Study of the performance of Analog to Digital Converters at FLASH

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September, 2016

Abstract

Experiments at FLASH require a well established DAQ system. That is why in this project it is studied the performance of the ADCs provided at FLASH I and II. It is analysed the performance of the DAQ when we have different kind of devices in between the signal and the ADC. On the other hand, it is studied the amount of data that can be acquired by the DAQ.

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1 Introduction

FLASH*(Free-electron -LASer in Hamburg)* is a single-pass Free Electron Laser (FEL) lasing in the soft X-ray regime. The generation of Soft X-Ray laser radiation is based on the Self-Amplified Spontaneous Emission (**SASE**) process that operates in the following way:

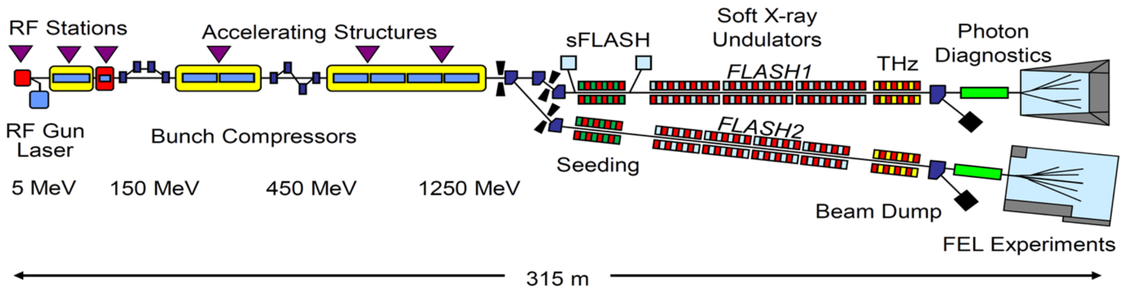

Figure 1: Diagram of the generation of FEL at DESY-FLASH.

A photo injector generates high quality electron-bunch trains, which are accelerated to energies up to $1.2GeV$ (hence, velocities near the speed of light c). These bunch trains produce laser-like Soft X-ray radiation during a single pass through an undulator. There, the electrons are wiggled and emit light characteristic of the undulator strength (synchrotron radiation). The electron bunch move slightly slower than the emitted photons and interact with them each undulator period. Depending on the phase, electrons gain or lose energy (velocity) and so the electron bunch density is periodically modulated by the radiation. This well-defined periodicity in the electron bunch, enhances the power and coherence of the radiation field exponentially while the electron bunch travels through the undulator.

The SASE FEL radiation itself has a stochastic nature because the exponential amplification process starts from spontaneous emission in the electron bunch, therefore each radiation pulse differs in its *intensity* , *temporal structure* and *spectral distribution*. That is why we need to obtain pulse-resolved diagnostic tools that operate parallel to the user experiments in a non-destructive way ("online" determination of beam parameters such as intensity, spectral distribution and temporal structure).

Eventhough the FEL (as a single-pass machine) can only serve 1 user at a time, the FLASH beam is delivered to 5 experimental stations ($BL1$,$BL2$,$BL3$,$PG1$,$PG2$). The beam can be switched from 1 station to another quickly by moving one or two-plane mirrors between in and out positions. In this way, the beam can be distributed in 2 different branches: the **direct**(SASE FEL:BL1-BL3) or **monochromatic**(high resolution monochromator:PG1,PG2) branch.

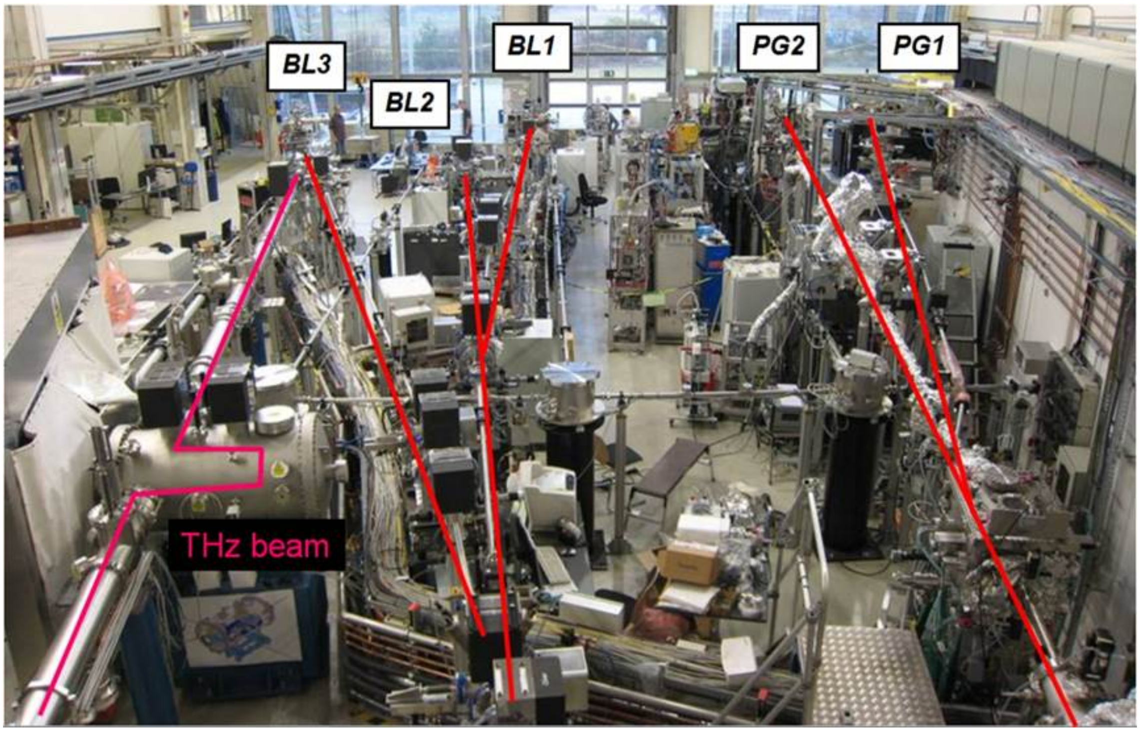

Figure 2: Experimental stations available in FLASH I-Hall

All the beams end with an interconnection point, which consists of a differential pumping unit interfacing the ultra-high vacuum of FLASH to the user experiments.

In order to collect beam-relevant data in real time, have monitoring tools and store the data for offline analysis, a Data Acquisition System (DAQ) at FLASH was implemented. The system enables storing user experiments data in parallel streams to make further correlations between the experimental measurements and the state of the accelerator on a bunch-by-bunch basis.
The control and data acquisition systems for FLASH are based on a Distributed Object-Oriented Control System (DOOCS). The control system functions are divided into a device layer containing servers with a direct connection to hardware, a middle layer to communicate the different devices or for data processing, and an application level offering not only data display but also other tools like LabView, Python, and MATLAB.

2 Measurement

2.1 Signal characterization

Many experiments performed in FLASH collect data as a high frequency voltage signals (e.g. time of flight spectroscopy, photodiodes, etc). To store such kind of signal for each FEL pulse, FLASH provides with ADCs. In this project the ADC performance will be tested, analyzing the influence of different devices (such as amplifiers, cables, attenuators) set up in between the signal (pulse) and the ADC. In order to do so, we used a pulser (Phillips scientific, Model 417) as a signal source, connected it to an amplifier and then connected the amplifier to the ADC with an attenuator in between (See Figure 3).

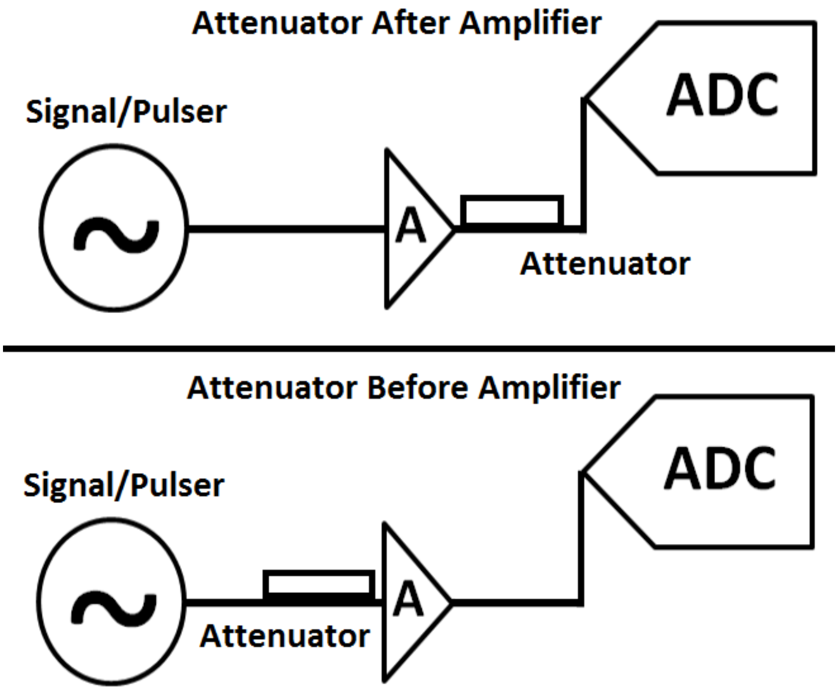

Figure 3: Experimental setup for signal measurements.

First we visualized the pulser signal with the oscilloscope in order to confirm its shape and parameters. As a second step, the experimental setup in FLASH II hall was built using the Micro Telecommunication Computing architecture (MTCA) provided there that includes ADCs(ADQ 412) from SP Devices fully integrated in the FLASH DAQ. Then the "DOOCS" online visualization system was used to make sure that the signal was arriving to the ADC. After that, a Matlab program was written to do the initial analysis and for final detailed analysis, a script that stores the data in $hdf5$ files and uses it to analyze it.

The following experimental set-ups where realized with the low noise ZFL-100NL+ amplifier:

- No amplifier
- 26dB, 16dB attenuators before Amplifier, no attenuator after.

- Only Amplifier (no attenuator)
- No attenuator before Amplifier, 26dB attenuator after.

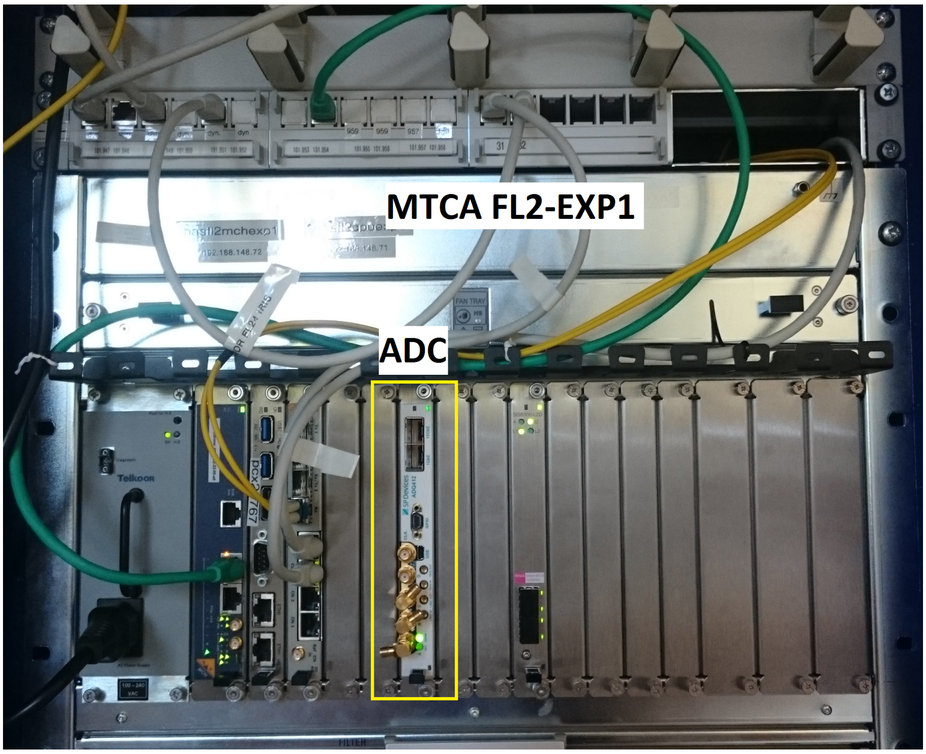

Figure 4: MTCA crate with the ADC (4 channels) provided in the FLASH II hall.

2.2 DAQ load test

Once we had defined our signal, we wanted to know the capacity of the ADC system to store data, in other words, how much data is the the DAQ able to save or better, how fast it is capable to save the data without losses.
In order to do so, we changed the total number of samples sent to the DAQ and some parameters were varied: the number of channels on and the number of crates on. The data loss of each run was determined.

These cases were studied:

- 2 Crates and 8 Channels on: BL1, BL2, BL3 and PG2 (two channels on each)
- 2 Crates and 4 Channels on: BL1, BL2 (two channels on each)
- 1 Crate and 4 Channels on: BL1, PG2 (two channels on each)

For details see Appendix A, it is shown a table with the different amount of samples taken, the number of crates and channels on and the analysis' results with its corresponding run number.
The procedure to acquire the data was the following:

Firstly, I set the parameters for the run:
-Number of channels on, that is, the number of "beam lines" on (BL1,BL2,BL3 or PG2).
-Number of channels on of each beam line, which in our case was always 2.
-Sample frequency to DAQ / Total number of samples.

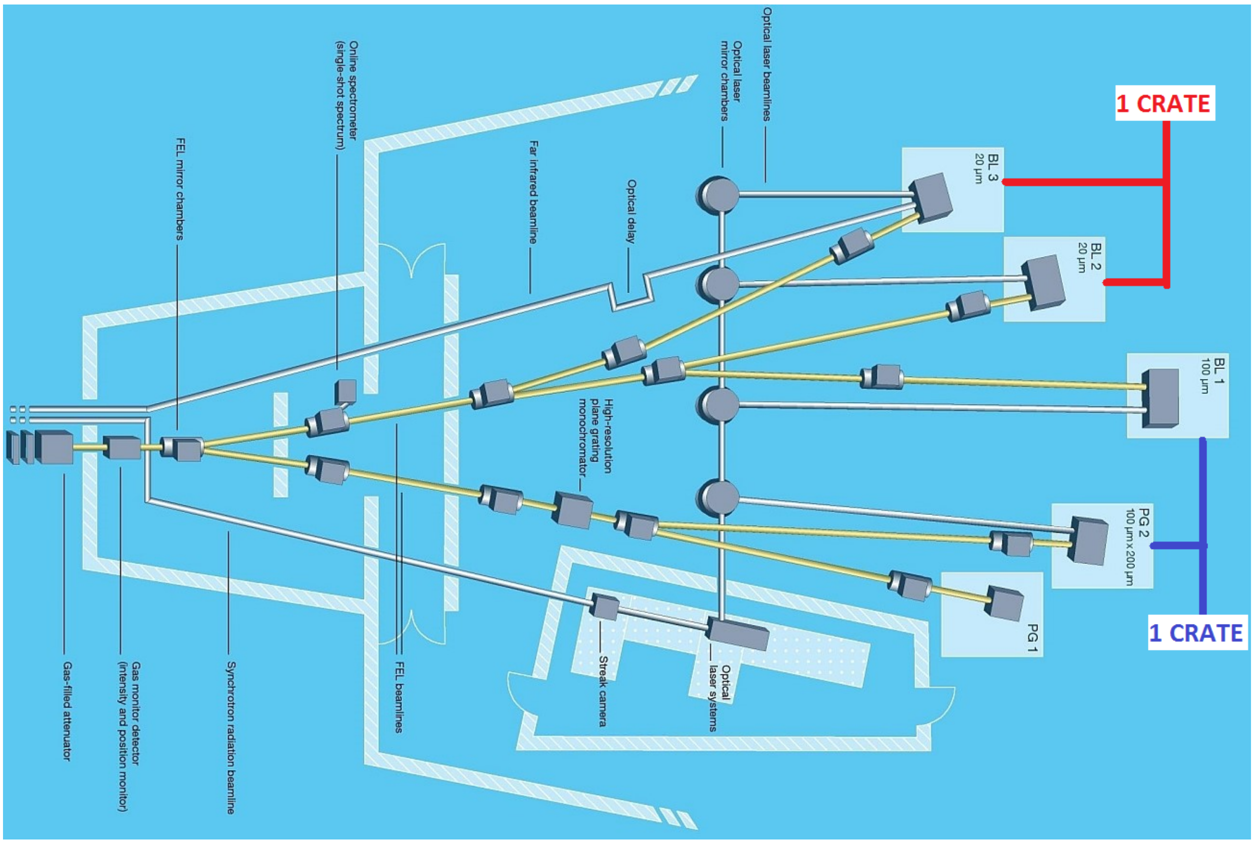

Figure 5: MTCA crate with the ADC (4 channels) provided in the FLASH II hall.

Then, we started the "dataGUI" viewer, looked at the data acquired and make an estimation of the amount of data that it is saved. This step is just to have a general idea or a rough estimation of the data loss. Finally, a code in Matlab was written to analyze the data acquired.

3 Analysis program

3.1 Signal characterization

As mentioned before, in order to visualize the data, a Matlab program was used that works in the following way:
It first looks for the ADC data, it accesses to it and then the program reads the sample spectra. For my analysis I used 6×10^5 samples (the maximum number of samples that could be read are $1,048,575$). After the data is read, the program reconstructs the time domain axis and plot the signal. For memory purposes, we made it find the signal peak (minimum value) and just plot the pulse signal and the one thousand samples that are in the vicinity. (See Figure 6)
The next step was to do the same measurements several times (100 in this case), by

```
for ii= 1:5e19
    %% ADQ Scope Server MTCA FL2-EXP1
    % Note CH00.SAMPLES can not be set -- it is fixed at 800
    %      CH00.INCR_LOGIC does not do anything
    %      CH00.RAW_COPY must be '1' in order to receive more than 800 values
    location= 'FLASH.FEL/ADC.ADQ.FL2EXP1/FL2EXP1.CH01/';
    [readback, errs]= jdoocs_call([location, 'CH00.RAW_COPY']);
    %[readback, errs]= jdoocs_call([location_1, 'CH00.RAW_COPY']);
    fprintf('jddocs_call errors: %s\n', errs);
    fprintf('readback RAW_COPY: %d\n', readback);


    nSamples= 600000;  % the maximum apears to be 1,048,575

    [spect, errs]= jdoocs_call([location, 'CH00.TD'], [-1, 0, 1, nSamples], 'DATA_TYPE=DATA_IIII');


    fprintf('jddocs_call errors: %s\n', errs);
    fprintf('spectrum size: [%s ]\n', sprintf(' %d', size(spect{6})));  % gives 800! instead of 1.6e6
    fprintf('    comment: %s\n    unix time: %s\n    start: %d\n    increment: %d\n    pulse ID: %d\n', ...
        spect{1}, datestr(datenum(1970,1,1,0,0,spect{2})), spect{3}, spect{4}, spect{5});

    %% reconstruct the time domain axis and plot
    start= spect{3};
    incr=  spect{4};
    nSamples= length(spect{6});
    usecs= (1:nSamples).*incr + start;
    [min_amplitude,min_pos]=min(spect{6});
    adctrace= spect{6};
    range=500;
    plot(adctrace);
    pause(0.1);

end
```

Figure 6: Matlab script that reads the data of the DAQ and plot it.

writing a script in Matlab that reads the data from the ADC repeated times and then to store it all in hdf5 files so that it can be easily read and analyzed with almost any program you want.

The data analysis was done with Matlab and consisted of plotting the mean value of the 100 measures of each taken run and fit the sample spectra to a Gaussian function (most

```
nRepeats=100;
nSamples= length(spect{6});
Result= zeros(nRepeats,nSamples, 'int16');

for eachRepeat = 1: nRepeats
    [spect, errs]= jdoocs_call([location, 'CH00.TD'], [-1, 0, 1, nSamples], 'DATA_TYPE=DATA_IIII');
    Result(eachRepeat,:)= spect{6};
end

%% Store CH01 data in a hdf File: Amplifier ZFL +26dB
h5create('pulsermeasurements.h5', '/Amplifiers/ZFL100NL/26dB/chan1/adc-counts', size(adctrace));
h5write('pulsermeasurements.h5', '/Amplifiers/ZFL100NL/26dB/chan1/adc-counts', adctrace);
h5create('pulsermeasurements.h5','/Amplifiers/ZFL100NL/26dB/chan1/adc-counts', size(usecs));
h5write('pulsermeasurements.h5','/Amplifiers/ZFL100NL/26dB/chan1/adc-counts', usecs);
%% Plot data CH01: Amplifier ZFL +26dB
adctracehdf5_attamp1=h5read('pulsermeasurements.h5','/Amplifiers/ZFL100NL/26dB/chan1/adc-counts');
%plot(adctracehdf5(min_pos-range:min_pos+range));
```

Figure 7: Matlab script that makes measurements repeated times and store the data in hdf5 ready to be analyzed.

alike fit).

3.2 DAQ load test

The data acquired in the load test was analyzed with Matlab. The program basically reads the data stored by the DAQ (one has to specify the run number, the date, the time of it and the channel we want to read). With this information, the script looks in the file for the columns with no data and counts it. Thus, by knowing the total number of columns that are supposed to be filled with data and the ones that don't have data at all, we can know the percentage of data loss present in the run. This program returns the value of the data loss in the DAQ for each channel.

4 Results

The plots shown in the Figure 9 represents the data obtained for the low noise Amplifier ZFL-100LN+ (Normalized and not normalized data) and a Gaussian fit was done to the experimental data. The normalized plot was done to have a better comparison of the influence of the different attenuators.

We can appreciate that saturating the signal broaden our original signal a lot as well as attenuating it. Nevertheless, having the correct amount of attenuation increases our signal and preserves its shape, which is what we are looking for an amplifier.
The Figure 11 shows the percentage of loss in function of the total number of samples recorded in the DAQ. Each plot corresponds to the different cases that wanted to be studied. We can see a clear difference in the behaviour of the DAQ when you switch from "1 crate on" to "2 crates on". The former one increases the loss in a linear way,

```
%% DAQ data losss anaysis PART 2
% RUN:13823

%BL1
[traceBL1, idsBL1]= DaqRead().exp2().run(13823).data('2016-08-22 14:41:29', .2, 'FLASH.FEL/ADC.ADQ.BL1/EXP1.CH00');
notanumberidxBL1= isnan(traceBL1(1,:));
find(notanumberidxBL1)
idsBL1(notanumberidxBL1)= [];
diffBL1= (idsBL1(end) - idsBL1(1)) +1;
[samplesBL1,timeBL1]=size(traceBL1);
data_lossBL1= (timeBL1*100)/diffBL1;
data_lossBL1

% BL2
[traceBL2, idsBL2]= DaqRead().exp2().run(13823).data('2016-08-22 14:41:29', 3, 'FLASH.FEL/ADC.ADQ.BL2/EXP2.CH00');
notanumberidxBL2= isnan(traceBL2(1,:));
find(notanumberidxBL2)
idsBL2(notanumberidxBL2)= [];
diffBL2= (idsBL2(end) - idsBL2(1)) +1;
[samplesBL2,timeBL2]=size(traceBL2);
data_lossBL2= (timeBL2*100)/diffBL2;
data_lossBL2

%BL3
[traceBL3, idsBL3]= DaqRead().exp2().run(13823).data('2016-08-22 14:41:29', 3, 'FLASH.FEL/ADC.ADQ.BL3/EXP2.CH02');
notanumberidxBL3= isnan(traceBL3(1,:));
find(notanumberidxBL3)
idsBL3(notanumberidxBL3)= [];
diffBL3= (idsBL3(end) - idsBL3(1)) +1;
[samplesBL3,timeBL3]=size(traceBL3);
data_lossBL3= (timeBL3*100)/diffBL3;
data_lossBL3

%PG
[tracePG, idsPG]= DaqRead().exp2().run(13823).data('2016-08-22 14:41:29', 3, 'FLASH.FEL/ADC.ADQ.PG/EXP1.CH02');
notanumberidxPG= isnan(tracePG(1,:));
find(notanumberidxPG)
idsPG(notanumberidxPG)= [];
diffPG= (idsPG(end) - idsPG(1)) +1;
[samplesPG,timePG]=size(tracePG);
data_lossPG= (timePG*100)/diffPG;
data_lossPG
```

Figure 8: Matlab code that reads the data from each channel, look for the number of times during the run that there was no data recorded and calculate the data loss.

whereas the later one suddenly (at approximately 2×10^6 samples) increases the loss in a drastic way.

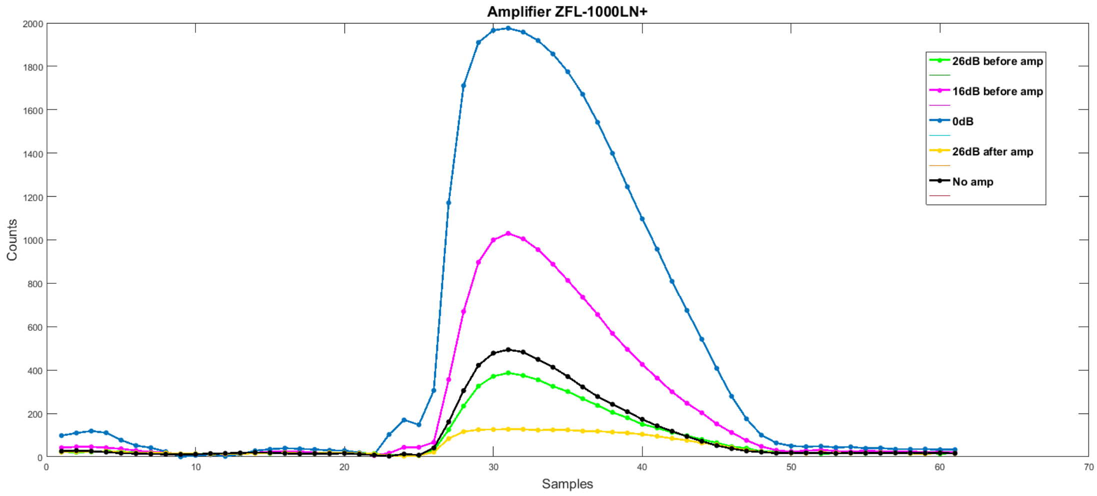

Figure 9: Measurements for the "Amplifier ZFL-10000LN+" with the different attenuators placed before or after the amplifier in the circuit. It is clearly seen that saturating the signal makes it wither and attenuating it a lot (after amp), makes it lose its shape.

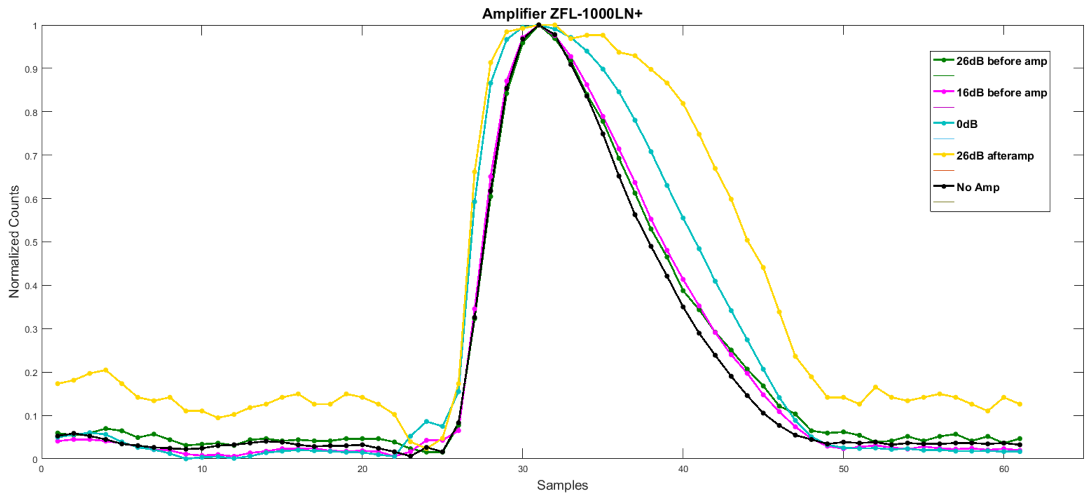

Figure 10: Normalized graph for the measurements of the "Amplifier ZFL-10000LN+". It is shown that putting just 26db and 16db before the amplifier preserves the shape of our signal.

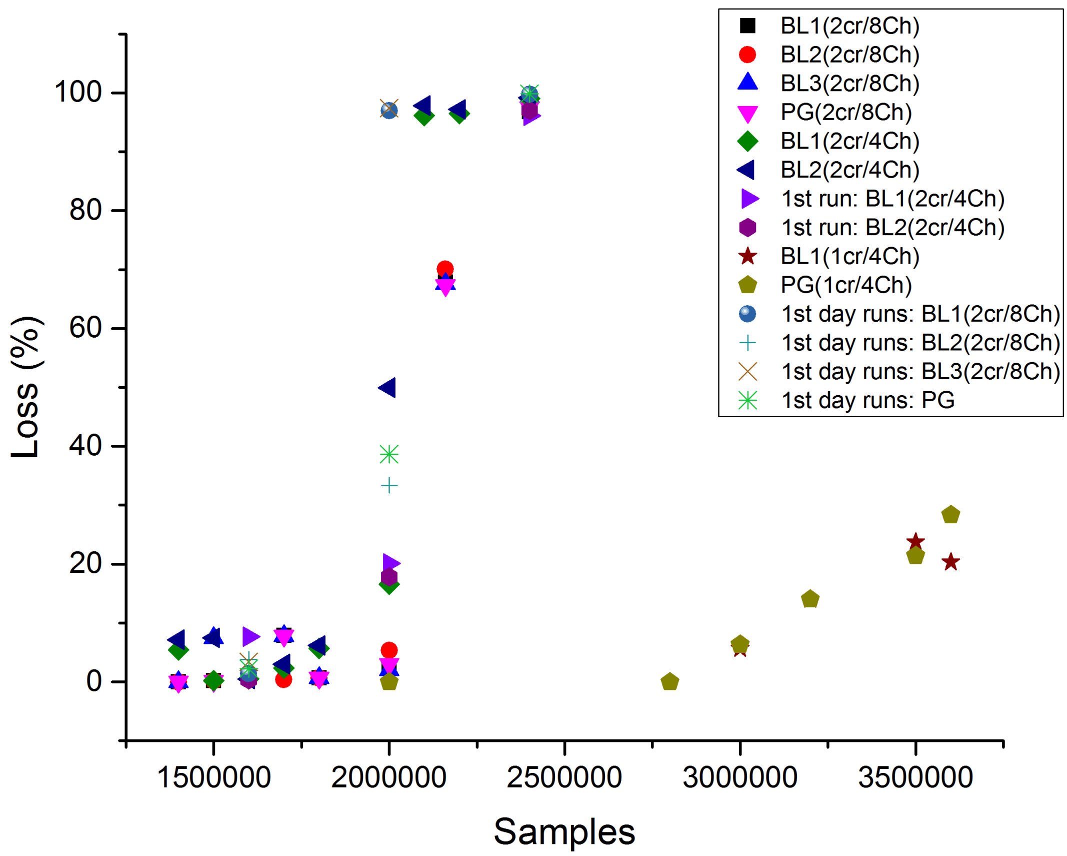

Figure 11: Graph of the total number of samples acquired vs the percentage of loss. The behaviour is clearly different when we have 1 crate on than when we have 2 crates on.

5 Summary and Conclusions

The performance of the ADC with the low noise amplifier in between was successfully done.The results showed that we have to put the right amount of attenuation in order to preserve our signal. The load test analysis showed new and inspected results. In one hand, the increasing linear behaviour when we had 1 crate on is a peculiar result. On the other hand, the drastic change in loss when 2 crates were on is not yet completely understood. These results will be shown to the DAQ team and further studies will be done in order to improve even more the performance of it.

6 Acknowledgements

I want to thank my supervisor, Stefan Duesterer for his kind help and guidance during the summer program. I learnt a lot during this summer and he made me feel useful for the team, which is very nice. I also want to give unending thanks to Erland Mueller, for his guidance and help during my stay, for making me feel part of the team and for being an amazing office-mate. Many thanks to the organisers of the Summer Student programme, and specially to Olaf Behnke for guiding all of the students in our life at DESY.

This summer has been amazing, I have learnt a lot and made a lot of friends. Thanks to all my now friends for making my time in DESY very special.

7 Appendix A

	Channels on	Crates on	Total Channels on	Run	Samples to DAQ	Total # samples	Gui Data loss	Data loss analysis % (Matlab)
BL1	2	2	8	13833	175000	1 400 000	No	0
BL2	2	2			175000			0
BL3	2	2			175000			0
PG	2	2			175000			0
BL1	2	2	8	13834	225000	1 800 000	No	0,6623
BL2	2	2			225000			0,6623
BL3	2	2			225000			0,6623
PG	2	2			225000			0,6623
BL1	2	2	8	13855	187500	1 500 000	No	0.188
BL2	2	2			187500			0.182
BL3	2	2			187500			7.4444
PG	2	2			187500			0.12
BL1	2	2	8	13823	200000	1 600 000	No	1,4139
BL2	2	2			200000			3,8168
BL3	2	2			200000			3,3974
PG	2	2			200000			2,2409
BL1	2	2	8	13837	200000	1 600 000	No	0,1333
BL2	2	2			200000			0,1333
BL3	2	2			200000			0,1333
PG	2	2			200000			0,1667
BL1	2	2	8	13856	212500	1 700 000	No	7.9065
BL2	2	2			212500			0.3628
BL3	2	2			212500			7.7862
PG	2	2			212500			7.7951
BL1	2	2	8	13825	250000	2 000 000	A lot	97,0000
BL2	2	2			250000			33,3612
BL3	2	2			250000			97,4167
PG	2	2			250000			38,6849
BL1	2	2	8	13839	250000	2 000 000	No	2.6667
BL2	2	2			250000			5.3333
BL3	2	2			250000			2.0667
PG	2	2			250000			3

BL1	2	2	8	13843	270000	2 160 000	No	28.866/67.8992
BL2	2	2			270000			18.42/70.0655
BL3	2	2			270000			4.386/67.6037
PG	2	2			270000			10.5263/67.3469
BL1	2	2	8	13822	300000	2 400 000	A lot	99,7917
BL2	2	2			300000			No events shown ☹
BL3	2	2			300000			No events shown ☹
PG	2	2			300000			99,8333
BL1	2	2	8	13840	300000	2 400 000	~90	96.8354
BL2	2	2			300000			99.4877
BL3	2	2			300000			99.3307
PG	2	2			300000			97.5782
BL1	2	2	4	13835	350000	1 400 000	No	5.4348
BL2	2	2			350000			7.1429
BL1	2	2	4	13857	375000	1 500 000		0.1883
BL2	2	2			375000			7.461
BL1	2	2	4	13845	400000	1 600 000	No	0.5008
BL2	2	2			400000			0.5008
BL1	2	2	4	13820	400000	1 600 000	No	7,6667
BL2	2	2			400000			0,3631
BL1	2	2	4	13858	425000		A bit	2.3333
BL2	2	2			425000			
BL1	2	2	4	13836	450000	1 800 000	No	5.6667
BL2	2	2			450000			6.1667
BL1	2	2	4	13847	500000	2 000 000	BEGINNING LOSS	58.317/16.5541
BL2	2	2			500000			96.1722/49.9391
BL1	2	2	4	13819	500000	2 000 000	Some loss	20,0963
BL2	2	2			500000			17,8099
BL1	2	2	4	13853	525000	2 100 000	A lot	96.1728
BL2	2	2			525000			97.8555
BL1	2	2	4	13851	550000	2 200 000		96.5217

BL2	2	2			550000			97.2074
BL1	2	2	4	13849	600000	2 400 000	A lot	99.0138
BL2	2	2			600000			99.2495
BL1	2	2	4	13817	600000	2 400 000	A lot	96,1248
BL2	2	2			600000			97,0414
BL1	2	2	4	13818	700000	2 800 000	A lot	No events shown ☹
BL2	2	2			700000			No events shown ☹
BL1	2	1	4	13784	500000	2 000 000	No	0
PG	2	1			500000			0
BL1	2	1	4	13785	600000	2 400 000	No	No events shown ☹
PG	2	1			600000			No events shown ☹
BL1	2	1	4	13786	700000	2 800 000	No	0!!!!!
PG	2	1			700000			0
BL1	2	1	4	13838	800000	3 200 000	No	14
PG	2	1			800000			14.0468
BL1	2	1	4	13787	800000	3 200 000	10-20%	No events shown ☹
PG	2	1			800000			No events shown ☹
BL1	2	1	4	13788	900000	3 600 000	20-30%	20.3333
PG	2	1			900000	3 600 000		28.3333
BL1	2	1	4	13861	750000	3 000 000	No	5.6667
PG	2	1			750000	3 000 000		6.3333
BL1	2	1	4	13863	875000	3 500 000	Few loss	23.7458
PG	2	1			875000	3 500 000		21.4047

(blue)	2 Crates 8 Channels on
(orange)	2 Crates 4 Channels on
(green)	1 Crate 4 Channels on

References

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