DOOCS hardware and software integration for Avesta autocorrelator

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Abstract

In the following we introduce the basic theory of autocorrelation for pulse duration measurements, and present a standard method on how to integrate the Avesta autocorrelator into DOOCS using a Basler acA-1300 60g camera. With the introduced changes there is a unified interface for the cameras, which now can be remote controlled.

Contents

1 Introduction

There are several equipment for pulse diagnostic, including pulse duration measurement too. Using a one-shot autocorrelator is a good choice for that. Nowadays in DESY these Avesta autocorrelator's cameras are not part of the Distributed Object Oriented Control System (DOOCS), and their software only runns under Windows. My work was to change a camera for a new one, to Basler acA-1300-60g, which is already included in the DOOCS. For that I had to make an adepter, to attach the camera to the autocorrelator's housing, create a DOOCS panel, and take measurements with it. After the changes, the remote control of the camera is now available, and we can use only one DOOCS panel to access all of the same cameras.

2 Theory

2.1 Chirp, pulse stretch and compression

To represent the attributes of an ultrashort laser pulse, it is a good choice if we take the most commonly present pulse shape. Let us consider a complex Gaussian impulse with A_0 amplitude and ω_0 mean carrier frequency. We can describe it - neglecting the spatial coordinates - as the follos [6]:

$$E(t) = \frac{1}{2}\widehat{E}(t)e^{j\omega_0 t} + c.c =$$

$$= \frac{1}{2}A_0 e^{(at^2)} e^{j(\omega_0 t + bt^2)} + c.c = \frac{1}{2}A_0 e^{(-rt^2 + j\omega_0 t)} + c.c$$

where $r = a - ib$ is the complex Gaussian parameter. The quantity which determine the pulse duration and the frequency modulation is a and b respectively. The third term's argument of the equation describes the current phase. The time derivative of that gives us the current frequency:

$$\omega(t) = \frac{d}{dt}(\omega_0 t + bt^2) = \omega_0 t + 2bt$$

The b parameter describes a linear frequency modulation in the pulse. When $b \neq 0$, the carrier frequency varies with time, and the corresponding pulse is said to be frequency modulated or chirped. For $b < (>)\ 0$, the carrier frequency decreases (increases) along the pulse, which then is called down (up) chirped. In Figure 1 a positively chirped pulse is shown.

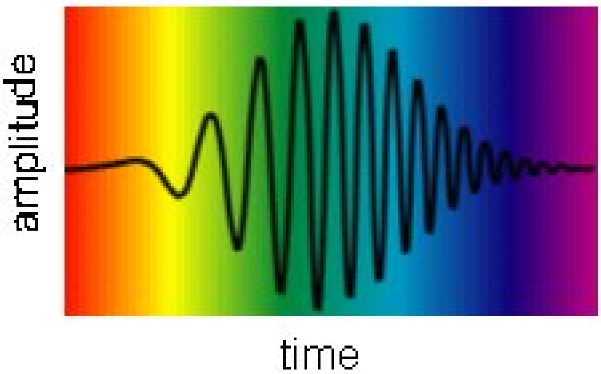

Figure 1: Positively chirped pulse [1]

The optical substances usually have positive dispersion, so they cause positive chirp in the pulse, and because of that the pulse duration gets longer. To compensate this effect, we can use optical elements which has angular dispersion, such as gratings. With the angular dispersion we send the lower frequency components on a longer distance, thus we can create a fourier limited (non chirped) pulse. In Figure 2 a pulse compressor is shown.

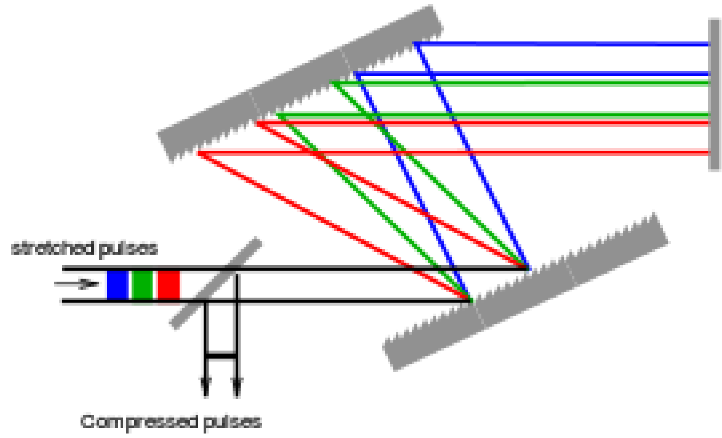

Figure 2: Pulse compressor [2]

For pulse stretching we need an angular magnification element (which is behaves as a telescope), between the gratings. In the case of Figure 3 ($L < f$) the setups acts as a positive-dispersion stretcher.

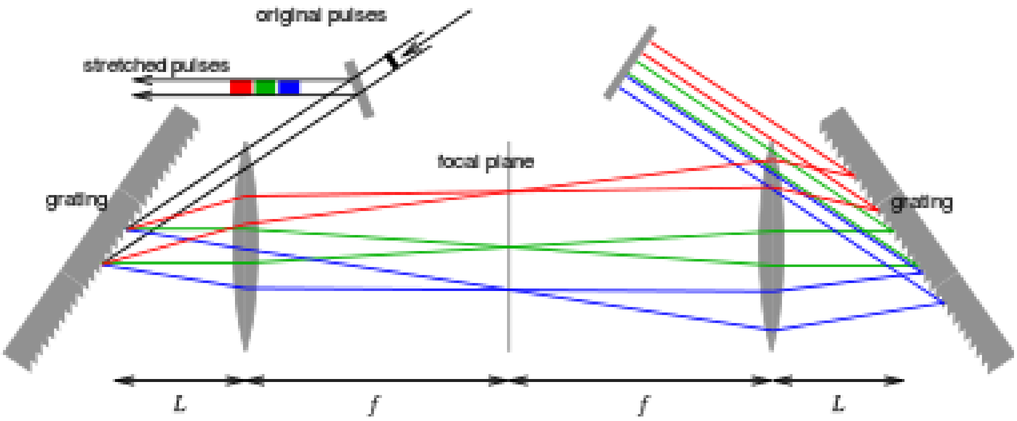

Figure 3: Pulse stretcher [3]

2.2 Second order nonlinearity

Non-linear optical processes occurs when the induced polarization in the material is not a linear function of the (external) electric field. This occurs in cases where the external field (E) has a high intensity . In this case the polarization can be described by it's Taylor series[8]:

$$P(E) = \epsilon_0(\chi^{(1)}E + \chi^{(2)}E^2 + ...) = P^{(1)} + P^{(2)} + ... = P^{(1)} + P^{(NL)}$$

where $\chi^{(n)}$ is the nth-order susceptibility, which is an n + 1 th rank tensor, which has 3^n component. In these cases, the wave equation looks like this:

$$\nabla^2 E - \frac{n^2}{c^2}\frac{\partial^2}{\partial t^2}E = \frac{1}{\epsilon_0 c^2}\frac{\partial^2}{\partial t^2}P^{(NL)}$$

Let us consider that the external electric field has two different frequency components:

$$E(t) = \frac{1}{2}\widehat{E}_1 e^{i\omega_1 t} + \frac{1}{2}\widehat{E}_2 e^{i\omega_2 t} + c.c$$

then, the second order nonlinear response can describe as the following equation:

$$P^2(t) = \epsilon_0\chi^{(2)}E^2 =$$

$$= \frac{1}{4}\epsilon_0\chi^2\left[\widehat{E}_1{}^2 e^{i2\omega_1 t} + \widehat{E}_2{}^2 e^{i2\omega_2 t} + 2\widehat{E}_1\widehat{E}_2 e^{i(\omega_1+\omega_2)t} + 2\widehat{E}_1\widehat{E}_2{}^* e^{i(\omega_1-\omega_2)t} + 2\widehat{E}_1\widehat{E}_1{}^*\right] + c.c$$

Between the brackets the first two terms is the two different frequency second harmonic (SHG) respectively, the third term describes the sum of the frequencies (SFG), the fourth the difference of them (DFG), while the last one is the optical rectification (OR).

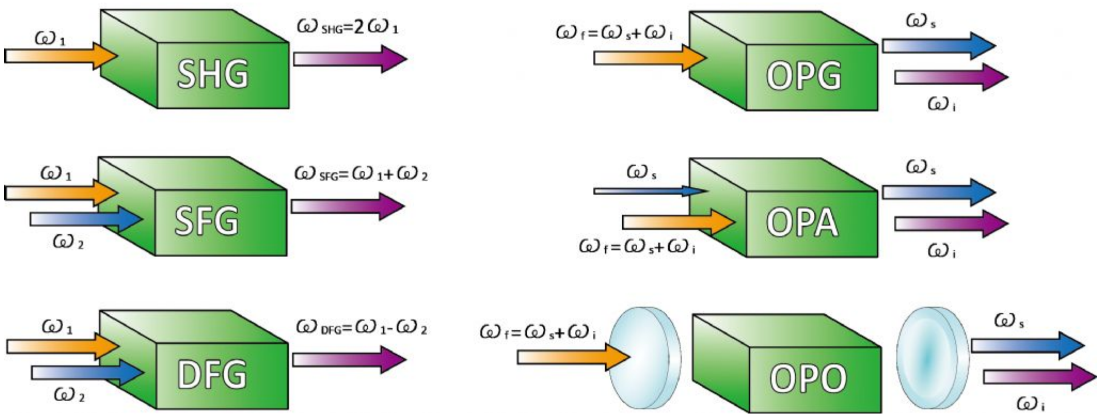

Figure 4: Second order nonlinear processes [4]

2.3 Autocorrelation

For pulse duration measurements the first commonly used process was the autocorrelation. With that technique we have no information about the spectral phase and we have only limited information about the pulse shape. As we can see in Figure 5 the, so called second order intensity autocorrelator, has five main parts. The two (splited) pulse is focused to the SHG crystal in every possible delay between the two pulse, and the detector measures the second harmonic intensity as the function of the delay. The measured sigal can be written as [9]:

$$A^{(2)}(\tau) = \int_{-\infty}^{\infty} I(t)I(t-\tau)dt$$

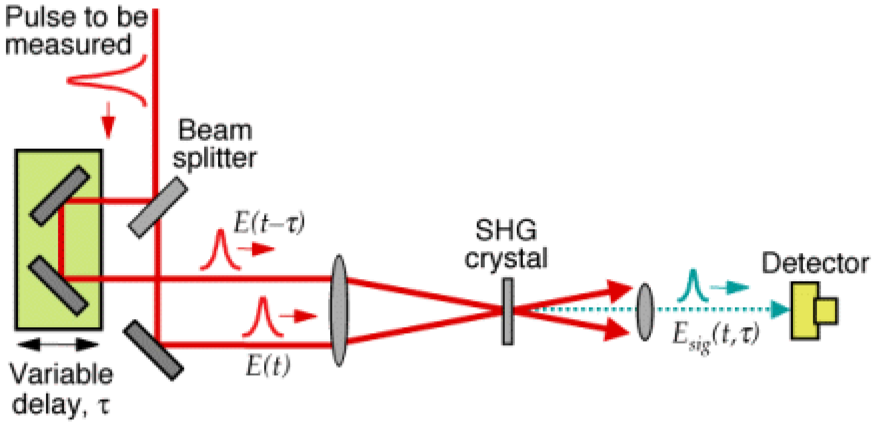

Figure 5: Schematic of the second order intensity autocorrelator [5]

The single-shot autocorrelation is an elegant solution to eliminate the (usage of the) delay line. Here we first need to do a calibration, which determinate how long is a pixel of the CCD camera in time. We can do that by changing the delay and record the deviation of the signal's mean. Than we can give the time factor (F) of one pixel with the next equation:

$$TF = \frac{\tau}{c|m_2 - m_1|}$$

where τ is the delay in longitude, c is the speed of light and m_x is the mean of the signal in pixel. After we done the calibration we can easily calculate the pulse duration at every shot, if we guess the autocorrelation shape for the deconvolution factor:

$$T_p = TF * 2\sigma * DF$$

where TF is the time, DF is the deconvolution factor and 2σ is the variance of the fitted function. For the deconvolution factors see Table 1.

$I(x)$	$Rectangle$	$Gaussian$	$Sech^2$	$Lorentzian$
$\frac{\tau_P}{\tau_A}$	1	$\frac{1}{\sqrt{2}}$	0.6482	$\frac{1}{2}$

Table 1: Deconvolution factors for different autocorrelation signals [7]

3 Results

3.1 Camera adapter

To attach the camera for the autocorrelator's housing I needed to design an adapter. This adapter includes three parts. A bracket for the camera, a transformer between the bracket and the housing, and a lens tube. In Figure 6 and 7 the old and the new setup is shown.

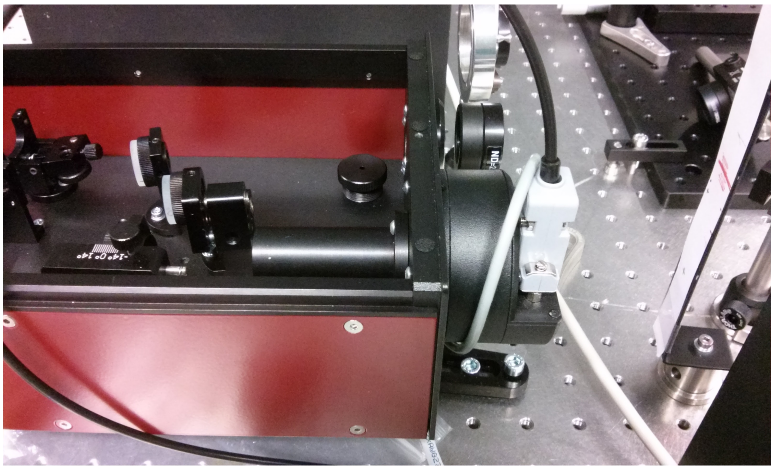

Figure 6: Picture from the original design

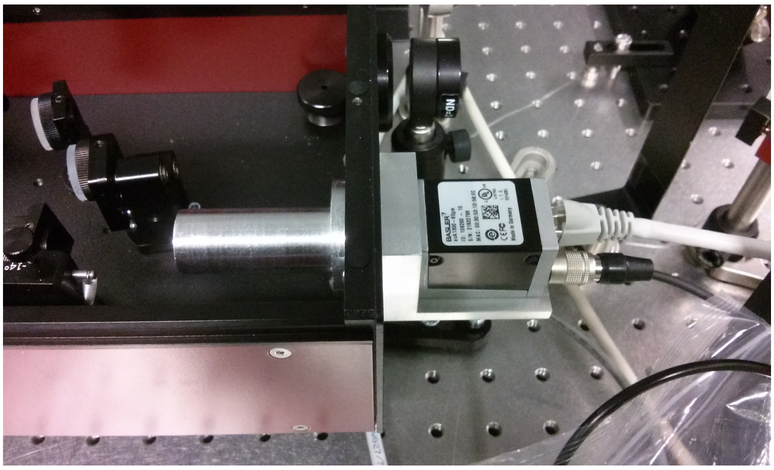

Figure 7: Picture from the new design

I made the design in Solid Edge, the drawing (.dft) files are shown in the followings:

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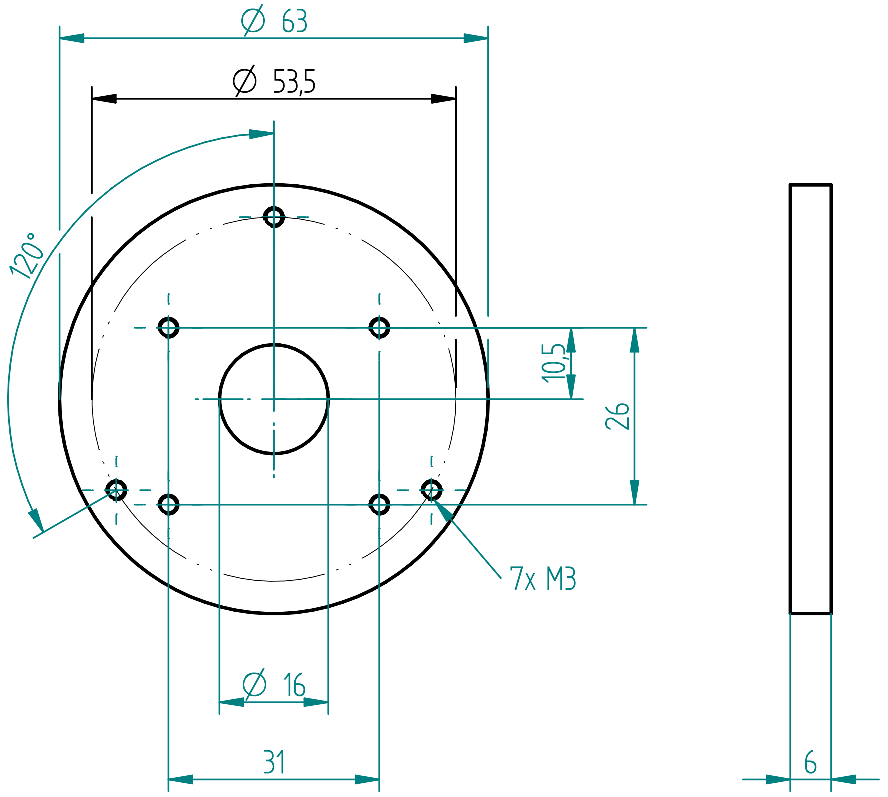
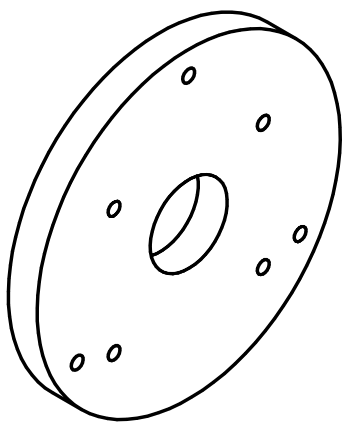




Projekt / PROJECT	Arbeitspaket / WORKPACKAGE	Gruppe / GROUP	Ers.für / REPLACES	Ers.durch / REPLACED BY
Gewicht / WEIGHT 0,047 kg	Halbzeug / SEMIFINISHED PRODUCT	DESY	Werkstoff / MATERIAL EN AW-5754 (AlMg3)	Format/SIZE A4

Allg. Toleranzen / GENERAL TOLERANCES ISO 2768, ISO 13920
Tolerierungsgrundsatz / FUNDAMENTAL TOLERANCING PRINCIPLE ISO 8015
Oberflächenkenngrößen / SURFACE TEXTURE ISO 1302, 4287, 4288

Toleranzklasse / TOLERANCE CLASS: mK

Maßstab / SCALE: 1:1

Teile-ID PART-ID: SE001051663

Titel / TITLE: adapter_camera_and_housing

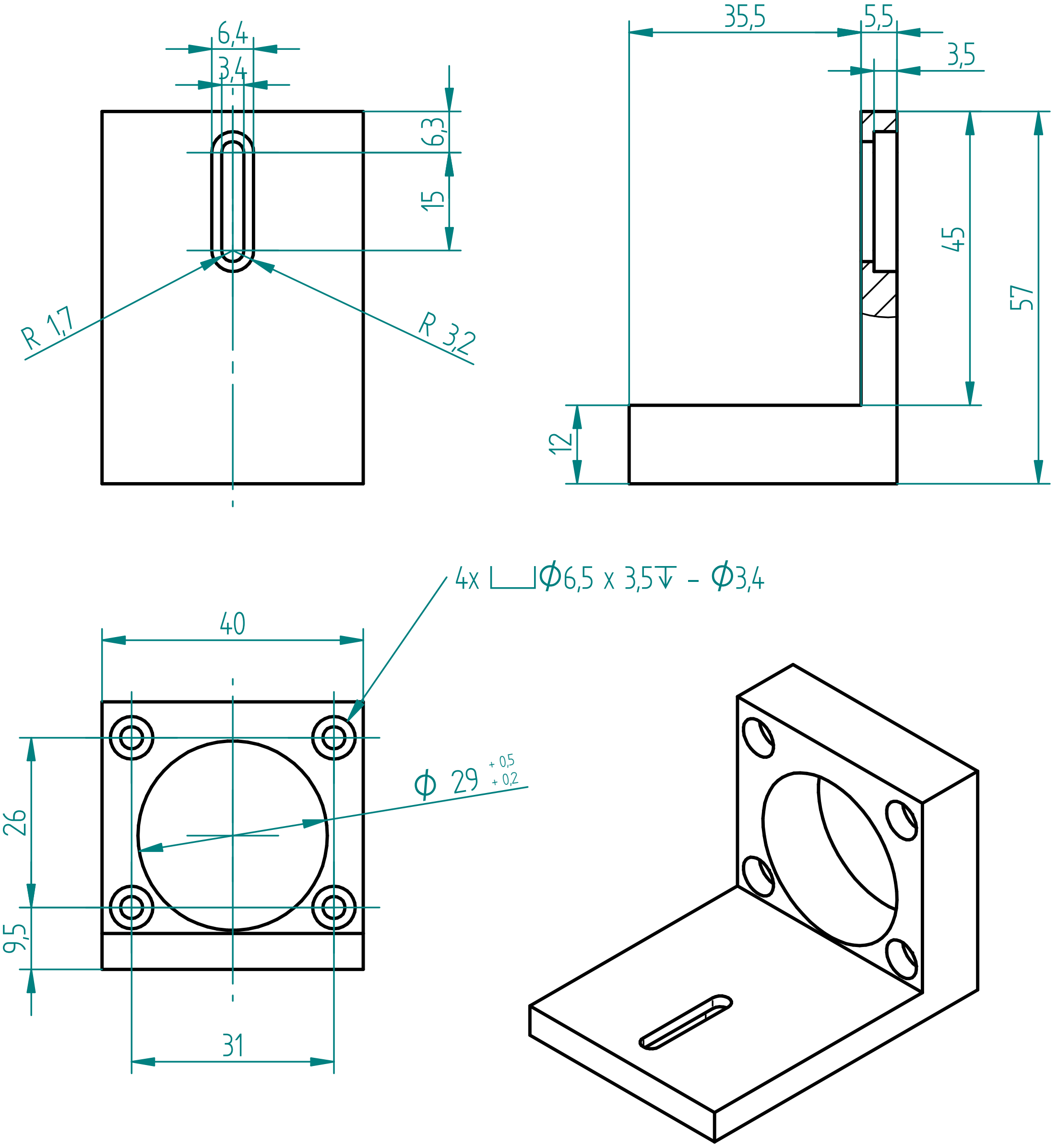
	Datum / DATE	Name / NAME
Gez. CRE.	02.08.2016	SK
Gepr. REV.		
Frei. REL.		
Gen. APR.		

Dokument-Nr. / DOCUMENT NO.

Blatt SHEET 1 von OF 1

Zchng.-ID DRAW.-ID: SE001051671 | Rev. REV. | Ver. VER. | Status STATUS: 3-Freigegeben

PLOT 02.09.2016



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	Datum / DATE	Name / NAME
Gez. CRE.	02.08.2016	skoehler
Gepr. REV.		
Frei. REL.		
Gen. APR.		

Dokument-Nr. / DOCUMENT NO.

Blatt SHEET 1 von OF 1

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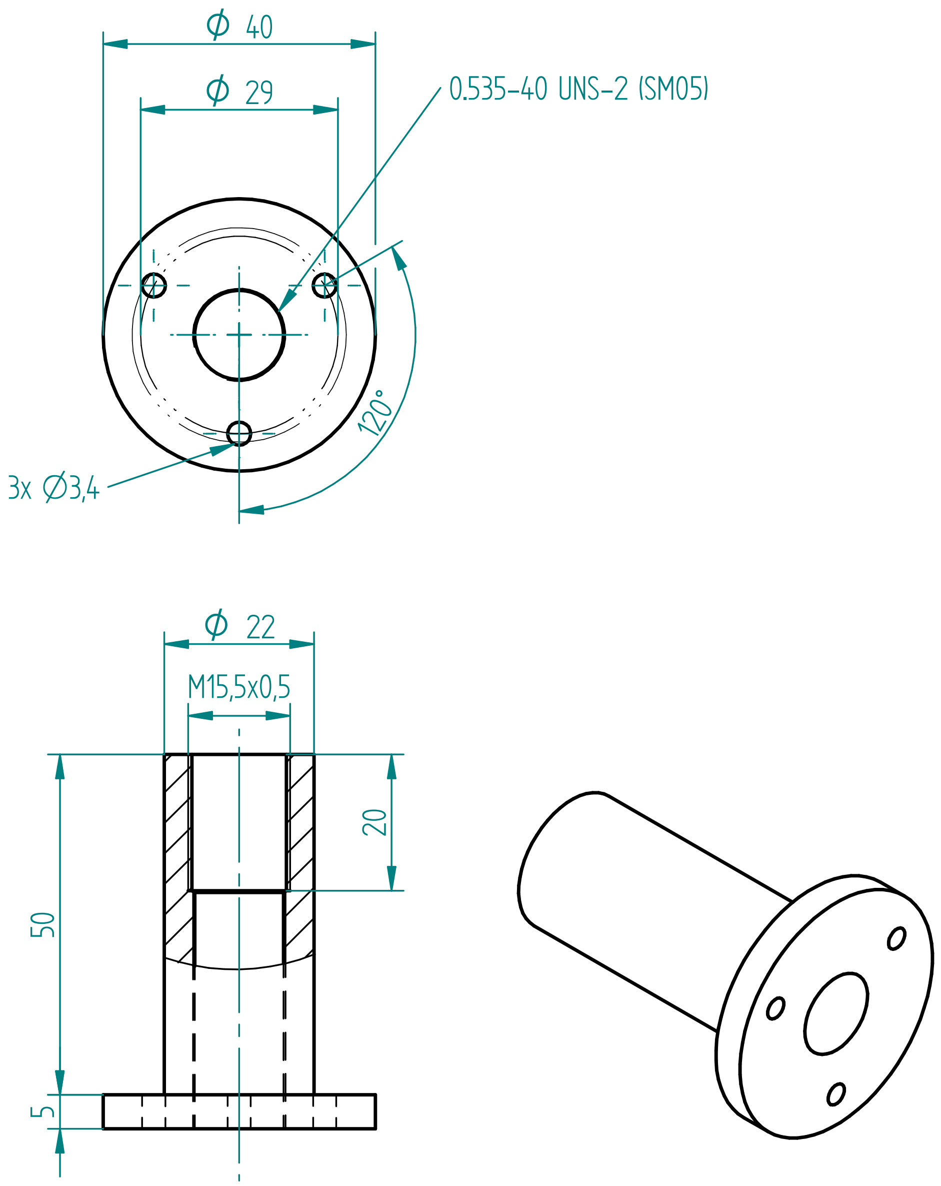

Projekt / PROJECT	Arbeitspaket / WORKPACKAGE	Gruppe / GROUP	Ers.für / REPLACES	Ers.durch / REPLACED BY
Gewicht / WEIGHT 0,047 kg	Halbzeug / SEMIFINISHED PRODUCT	DESY	Werkstoff / MATERIAL EN AW-5754 (AlMg3)	Format/SIZE A4

Allg. Toleranzen / GENERAL TOLERANCES ISO 2768 ISO 13920
Tolerierungsgrundsatz / FUNDAMENTAL TOLERANCING PRINCIPLE ISO 8015
Oberflächenkenngrößen / SURFACE TEXTURE ISO 1302 4287, 4288
Toleranzklasse / TOLERANCE CLASS mK

Maßstab / SCALE 1:1
Teile-ID PART-ID SE001051652

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Gepr. REV.		
Frei. REL.		
Gen. APR.		

Titel / TITLE tube_for_autocorrelator

Dokument-Nr. / DOCUMENT NO.
Blatt SHEET 1 von OF 1

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3.2 DOOCS camera panel

Distributed Object Oriented Control System panel.

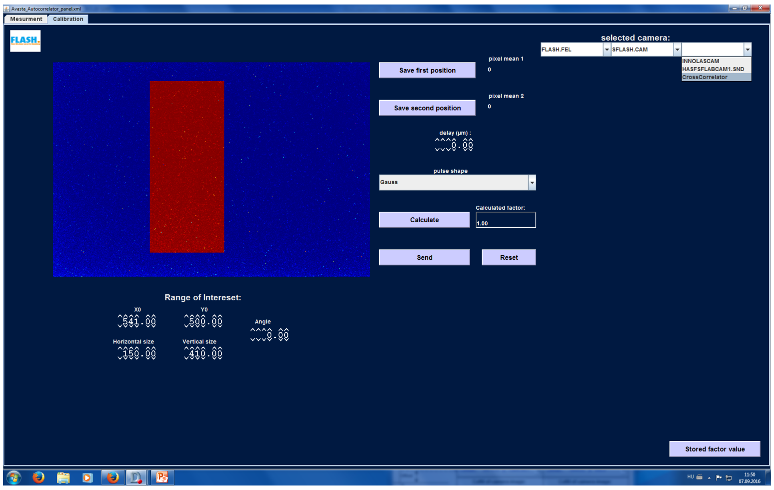

Figure 8: Calibration tab

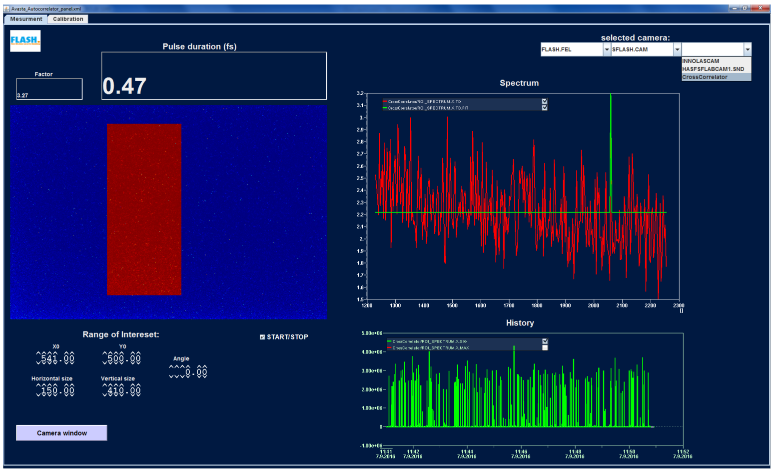

Figure 9: Measurement tab

3.3 Mesurements

From the autocorrelation signal we can easily get the pulse duration if we assume a pulse shape, in this case a Gaussian. The deconvolution factor is $\frac{1}{\sqrt{2}}$. As we can see in Figure 11 we got the same pulse duration with the new setup.

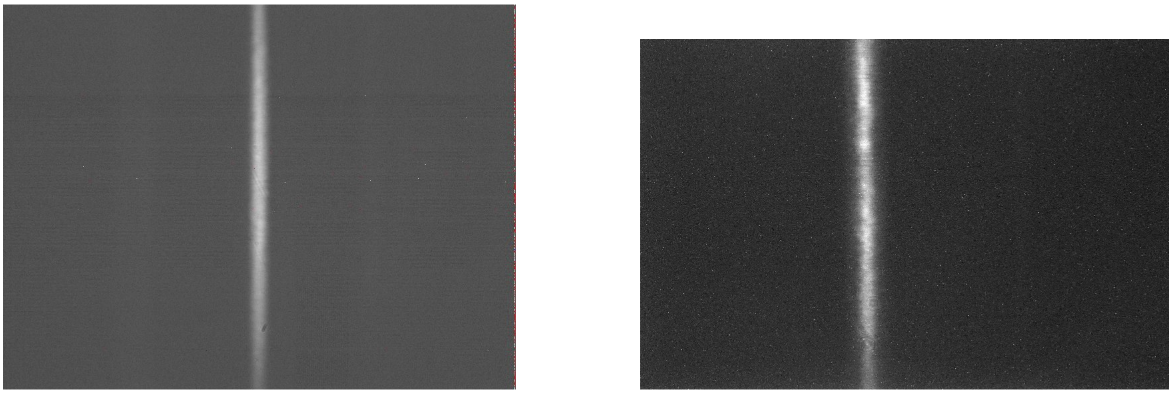

Figure 10: Image of the old (left) and the new (right) camera

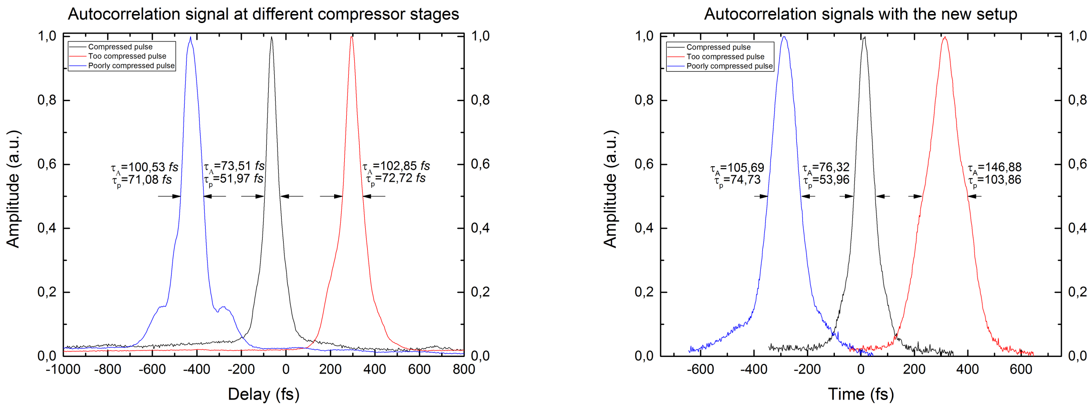

Figure 11: Autocorrelation signals at different compressor stages with the old (left) and new (right) camera.

4 Conclusion

Using a few new parts there is a standard method to change the autocorrelator's camera. With the new setup there is no change in the measurement, but we can remote control it using the DOOCS panel, furthermore we can reach all of the new cameras from one panel.

References

[1] URL: http://electron6.phys.utk.edu/optics421/modules/m5/images/wp1.gif (visited on 08/29/2016).

[2] URL: https://upload.wikimedia.org/wikipedia/en/thumb/2/2b/CPA_compressor.svg/330px-CPA_compressor.svg.png (visited on 08/29/2016).

[3] URL: https://upload.wikimedia.org/wikipedia/en/thumb/6/6e/Cpa_stretcher.svg/550px-Cpa_stretcher.svg.png (visited on 08/29/2016).

[4] URL: http://hcphotonics.com/program/cmx/library/img/bulkchips/img_15032014_085225_QAAmk.PNG (visited on 08/29/2016).

[5] URL: https://www.phys.ksu.edu/reu2011/rmrshall/index_files/image011.jpg (visited on 08/30/2016).

[6] Jean-Claude Diels and Wolfgang Rudolph. *Ultrashort laser pulse phenomena*. Academic press, 2006. ISBN: 0-12-215493-2.

[7] Prof Krtner et al. “Ultrafast Optics (PDF)”. In: (2006).

[8] Geoffrey New. *Introduction to nonlinear optics*. Cambridge University Press, 2011. ISBN: 978-0-521-87701-5.

[9] Rick Trebino et al. “Measuring ultrashort laser pulses in the time-frequency domain using frequency-resolved optical gating”. In: *Review of Scientific Instruments* 68.9 (1997), pp. 3277–3295.