.) and distributing the optical pulse train via fiber links inside the facility [3]. The distributed optical pulses are converted into RF signals using photodiodes. The optical pulse train with a repetition rate of $f_{\text{rep}} = 54\,$MHz is generated with an erbium-doped mode-locked stretched pulse laser [4]. Here we investigate the phase noise and phase drift limitations given by the components used for the extraction of the RF signal.

GENERATION OF RF SIGNAL

The optical pulse train generated in an erbium-doped mode locked stretched pulse fiber laser is fed to a photodiode that generates an electrical pulse train with a repetition rate $f_{\text{rep}} = 40.625\,$MHz given by the laser. A fourier transform of the electrical pulse train will lead to fourier components equally spaced at the repetition frequency of the pulses. We extract the 32^{nd} harmonic of the pulse train at $1.3\,$GHz with a bandpass filter and amplify the signal using a low noise amplifier with a gain of approximately $G = 30\,$dB. We designate this method as the direct conversion scheme for extracting the RF signal out of the pulse train. The measurement principle is sketched in figure 1.

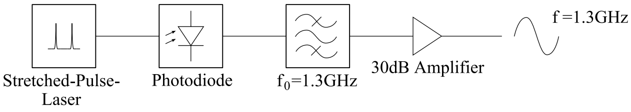

Figure 1: Direct conversion scheme for extracting 1.3 GHz

PHASE NOISE AND INTEGRATED TIMING JITTER

After the extraction of the RF signal from the optical pulse train with the method described above we measure its single sideband phase noise spectral density. We integrate the phase noise in a bandwidth from $f_1 = 1\,$kHz to $f_2 = 20\,$MHz and obtain the integrated timing jitter by

$$\Delta T_{\text{rms}} = \frac{1}{2\pi f_0}\sqrt{\int_{f_1}^{f_2} S_\phi(f)df}\,[s]_{\text{rms}} \tag{1}$$

where $S_\phi(f)$ is two times the measured single sideband phase noise $\mathscr{L}(f)$ [5].

Integrated timing jitter of direct conversion

Experiments have shown, however, that for obtaining a suitable integrated timing jitter performance and enough power for the distribution of pulses in the fiber link an Erbium-Doped Fiber Amplifier (EDFA) between the laser source and $10\,$GHz bandwidth photodiodes are inevitable. The measurement setup includes a signal source analyzer to measure the single sideband phase noise of the detection chain. A minimum of phase noise obtained during our investigation is shown in figure 2.

The integrated timing jitter for the direct conversion scheme in a bandwidth from $f_1 = 1\,$kHz to $f_2 = 20\,$MHz amounts to $\Delta T_{\text{rms}} = 9\,$fs.

Phase noise contribution of photodiodes

The phase noise limitation of the detection chain photodiode, bandpass filter and low noise amplifier has been experimentally observed to mainly originate in an AM[1] to PM[2] conversion process in the photodiodes. We compared four $10\,$GHz photodiodes in their AM to PM characteristics with the setup in figure 3. For approximately $5\,$mW of optical power, the diodes are not saturated and show a significantly higher AM to PM contribution (see figure 4) than for higher optical powers. The conversion coefficients

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[1] Amplitude Modulation

[2] Phase Modulation

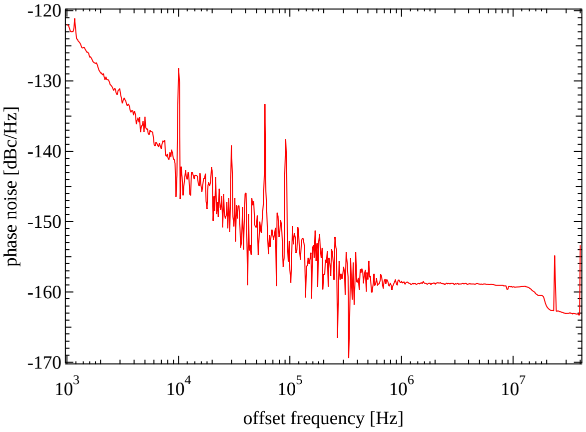

Figure 2: Measured phase noise, integrated timing jitter in a bandwidth from $f_1 = 1\,\text{kHz}$ to $f_2 = 20\,\text{MHz}$ amounts to $\Delta T_{\text{rms}} = 9\,\text{fs}$

are estimated as a linear fit for power fluctuations between 10 mW and 20 mW. They are summarized in table 1.

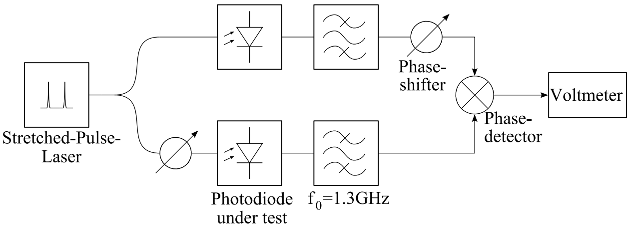

Figure 3: Setup to examine AM to PM conversion of photodiodes

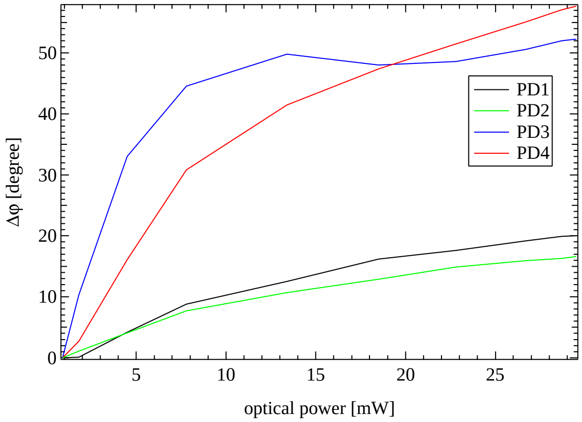

Figure 4: AM to PM characteristics of photodiodes

These photodiodes are investigated concerning their integrated timing jitter performance with a variation of the optical input power, as shown in setup 5. Figure 6 reveals this measurement for photodiode PD3 for different pump powers of the EDFA. The integrated timing jitter dependence of the EDFA gain is neglectible compared to the photodiodes but has a minimum value for an optical power of approximately 12.5 mW showing consistency with a minimum for the AM to PM conversion coefficient for the same optical power (see figure 4). The RF power for the extracted 1.3 GHz signal varies as the integrated timing jitter causes a change of the power in the sidebands.

Photodiode	$\frac{\Delta\phi}{\Delta P_{\text{opt}}}\left[\frac{°}{\text{mW}}\right]$	$\frac{\Delta T}{\Delta P_{\text{opt}}}\left[\frac{\text{ps}}{\text{mW}}\right]$
PD1	1.6	3.4
PD2	0..0.9	0..1.9
PD3	0.7	1.5
PD4	0.5	1.1

Table 1: AM/PM conversion coefficients

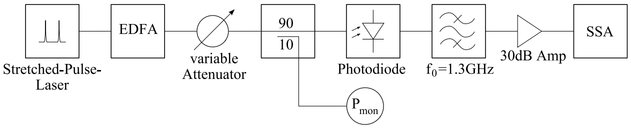

Figure 5: Photodiode phase noise measurement setup with variation of optical power

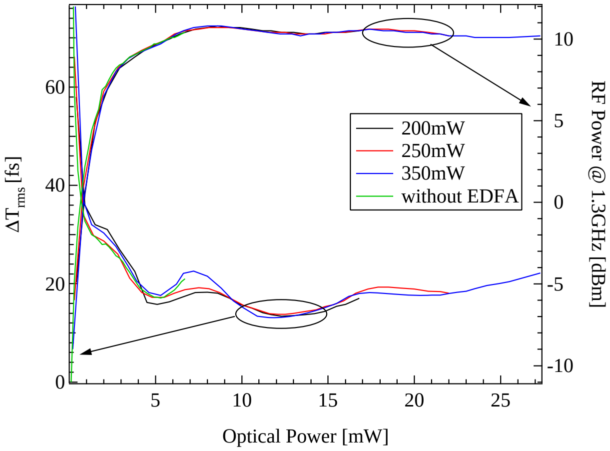

Figure 6: Integrated timing jitter and RF power of photodiode PD3 vs. optical power for different EDFA pump-powers at 980nm

PHASE DRIFT PERFORMANCE OF PHOTODIODES

For the determination of the phase drift contribution of the photodiodes in the direct conversion detection process described above, we make defined temperature steps on a photodiode and observe its temperature dependent characteristics in comparison to a reference photodiode which is stabilized in temperature (figure 7). The phase difference of the amplified 1.3 GHz signals is measured with a phase detector and recorded with a high resolution data logger. The recorded voltage fluctuations ΔV are converted to phase fluctuations $\Delta\phi$ by the conversion gain K_ϕ of the phase detector

$$\Delta\phi = \frac{\Delta V}{K_\phi} \tag{2}$$

and then related to the period T_0 of the carrier with frequency $f_0 = 1.3\,\mathrm{GHz}$[3].

$$\Delta T = \frac{\Delta\phi}{360°}\, T_0 \tag{3}$$

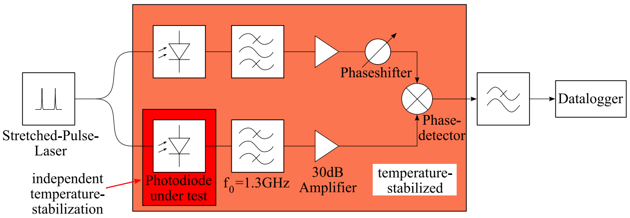

Figure 7: Setup for drift determination of 10 GHz bandwidth photodiodes

To minimize the influence of the temperature dependent characteristics of all devices on the overall phase drifts, everything but the photodiode under test has been mounted on an aluminum plate that is kept at a constant temperature of around $36°C$ with a temperature stability of $0.1°C$ indicated by the outer red box in figure 7. Our measurement limit of the setup when stabilizing all components in temperature is in the range of 50 $\mathrm{fs}_{\mathrm{pp}}$ and is shown in figure 8.

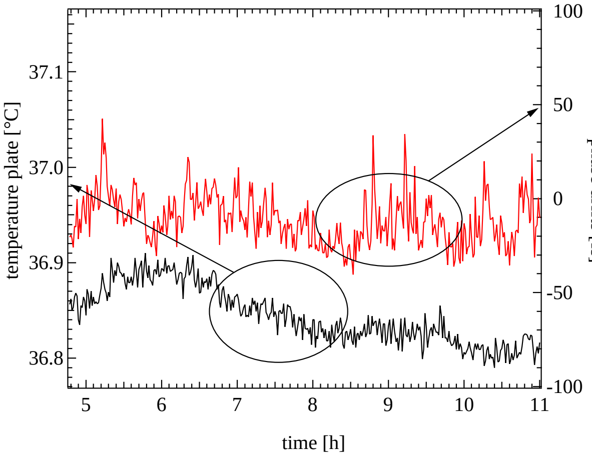

Figure 8: Measurement limit for phase drift characterization of photodiodes

With an independent temperature stabilization (inner red box in figure 7), we provide temperature steps on the photodiode under test and extract the temperature dependent phase drift coefficients in $\left[\frac{\mathrm{fs}}{°\mathrm{C}}\right]$ for each temperature step. The temperature coefficients for the measurement shown in figure 9 vary between 128 $\frac{\mathrm{fs}}{°\mathrm{C}}$ and 224 $\frac{\mathrm{fs}}{°\mathrm{C}}$.

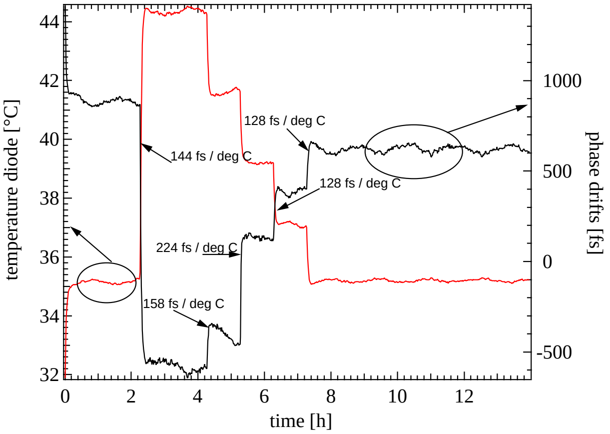

Figure 9: Phase drift dependence of photodiode

OUTLOOK

We have shown that the direct conversion scheme is limited by the performance of the photodiodes. This limitation is 10 fs for the integrated timing jitter and 150 $\frac{\mathrm{fs}}{°\mathrm{C}}$ for the phase drifts. The phase noise contributions of this detection method have been shown to originate in an AM to PM conversion process that either could be overcome with amplitude stabilization of the optical pulses or an alternative conversion method independent from amplitude fluctuations [6]. The noise contribution of the EDFA is significantly lower than the phase noise limitations given by our measurement methods and should be figured out with optical measurement methods.

A high degree of correlation between the photodiode temperature and the phase drifts is observable. However, repetitive phase drift measurements show a big variance of the temperature dependent phase change. A miniaturization and improved temperature stabilization for the extraction of the RF signal to overcome the RF phase drifts due to temperature changes in the detection chain is currently in preparation.

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[3] T_0 is the period of the carrier with a frequency of f_0