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Configuring an Interlock System for the pnCCD and the First Detector Test at THz Beamline

Internship Type: Electric and Electronic

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Hamburg
2016

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Organization Unit : Centre for Free-Electron Laser (CFEL) Science, Hamburg
Starting Date : July 19, 2016
Ending Date : September 8, 2016
Duration : 8 weeks

Evaluation	**Note**	**Comments**
Regularity		
Diligence and Effort		
Behaviour to the instructors		
Attitude to the workers and friends		

Notes : A(Excellent) - B(Good) - C(Moderate) - D(Satisfactory) - E(Unsatisfactory)

Date: ___/___/________

Dr. Jonathan Correa

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Topic	Date
DESY	July 19-July 26,2016

Abstract

The purpose of the "Electric and Electronic" internship is to implement some tasks related to electric and electronic hardware. During the eight week long program at DESY, focus was given to two different projects which are: 1) configuring an interlock system for the pnCCDs and 2) the first detector test at the THz beamline. These took place at FLASH experimental Hall.

In the first project, a special type of charged couple device pnCCD is introduced with its structure and some properties. Then the challenges in working with the pnCCDs are described. As an efficient solution method to the challenges, an automatic start up process of ramping down of voltage is explained. The pertinent device UPS (uninterruptible power supply) is also discussed in details.

In the second project, a fast detector module GOTTHARD is used. This report compares this to another detector Basler Camera Link and explains why GOTTHARD is more efficient than the other.

Finally, the raw data from the experiment at THz beamline were analyzed and conclusions from them were extracted.

Evaluation	Signature of the internship instructor
	Dr. Jonathan Correa

1. Introduction to DESY

1.1 What is DESY

DESY is one of the largest scientific organization and particle accelerators in Germany and it is a research center of the Helmholtz Association. The term is coined from German Deutsches Elektronen-Synchrotron (i.e. German Electron Synchrotron). It started its journey on December 18^{th}, 1959 with the motto "Insight Starts Here." The DESY director is Prof. Dr. Helmut Dosch. Currently, about 2300 staffs and 700 students are working on different interdisciplinary projects. It operates in two branches, one in Hamburg and the other in Zeuthen, Berlin.

1.2 Main Research Fields at DESY

DESY concentrates on the following topics with many projects under them.

- Particle Acceleration and Particle Physics
- Photon Science

2. The Particle Acceleration and Particle Physics

Different facilities were used for particle acceleration purpose at different times according to the needs of the experiments at DESY. Briefly described below are some of them.

2.1 DESY

The first large particle accelerator, also called DESY, started in 1960. It could accelerate electrons to 7.4 GeV. On 1964, first electron was accelerated and research on elementary particle began. The synchrotron radiation which came as a side effect of particle acceleration was first used by the European Molecular Biology Lab (EMBL) to analyze the structure of biological molecules.

2.2 DORIS III

In German Doppel-Ring Speicher (DORIS) means double ring storage. It is DESY's first electron-positron storage ring with a circumference of 300 m and second circular accelerator. Some of the most important contributions of this storage ring was proving the presence of heavy quarks and the development of X-Ray depth lithography. The closure of DORIS III paved the way of opening its successor PETRA III at the end of 2012.

2.3 OLYMPUS

In order to measure the positron-proton to electron-proton cross section ratio and finding the size of two-photon exchange in elastic electron positron scattering, OLYMPUS was installed in 2010 and started taking data in 2012.

2.4 HERA

HERA (Hadron-Elektron-Ring-Anlage, i.e. Hadron Electron Ring Facility) was a collider at DESY from 1992 to 2007.

Electrons or positrons collide with protons at a center of mass energy up to 318 GeV. While operational, it was the only lepton-proton collider in the world.

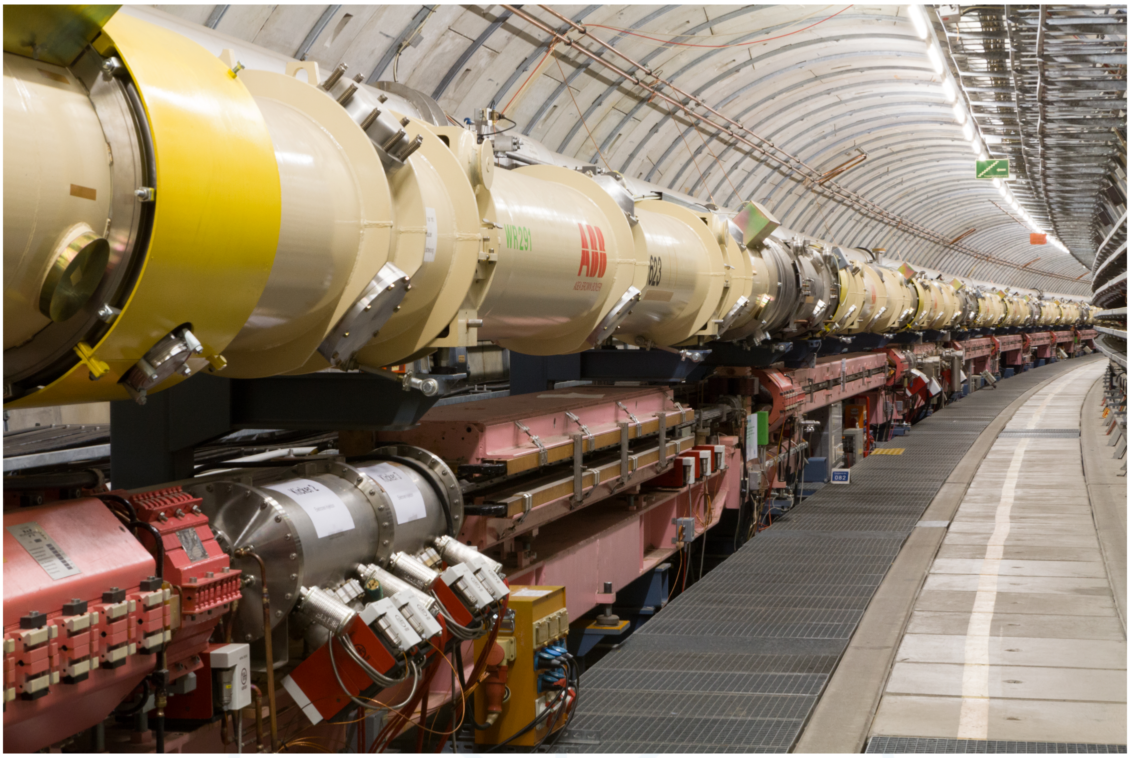


Figure 2.1: A part of the long HERA tunnel in Hamburg

Some facts and figures:

- length: 6.3 km
- research operation : 1992-2007
- electron-proton storage ring for particle physics
- data analysis still going on for future research
- experiments: H1, ZEUS, HERMES, HERA-B

Figure 2.1 shows a part of the HERA tunnel and Figure 2.2 shows the aerial view along with the PETRA at the DESY campus.

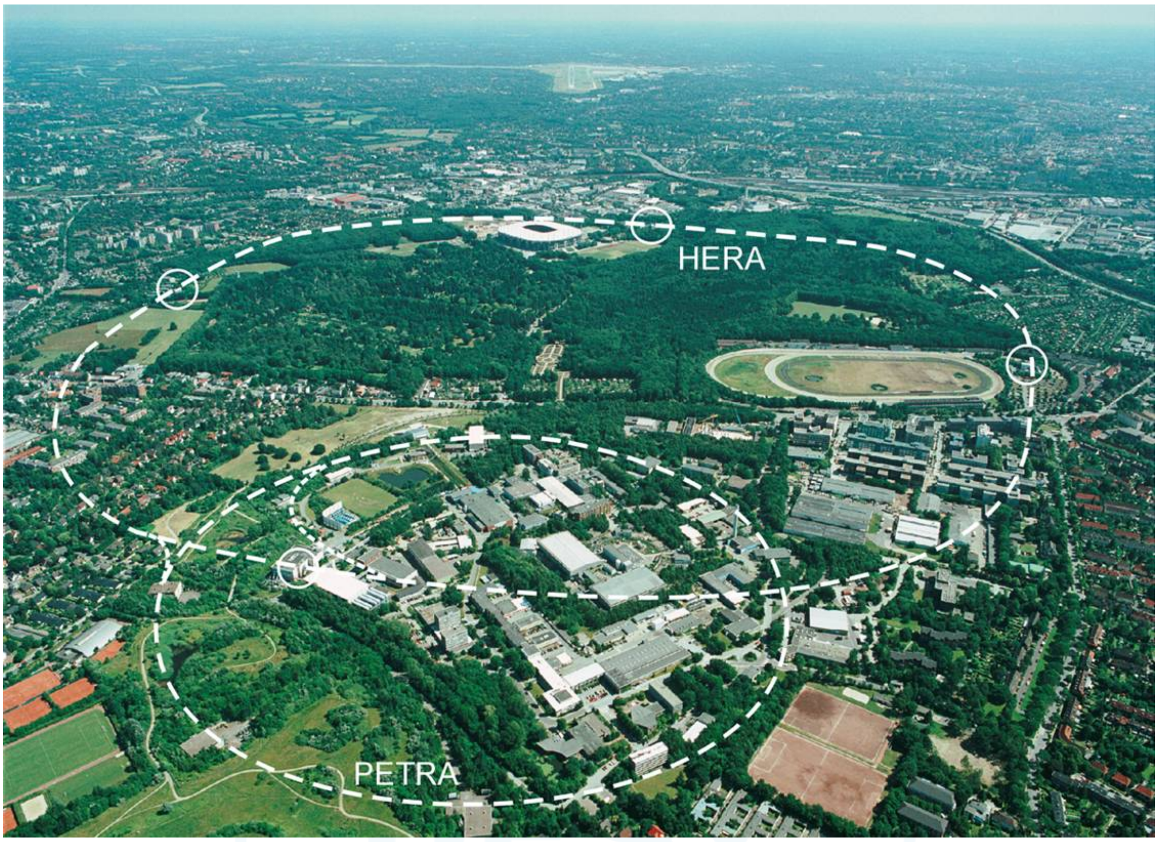


Figure 2.2: HERA and PETRA from above at DESY,Hamburg

2.5 PETRA

Positron-Elektron-Tandem-Ring-Anlage (PETRA) was the biggest storage ring when built at DESY. Its purpose was to do research on elementary particles. PETRA gave many successful discoveries in the field of particle physics. One of them was the discovery of gluon, the messenger particle of the strong nuclear force. This accelerator could accelerate electrons and positrons up to an energy of 19 GeV. It should be noted that PETRA is no longer used for particle physics [7].

3. The Photon Science

The scope of research of photon science covers Physics, Chemistry, Biology, Earth Science, Material Science, Medicine etc. Researchers here analyze the minuscule impurities in silicon used in computer chips and microscopic properties of materials.

Two type of sources are used at DESY. They are :

1. Synchrotron radiation Facility
   - PETRA III
2. Free Electron Laser (FEL) Facility
   - FLASH
   - XFEL

3.1 Synchrotron Radiation Facility

Synchrotron radiation is produced when charged particles are accelerated radially at very high speed comparable to that of light. In modern days, they are produced by undulators (See 3.2.1). A picture of synchrotron radiation production is shown in Figure 3.1 [8].

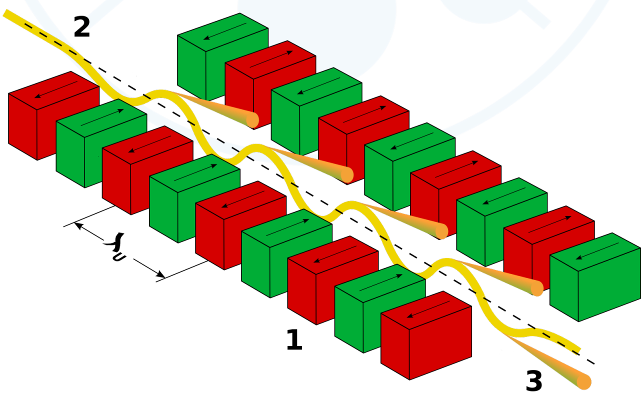


Figure 3.1: Synchrotron radiation in undulator

PETRA III is operational as the synchrotron radiation source at DESY.

Figure 3.2: The PETRA III Hall located at DESY Campus, Hamburg,Germany

Some important facts about PETRA III

- length: 2304 m
- used as a ring accelerator for electrons and positrons
- most brilliant storage-ring-based X-ray radiation source of the world since 2009
- 14 experimental stations with up to 30 instruments

The PETRA Hall is shown in the Figure 3.2.

3.2 Free Electron Laser (FEL)

Examples of this type of facility are FLASH and XFEL. Let us discuss the principle of operation.

3.2.1 Principle of Operation of the FEL

A FEL is produced when an electron bunch is accelerated to almost the speed of light by a linear accelerator. The electrons race through a series of undulators (a group of magnets arranged in a particular array), which literally force the electrons to move along a slalom course within this magnetic field.

During the slalom, the electrons lose energy in the form light, which is then amplified by Self-amplified Spontaneous Emission (SASE) [2] process to form extremely short laser flashes. These flashes are extremely *intense* and their *wavelength* (λ) or *energy* can be adjusted relatively smoothly across a wide range of values.

These two qualities distinguish them from conventional lasers, whose adjustablity is limited because they generally radiate only in definite *energy* or *wavelength* (λ) depending on the material used to amplify the light.

3.2.2 FLASH

Free-Electron Laser at Hamburg (FLASH) is a superconducting linear accelerator. It started its journey in 2005. It operates in two parts- FLASH1 and FLASH2. The Figure 3.3 shows schematically the FLASH operation and its two parts.

Some of the FLASH parameters are

1. **XUV-Photons**
   - Pulse repetition rates: 40, 50, 100, 200, 250, 500, 1000 kHz
   - wavelength: 4.2-45 nm
   - photon energy: 28-295 eV
   - pulse duration: 30-300 fs
2. **THz-Photons**
   - wavelength: 10-230 μm
   - photon energy: 5-125 meV
   - photon frequency: 1.3-30 THz [4]

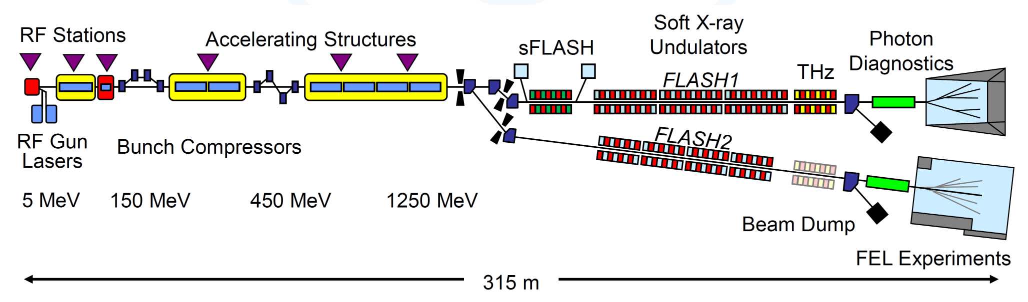


Figure 3.3: Schematic layout of FLASH at DESY

There are several beamlines at FLASH. Since this internship projects deal with only two of them namely BL1 and THz beamlines, they are described here briefly.

BL1 Beamline

The CAMP (See 4.1) is used in the BL1 with the following characteristics.

- non-monochromatic free electron laser (FEL) photons
- modular layout allowing combination of large-area, single photon pnCCD photon detectors
- multilayer split-and-delay unit for XUV pump-XUV probe experiments
- dedicated collinear laser in-coupling optics and diagnostics for the FLASH1 optical pump-probe laser systems [6]

THz Beamline

GOTTHARD module (See 4.2) is used in the THz beamline with the following characteristics.

- tunable: 10-230 μ m, up to 100 μ J/pulse, $\sim$ 10% bandwidth,
- broadband at 200μm, up to 10 μJ/pulse, $\sim$ 100% bandwidth
- synchronized and phase stable to X-ray pulses (down to 5 fs)
- delivered to the experiment via vacuum beamline as:
  1. ultra-high vacuum, shorter delay between THz and X-ray, can accommodate up to 0.3 m wide setup
  2. high vacuum, longer delay between THz and X-ray, can accommodate up to 2 m wide set up [13]

3.2.3 European XFEL

The European X-ray Free Electron Laser (XFEL) is the biggest project of its kind which is under construction at a stone's throw distance from the DESY campus. Eleven countries namely Denmark, France, Germany, Italy, Poland, Russia, Hungary, Slovakia, Spain, Sweden and Switzerland are members of the European XFEL. It will provide ultrashort X-rays with 27,000 flashes per second and which will have a brilliance a billion times higher than the conventional X-ray sources. DESY is the major shareholder of European XFEL.

European XFEL at a glance

The following list summarizes the European XFEL.

- length: ca.3.4 km
- electron energy: 17.6 GeV
- photon energy [15]: 3 keV to 25 keV
- generates extremely brilliant X-ray flashes
- FEL with superconducting linear accelerator
- one underground experimental hall with 10 measuring stations
- starts operation from January, 2017 [3]

3.3 Some Important Researches at Photon Science from Engineering Perspective

3.3.1 Golden Age for Solar Energy

Since solar energy is clean and safe, a number of research works is going on around the globe and DESY is not out of the scope. We know the organic solar cells are not very efficient and have short lifetime. DESY researchers are working to improve this situation.

Organic solar cells are made of electrically conductive plastics. To drain the current they produce, they must be fitted with electrical contacts, which are made of conductive metals such as gold. Normally, the stronger the force between the gold and the plastic, the better is the energy output. A team at DESY is using X-rays from PETRA III to sharply determine how well the establishment of bonds between gold and plastic are. The Technical University of Munich (TUM) provided some prototype of the organic solar cells which were coated at DESY by a process called *Sputtering*.

3.3.2 Bio-medical Detectors for Tumor Diagnosis

Positron Emission Tomography (PET) became a major European research project conducted jointly by DESY, CERN and three medical centers. One of the applications of PET scanner is the early tumor diagnosis. This is how it works. The doctor gives the patient a sugar dose with weak radioactive substance. In the human body, the sugar is preferentially absorbed by the cancer cells. When the radioactive substance decays, it emits high energy light flashes which are detected by specially designed sensors. The resulting signals are then converted to visible images based on what the doctors declare the presence of tumors in the patient's body.

3.3.3 Advances in Materials Research

The high-strength aluminum fuselage of passenger jets, corrosion-resistant steels for the ship propellers, heat-resistant turbine blades are some examples of material research done at DESY. The Helmholtz-Zentrum Geestacht maintains an outstation at PETRA III as a part of its German Engineering Materials Science Centre (GEMS) [7].

4. Experiments and Lab Works of the Internship

The main concentration of the internship lies on the following two detector projects namely

- Configuring interlock system for the pnCCD and
- The first detector test at THz beamline

A detailed description of each of them is given in order to better understand the experimental works.

4.1 Configuring an interlock system for the pnCCD

4.1.1 Introduction

The first project work was related to this device. The CAMP is a multipurpose endstation for electron and ion spectroscopy, pump probe and imaging experiments. The acronym is obtained from CFEL ASG (Advanced Study Group) Multipurpose (CAMP). This is a permanently installed endstation at BL1(See 3.2.2) which is available for all FLASH users. The modular and flexible layout of this allows using a variety of combinations of large area, single photon counting pnCCD, different gas jets and particle injectors and laser incoupling optics.

Figure 4.1 describes in detail the layout of the camp vacuum chamber with pertinent dimensions. The chamber consists of 4 sections C0-C3. The laser beam enters the chamber from the left and is focused onto the target at the center of section C1. The whole chamber can be moved along any spatial direction depending on the need with the help of the inner support. The first pnCCD is located at chamber C2 and the second is at chamber C3 [14].

Main goals of the CAMP are

- to get the data by momentum-resolved, large-solid angle correlated detection of a large number of electrons.
- to provide high variety of setups with high flexibility [14].

4.1.2 The pn-junction CCD (pnCCD)

This is a special kind of CCD (See 4.1.3) for X-ray imaging spectroscopy. It uses a pn junction formed when a p-type material and n-type material are brought into contact. Since a pn-junction

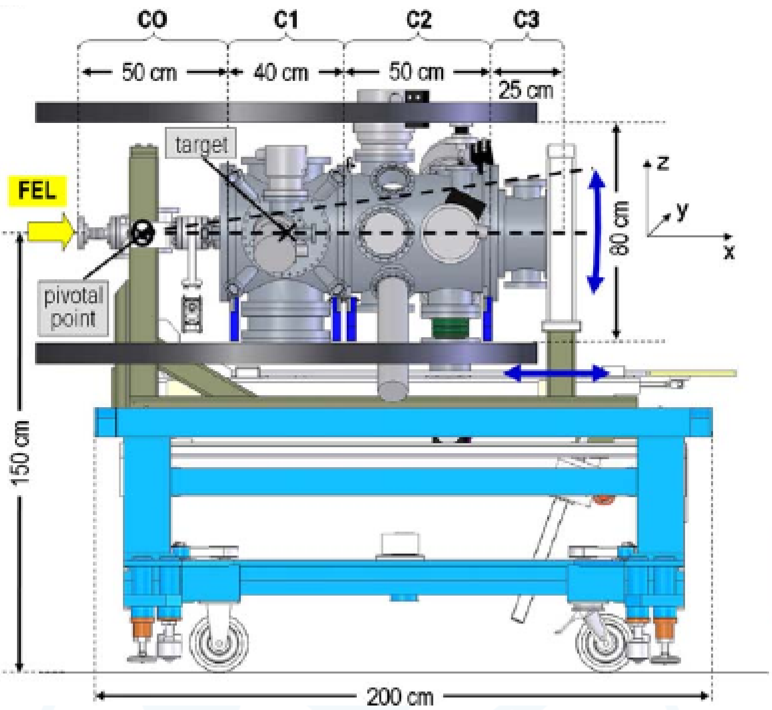


Figure 4.1: Layout of the CAMP vacuum chamber

is used in this type of CCD instead of metal oxide semiconductor (MOS), this CCD is termed as a pnCCD [11].

pnCCD that was developed for X-ray satellite mission XMM-Newton launched from France by the European Space Agency [14, 9].

4.1.3 The Construction of a pnCCD chip

The pnCCD is a 450 μm thick chip and it is depleted by a reverse-biased pn-junction on front and the back sides.

Unlike other detectors, back illumination ensures the thin and homogeneous photon entrance window. By minimizing the read capacitance, a high signal to noise ratio (SNR) can be achieved. Every CCD requires an n-channel junction field effect transistor (JFET) integrated in it to amplify on-chip signal. It is then connected by wire bond with a channel of the analog signal processor. This particular parallel arrangement ensures fast image readout. X-ray spectroscopy generally requires the CCDs to be kept at a temperature of $-60°C$.

In Figure 4.2, the cross-section through a frame-store pnCCD channel is shown. The back illumination process with the back contact, and relevant dimensions and pixel arrangement can be seen from the Figure 4.3 [14].

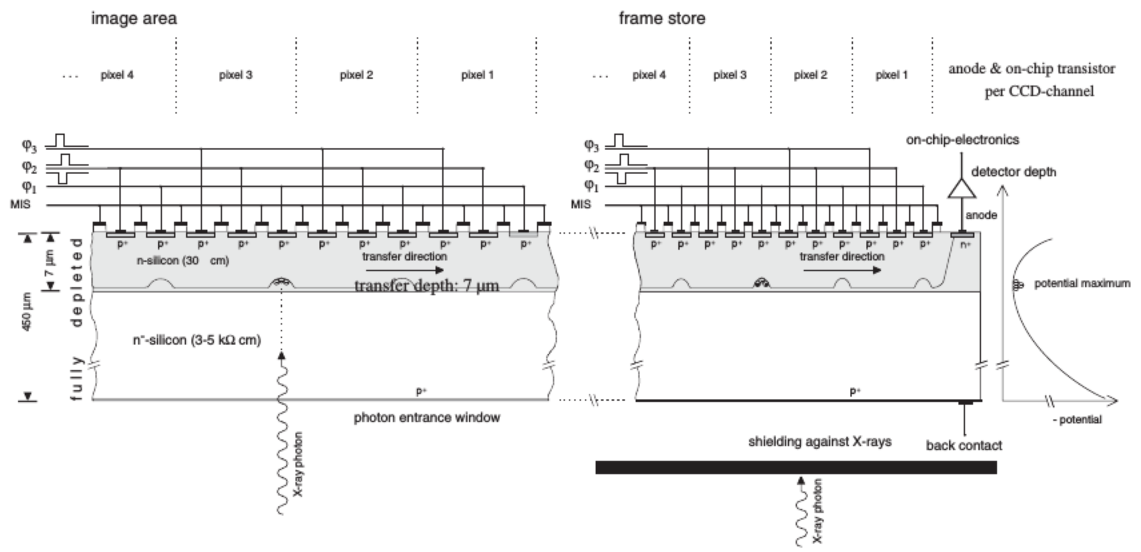


Figure 4.2: The cross-section through a pnCCD channel

CCD

The Charge-Coupled Device (CCD) is an electrical device to produce images of objects, store information as computers do, transfer electrical charge from within to a vicinity where it can be manipulated.

A CCD chip is a metal oxide semiconductor (MOS) device. It is made on a silicon substrate and the coated with silicon dioxide (SiO_2).

The wide range of applications of the CCDs include:

- fax machines
- xerox machines
- bar code readers
- close circuit television cameras (CCTV)
- video cameras
- typical photographic cameras
- sensitive light detectors [11].

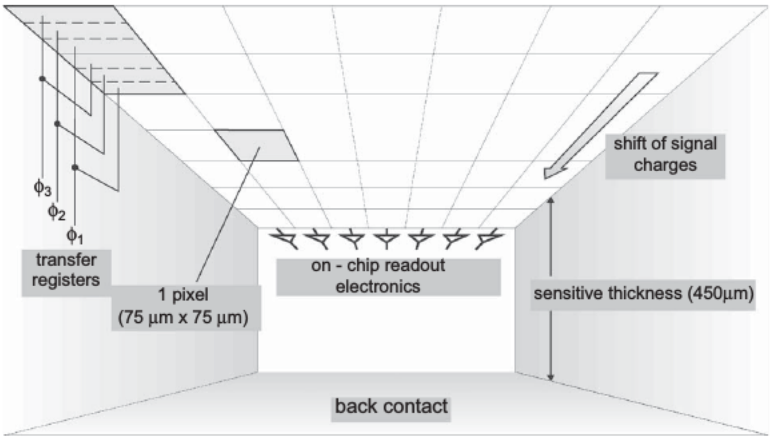


Figure 4.3: The readout schematic of a pnCCD

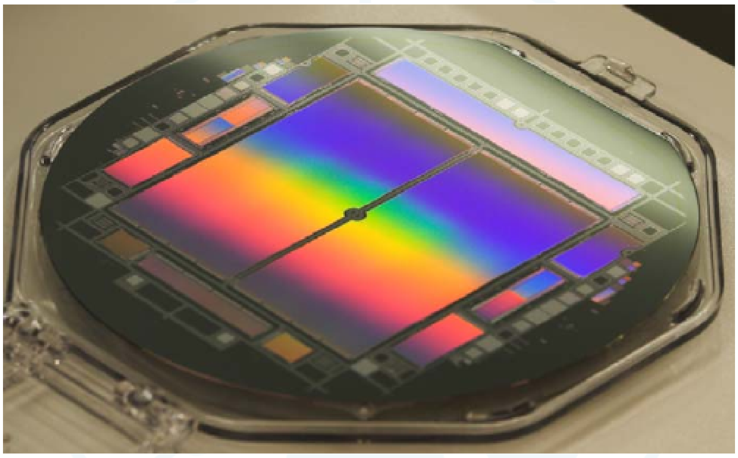


Figure 4.4: A pnCCD

4.1.4 Challenges in working with the pnCCD

The pnCCDs used in the experiments are extremely valuable and irreplaceable. That is why special attention must be paid to before and while it is operative.

A sudden power cut in the line can damage the whole system. The power should not drop sharply. If the potential between the front and the back side of the pnCCD chip drops all of a sudden, then severe damage is caused to the chip. For this reason, steps must be taken.

4.1.5 The solution to the power failure problem

An alternative power supply should be on standby to avoid the danger from the power cut. A battery or an uniterruptible power supply (UPS) can supply enough power for ca. 10 minutes during which the user can securely shut the whole system down manually. This is not safe enough and hence an automatic solution was set up.

An interlock system was put in place that would automatically ramp down the voltages and currents needed for the operation of the pnCCDs. This was done through a script able to read the output of the UPS as an input and command the control PC accordingly.

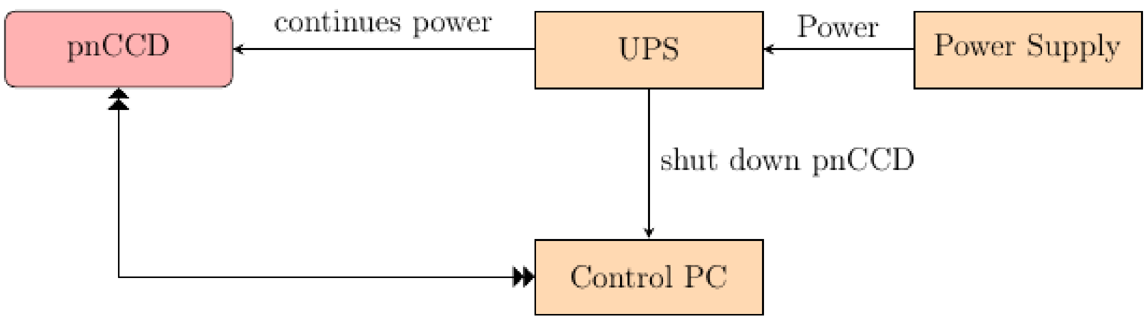


Figure 4.5: Schematic diagram of voltage ramping in pnCCD

Figure 4.5 depicts the schematic representation of the over all process of ramping down the voltage. If there is a power cut from the Power Supply, the UPS continues to supply the power to the pnCCD to keep operating. At the same time, it also sends a command to the Control PC to start the script to stop the operation of the pnCCD. When the pnCCD is securely shut down, another signal is sent to the Control PC via the same line to shut the whole system down. The arrows indicate the steps and directions of operation.

4.1.6 The UPS System

As mentioned in 4.1.5, the UPS equipment can be used to protect sensitive devices from the mains power failure. It prepares the mains voltage and ensures that the voltage values at the output to the consumer load remains constant.

The equipment description

The front side of the UPS (model: RMH 700/1000/1500) has the operator control panel as shown in the Figure 4.6.

The **LINE** indicates that the UPS is operating using mains power. This indicator goes out immediately if the mains power fails completely or the mains voltage tolerances are exceeded.

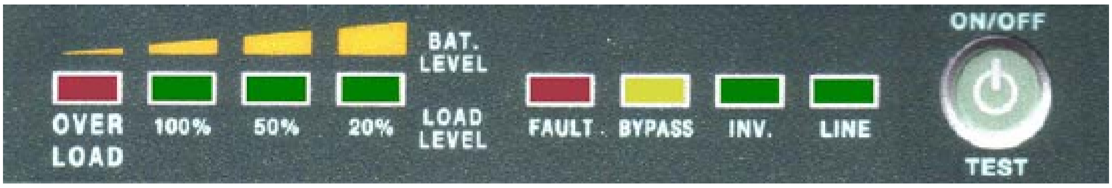


Figure 4.6: The display and operator control panel of the UPS

The **INV.** indicates that the UPS inverter is working normally and the UPS output voltage is available.

The **BYPASS** is activated when a serious equipment fault develops and the UPS cannot continue to operate normally. This function is mainly active during the UPS startup process. Damage to the UPS caused by high starting currents in a consumer load is thus prevented.

The **FAULT** is activated if there is an operating fault in the UPS or there exists a short circuit at the UPS output.

Similarly, the **BAT. LEVEL** and the **LOAD LEVEL** indicate the capacity status of the battery and the percentage of load respectively.

The rear side of the UPS is shown in the Figure 4.7.

Figure 4.7: The rear panel view of the UPS a) Fuse at mains power input, b) Mains power c) UPS output d) Communication

The main parts of the rear panel are described in brief.
a) Fuse at mains power input: The mains input is enabled when the fuse is inserted. The fuse is triggered in the event of high overcurrents or an equipment defect such as internal short circuit and the device is immediately disconnected from the main power supply.

b) Mains power input: It is the place to connect the mains power to the UPS.

c) UPS output: It is a 16A socket with earthing contact.

d) Communication: All relevant data are transmitted to an appropriate primary control unit (e.g. Control PC, See Figure 4.5) via serial interface. Additionally, a shutdown signal can be sent to the UPS [5].

The system description

Figure 4.8 depicts pictorially the individual modules of the UPS and provides a general impression of how they interact.

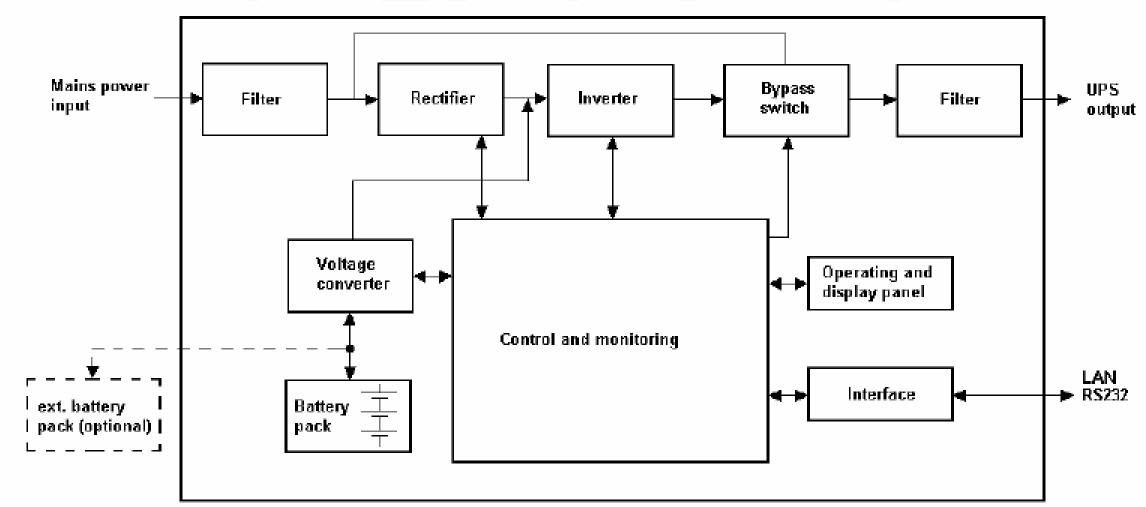


Figure 4.8: The schematic representation of the UPS

The UPS operates by the principle of double converter. It ensures the preparation of the line current and delivers an uninterrupted and fault-free $1-\phi$ voltage to mission-critical consumer loads. The UPS also keeps its internal batteries fully charged to deliver voltage continuously to the load.

The main performance features of the chosen UPS system

- absolutely no interruption or signal modification in event of primary mains power supply failure
- perfect sine voltage at the UPS output
- processor control bypass operation
- input-side pf correction (>0.95)
- high efficient inverter (>90% DC/AC)
- high performance communications interface [5]

4.2 The first detector test at THz beamline

To detect the the photons at THz beamline, the Basler spL2048-70km Camera Link device was used. It delivered 70 kHz at 2k resolution [1]. It was not able to cope up with the THz beamline (See 3.2.2) properties. A much faster detector was necessary and the GOTTHARD module was used at THz beamline.

4.2.1 Introduction

GOTTHARD or Gain Optimizing microsTrip sysTem witH Analog ReaDout, is an Application Specific Integrated Circuit (ASIC). In its present set up it uses a 1D microstrip detector system based on the principle of charge integration with automatic gain switching capability [12, 10]. It is used in THz Beamline (See 3.2.2).

4.2.2 The Module Architecture

The GOTTHARD module has ten readout ASICs wire bonded to a 1280 strip 50μm pitch silicon sensor. The 128 channels of the GOTTHARD ASIC operate in parallel and the periphery circuitry provides the I/O capabilities and chip control [10].

The specification summary of a GOTTHARD module is given in the Table 4.1.

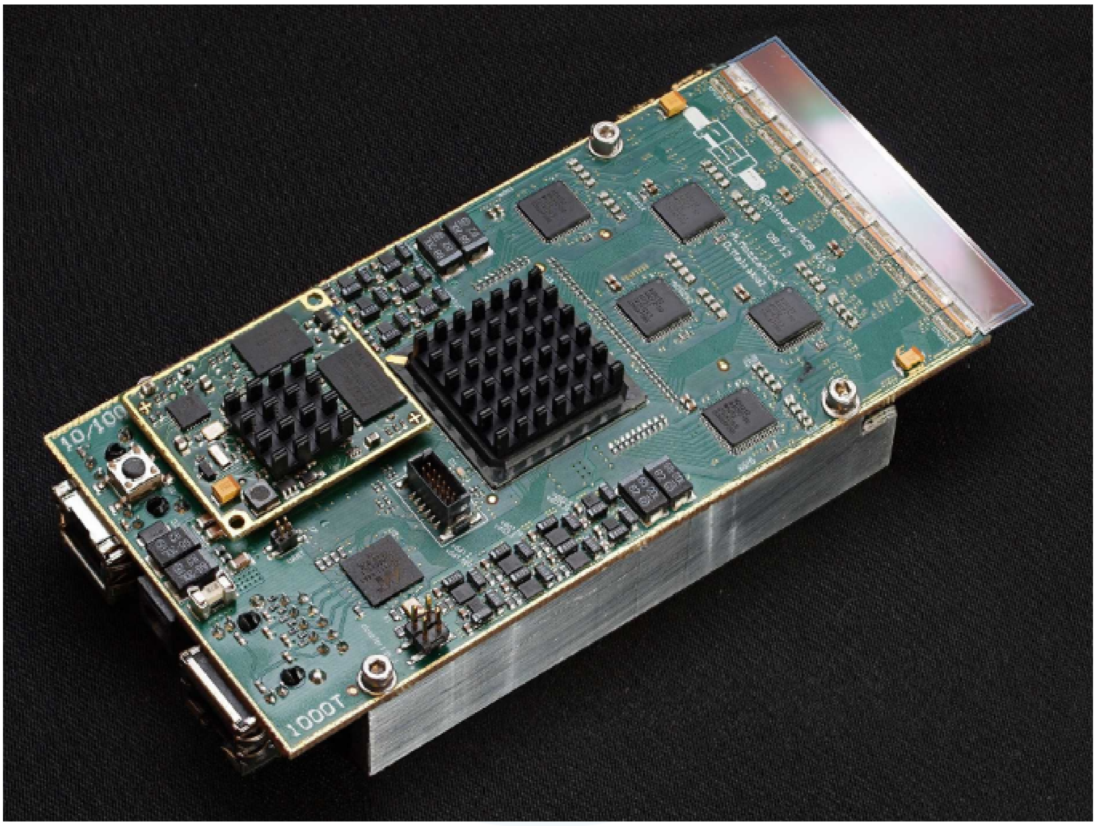


Figure 4.9: The GOTTHARD Module

Table 4.1: GOTTHARD Design Specifications [12]

ASIC Technology	IBM 130nm
Module Size	$6.7 \times 12.5 cm^2$
Sensitive Area	$64 \times 8 mm^2$
Sensor Thickness	320-500μm
Noise r.m.s	$\backsim 200 e.n.c$
pitch	50μm
Dynamic Range	10^4 12 keV photons
Min Energy	<3.5 keV
linearity	better than 0.5%
Point Spread Function	O (pitch)
min int. time	80 ns
dead time	<50 ns
cooling	air
readout time=1/frame rate	40 kHz continuous ,1MHz burst

4.2.3 Applications of GOTTHARD

The applications of the GOTTHARD Detector are :

In X-ray Free Electron Lasers (XFELs)

- XES/XAS with energy dispersive optics
- beam diagnostics: shot to shot spectral information with energy dispersive optics, beam position and intensity monitor
- powder diffraction

In Synchrotron Sources

- pump-probe experiments with up to 1MHz repetition rate
- diffraction experiments at very high photon rates
- high resolution applications

4.2.4 Some Useful Terms

Described in brief below are some important terms which are useful and necessary during the experiment.

Exposure Time

It is the time during which the detector detects X-rays for each image.

Period

The time in which the images are acquired is the period. It will be ignored if less than the exposure time plus the readout time.

Number of Frames

It is the number of images to be acquired per cycle.Frames and cycles are the same except in the trigger mode, when frames indicate the number of images per trigger. The total number of images is frames time cycles.

Number of Cycles

It is the number of times that the frames are acquired. Frames and cycles have the same meaning except in the trigger mode, when cycles mean the number of triggers that will be accepted. The total number of images is frames time cycles.

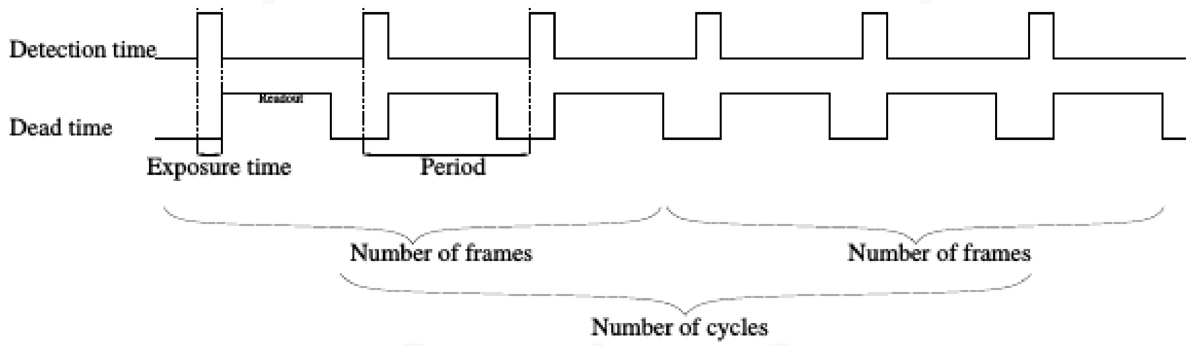
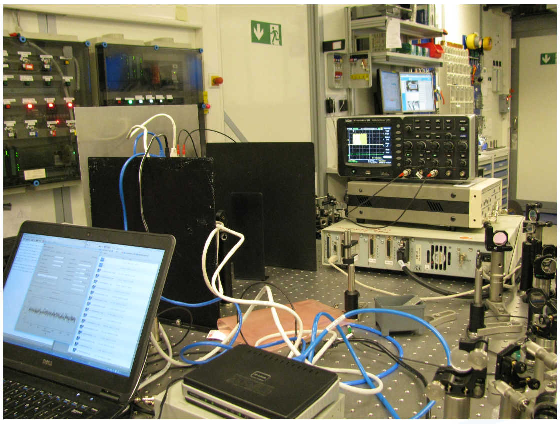


Figure 4.10: The auto timing mode showing different terms defined

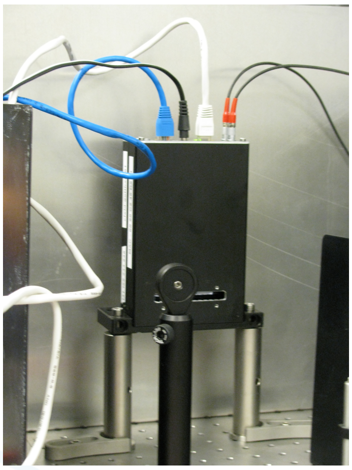
4.2.5 Experimental setup

The experimental setup for the first detector test at THz beamline at FLASH is given in Figure 4.11.

The schematic representation of the detector test at THz beamline can be shown as in Figure 4.12. It explains the whole process of detection. Silicon sensor of the GOTTHARD module is connected to the GOTTHARD chips (10 in number) by wire bonds (128 for each chip). The chips are again wire bonded to electronics.



(a) The whole experimental setup



(b) The GOTTHARD Module

Figure 4.11: The experimental setup of detector test at THz beamline

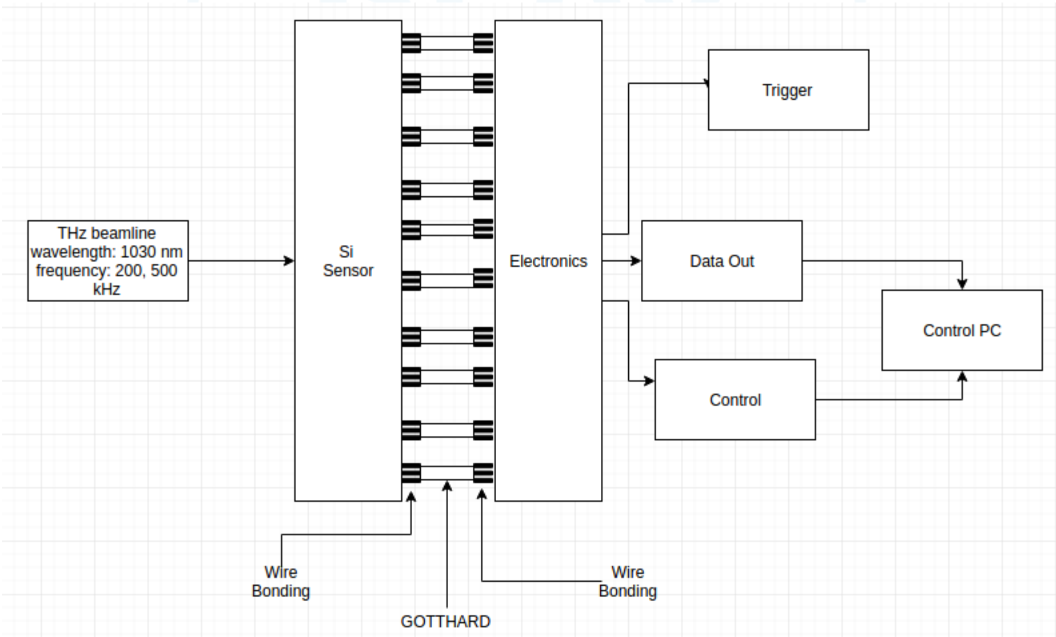


Figure 4.12: The pictorial representation of the THz beamline experiment

4.2.6 The data analysis process

The data obtained from the experiment are further processed for analysis. The process is explained here.

Converting the Raw Data to ASCII Form

The raw data obtained from the real experiment is faster to be readout. But the format may not be user-friendly. That is why a conversion is required so that users can use them according to their need. For our case we chose to convert the raw data to the ASCII form for further processing in other programs like MATLAB.

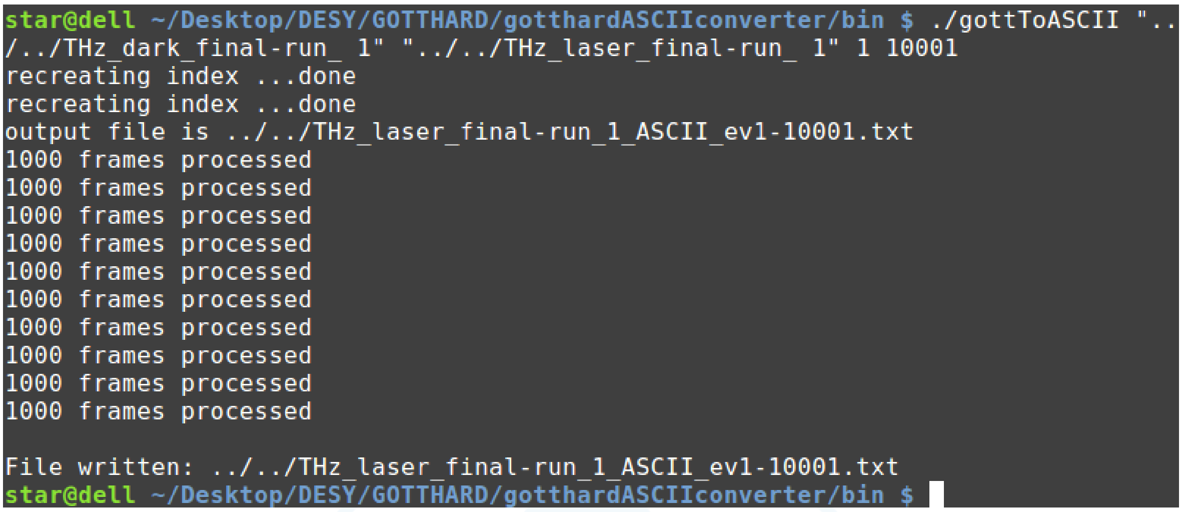
The following commands are executed in a Linux terminal for this conversion process.

```
 from the  gotthardASCIIconverter folder:
bin/gottToASCII "./agbe_pede_ 0" "./agbehenate_25_ 1" 1 102

./agbe_pede_  is the FULL path+name to the pedestal file until the
f  (f excluded)
0 is the index  of the pedestal file (the number bedore .raw)

./agbehenate_25_ 1  is the FULL path+name to the data file until the
 f (f excluded)
1 is the index  of the data file (the number bedore .raw)

1 is the first frame in the set that you want to analyze
102 is the last frame in the set that you want to analyze
(e.g. 1 102 will generate an ASCII file with 102 images in)

the output format is should be evident:
nch  pedestal_corrected_adc_value
nch loops from 0 to 1279, and then starts from 0 for the next frame.
```

Figure 4.13: The sequence of the commands to be executed

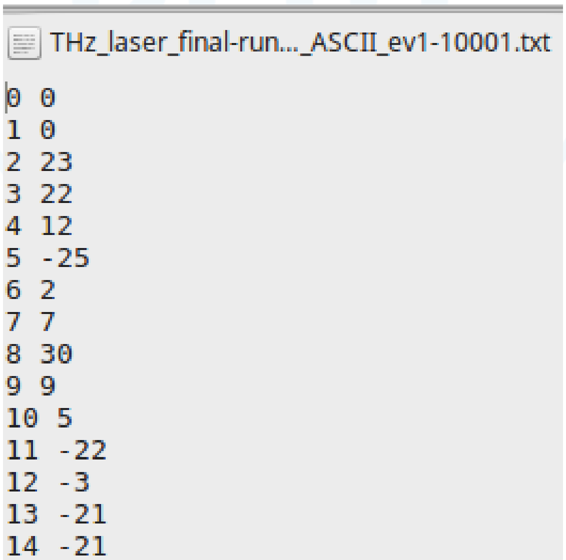
For example, the screen shot of the above procedure executed in a Linux terminal is given in Figure 4.14.

The processed data then take the form as given in the Figure 4.15. These data now can be further processed.



```
star@dell ~/Desktop/DESY/GOTTHARD/gotthardASCIIconverter/bin $ ./gottToASCII "..
/../THz_dark_final-run_ 1" "../../THz_laser_final-run_ 1" 1 10001
recreating index ...done
recreating index ...done
output file is ../../THz_laser_final-run_1_ASCII_ev1-10001.txt
1000 frames processed
1000 frames processed
1000 frames processed
1000 frames processed
1000 frames processed
1000 frames processed
1000 frames processed
1000 frames processed
1000 frames processed
1000 frames processed

File written: ../../THz_laser_final-run_1_ASCII_ev1-10001.txt
star@dell ~/Desktop/DESY/GOTTHARD/gotthardASCIIconverter/bin $
```

Figure 4.14: Example of command execution of data conversion process



```
THz_laser_final-run..._ASCII_ev1-10001.txt
0 0
1 0
2 23
3 22
4 12
5 -25
6 2
7 7
8 30
9 9
10 5
11 -22
12 -3
13 -21
14 -21
```

Figure 4.15: The converted data in ASCII form

The first column in the Figure 4.15 represents the pixel numbers which ends at a value of 1279 and then again starts from 0 and repeats until the last frame is taken. And the second column represents the value in ADU. The ADU value is converted to photons multiplying by a factor.

4.2.7 Result and Conclusion

The converted data (See 4.2.6) are imported to MATLAB . They are then plotted as given in the Figure 4.16.

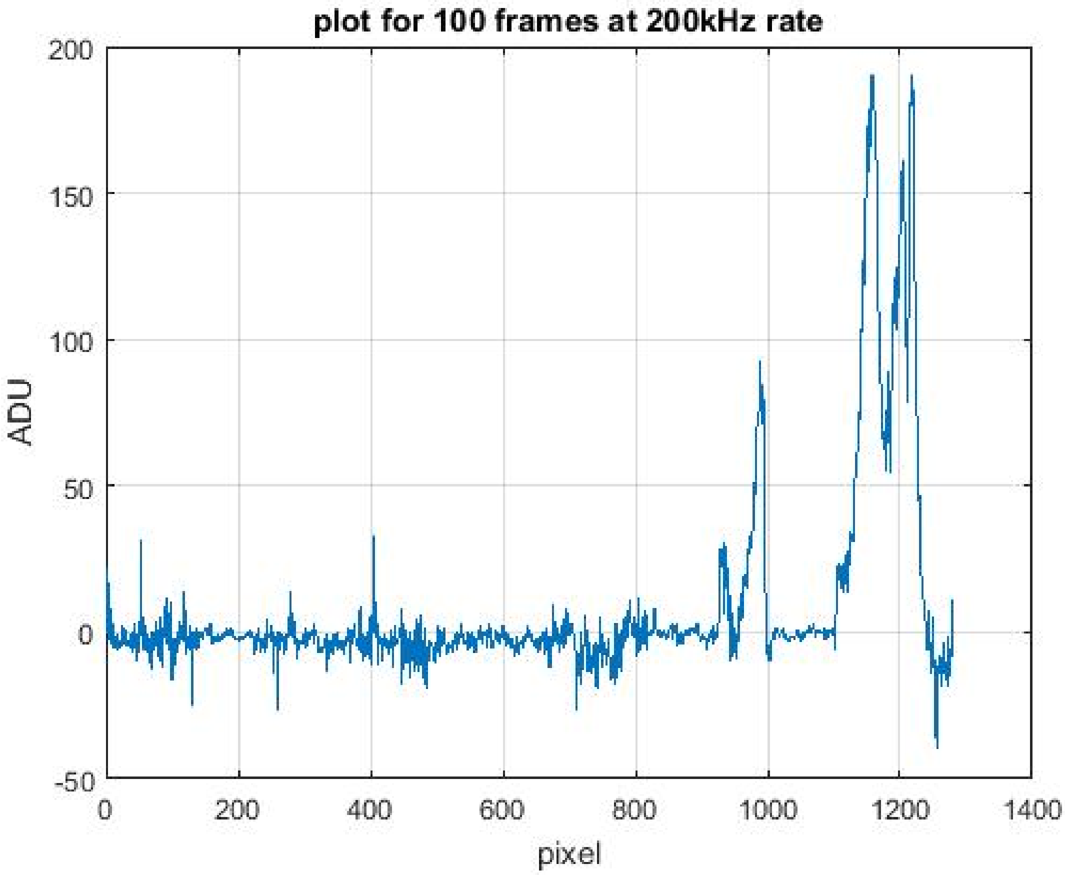


Figure 4.16: The plot of pixel versus ADU

The right higher peak in the Figure 4.16 represents the incident photons. Ideally the shape of the curve should be Gaussian. The side peak to the left of the higher peak is however unexpected. It may be caused by the following reasons.

- The pedestral subtraction was not performed correctly.
- There was a sync problem between the acquisition trigger and the laser trigger.

Further analysis and experiments are needed to fully understand the causes of this behavior.

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