# PERCIVAL CALIBRATION

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# Abstract

Due to Free-Electron Lasers and Synchrotrons radiations are rapidly increasing in brilliance in Fig.1.

So we need a detector to detect this photons with high intensities :

1. High dynamic range ——► high full well up to $10^7$ e-.
2. High frame rate sensors ——► Up to 300 Hz.

So that is why we are using PERCIVAL because it realises these requirements, We wanted to have sources with high flux intensities as the Flash radiations : to be able to test it with the detector but it was not easy to obtain sources with these high intensities, in order to solve this problem we had to come up with a solution as designing large LED array in Section 2 ,we are going to implement a mechanical set-up test-bench for the light source with the optical components like the diffuser and the filters.

And in the end ,we will analyse the images taken from this implementation.

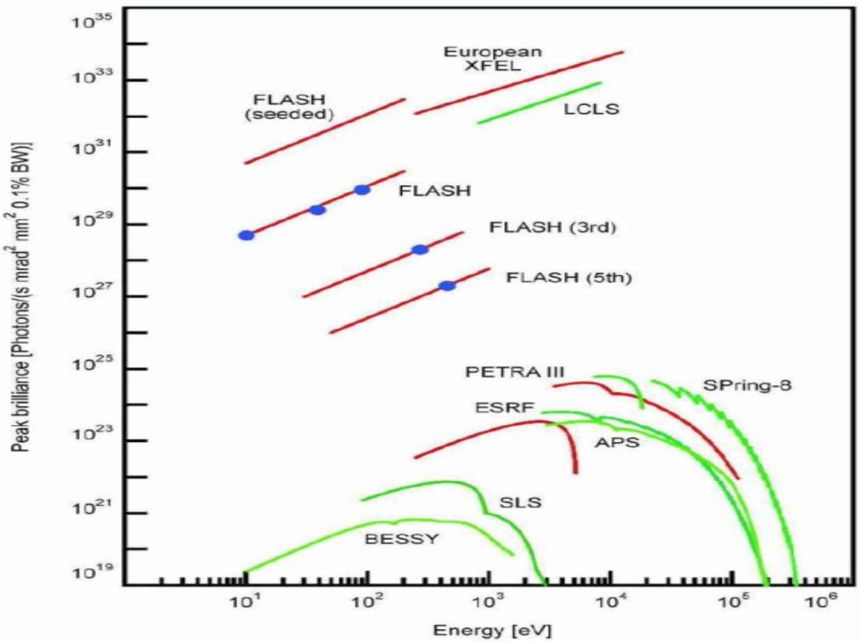



**Fig.1**: Energy range and peak brilliance of FEL facilities around the world.

# Contents:

# 1 Introduction

PERCIVAL ("Pixelated Energy Resolving CMOS Imager, Versatile And Large") is a photon imaging detector .

It is currently being developed by a collaboration of DESY, RAL, Elettra, DLS and PAL to study the low energy photon range like the soft X-ray radiation generated by the synchrotron radiation sources and free electron laser with target efficiencies above 90%.

It is based on CMOS technology.

The final PERCIVAL sensor size :P2M (1408 × 1484 pixels) featuring a large imaging area (~4x4cm$^2$ ) without any dead or blind spaces, with a pixel pitch of 27 μm.

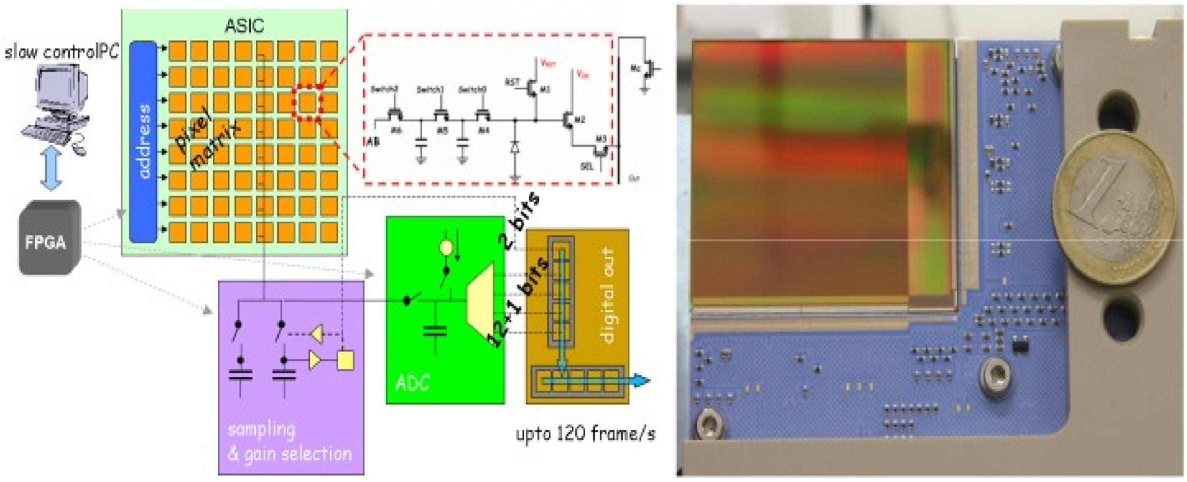



**Fig.2:** the core of the P2M system , at the right of the picture .

At the left of the pictures:

Each pixel is provided with 15 bits:

- 2 bits: to identify its "Gain" stage in the image thus to be able to reconstruct the collected charge . There are a 3-level signal .It has a Multiple-gain dynamic switching : in each pixel , there is a system of switches and capacitors embedded to be able to change the charge-to-voltage transfer function of pixel exposed to a high photon flux, so the pixel will not be saturated quickly, this will allow it to effectively increase its dynamic range.

- The left 13-bits for the ADC are divided : The 5 most significant bits : a "coarse" ADC conversion step. The 8 least significant bits : a "fine" conversion step. Where each column of pixels is connected 7 ADCs in order to convert the signal from up to 1440 rows within 300 Hz .

There are two illumination modes:

FSI and BSI MODE:

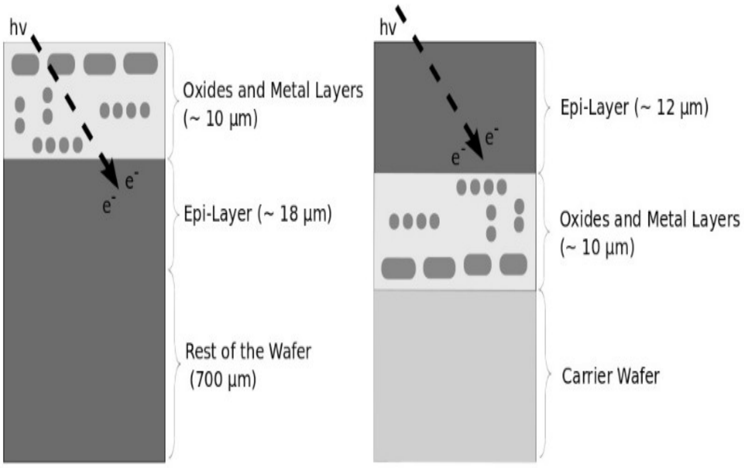



**Fig.3**: FSI and BSI.

Front-side-illuminated (FSI): on the left of Fig.3.There is a thick passive entrance window of circuitry, SiO2 and metals which allows only high energies to pass through having reasonable QE , and low energies like soft x-rays will be absorbed in these layers and lost. This happened due to the attenuation length of Si and SiO2 are on the order of 100 nm, as shown in Figure 4.

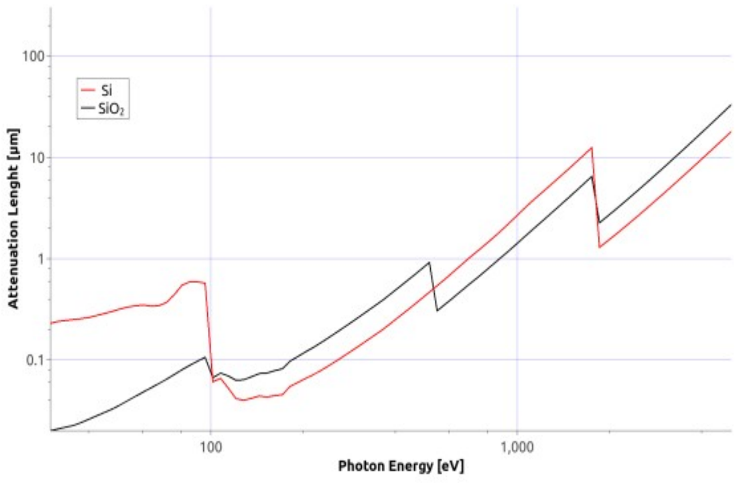



**Fig.4**: Attenuation lengths for Si and SiO2 versus photon energy.

The uppermost layer of a CMOS sensor, containing SiO2 and the metal lines of the circuitry, is in general several µm thick. So, in order to achieve good performance of QE for soft X-ray and so that PERCIVAL will be usable under high fluxes down to 100 eV and lower, in order to fully cover the FLASH operational energies : a regular FSI chip has to be back-thinned and backside-illuminated (BSI): (on the right of Figure 3) passive entrance windows have to be reduced by orders of magnitude (from the original 700 μm to 12 μm). So that , low-energy photons are now absorbed in a depleted region, increasing the efficiency.

# 2. Light source design (LEDs)

Why are we using LEDs:

We are going to design large array of LEDs as our synchrotron radiation in order to test it with the detector,besides this, we will able to calculate the depth of SiO2 and circuit layers by a more safely low energy photons and in the end we will know if these low energy photons will be absorbed by these layers or not.

## 2.1 General overview of LEDs

An LED is a variant on the basic diode. A Diode is an electronic component that only conducts electricity in one direction. An LED is basically the same as a Diode, with the key difference being it generates light when the electricity flows.

Diodes have a forward voltage rating which determines the minimum voltage difference between the Anode (+) and Cathode (-) in order to allow electrons to flow, also it defines the amount of voltage required in order to conduct electricity and produce light like in Fig.5.

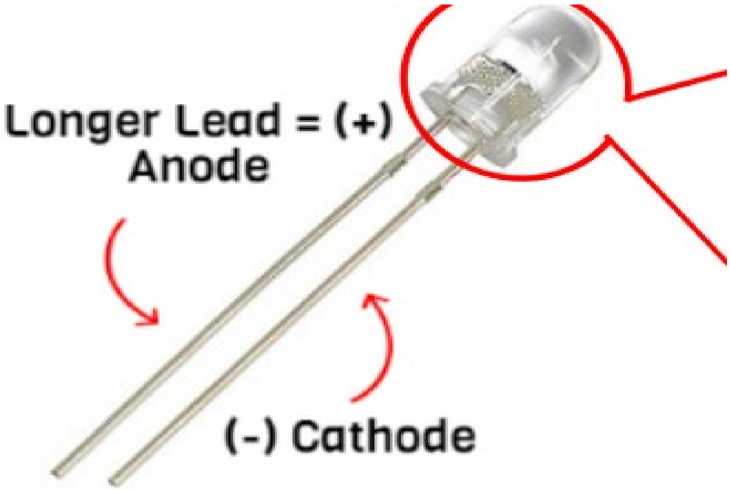



**Fig.5**: LED configuration

LED BRIGHTNESS :

The wavelength of the light generated depends on the semiconductor material but the light intensity depends on the current being drifted to the diode. Therefore, the higher the drive current, the brighter your LED will be. Here , we intend to use five colored LED.

## 2.2 Circuit design

### 2.2.1 Picture of the schematic

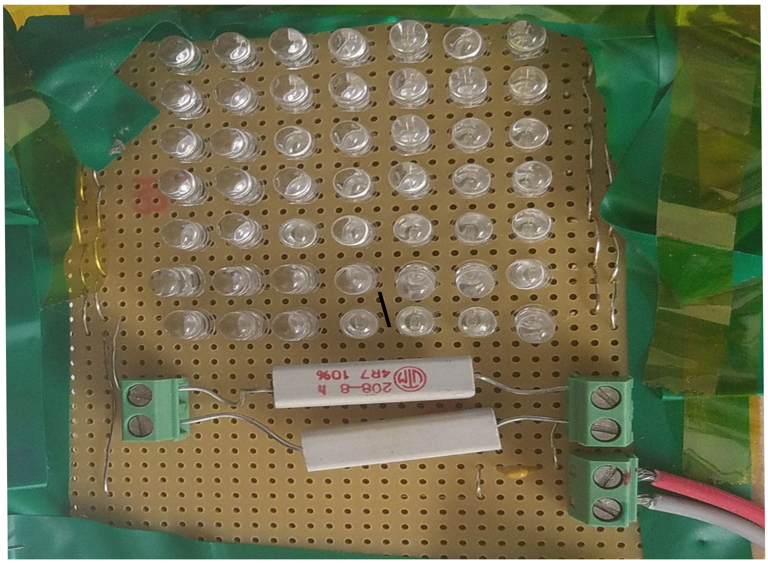



**Fig.6 :** 7 X 7 green LED array.

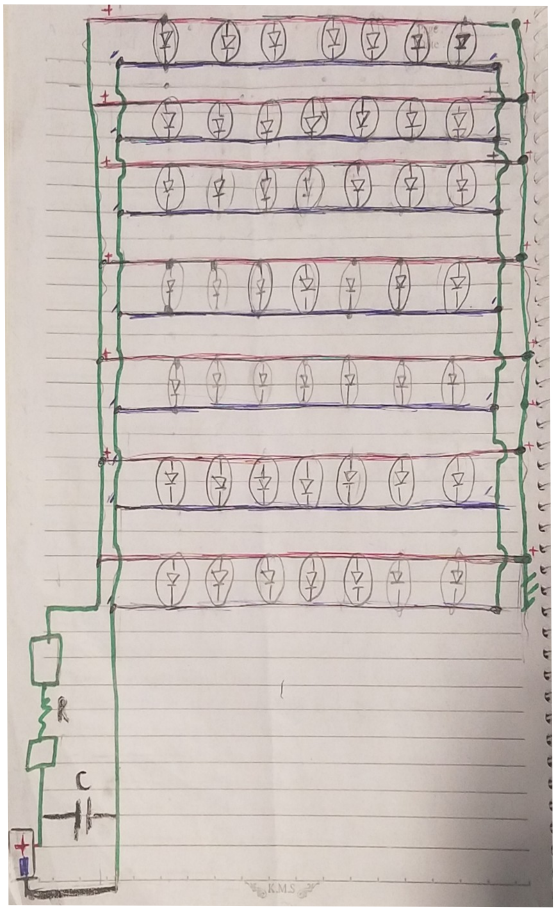



**Fig.7:** Circuit Schematic.

The 49 LEDs are conneted in parallel in Fig.7 instead of being connected in series in order to minimize the voltage given to the supply.

### 2.3.2 LED's characteristics table :

| LED Code | LED Color | Wavelength | Typical current | Peak current | Typical forward volt (Vf) | MAX Forward VOLT | Luminous Intensity |
|---|---|---|---|---|---|---|---|
| 810-0439 | GREEN | 527 nm | 30 mA | 100 mA | 3.2 V | 4 V | 20000 mcd |
| 818-7540 | Red | 616 nm | 50 mA | | 2.1 V | 2.7 V | 35 000 mcd |
| 123-8663 | BLUE | 470 nm | 30 mA | 100 mA | 3 V | 3.8 V | 11000 mcd |
| OED-EL-1L1 | IR | 940 nm | 100 mA | 1 A | 1.4 V | 1.5 V | 120 mW/str |
| VAOL-5EUV0T4 | UV | 405 nm | 30 mA | 100 mA | 3 V | 3.8 V | 200 mcd |

**Table 1.** LED datasheet information.

## 2.3 CALCULATIONS:

Vs: Input Voltage , VF: Forward voltage of LED , VR: Resistor Voltage
IF :Current/ LED , I : LEDs total current , IT : Typical LED current
R :Resistance , C : capacitor

$$VS = VF + VR$$

$$VR = VS - VF$$

$$IF = \frac{2}{3} \times IT$$

$$IT = IF \times 49$$

$$R = \frac{VR}{IT}$$

- Green LEDs (7 X 7 array ):

VS = 6 V , VF = 3.2 V , VF = 2.8 V

IF = 20 mA , IT = 980 mA

R = 2.8 ohms , C = 473 µF

2.3.1 LED Calculation table :

We will notice that if we are giving the same voltage for all the LEDs , the value of the resistance will differ .But also, beside this the power for each resistance changes but the power of the resistance in case of IR will be very large so we have to decrease the supply voltage in that case in order to minimize it.

| LED Color | Supply voltage | Current/led | Total current (7*7) array | Resistance Voltage | Resistance | Power dissipated by resistance |
|---|---|---|---|---|---|---|
| GREEN | 6 V | 20 mA | 980 mA | 2.8 V | 2.8 ohms | 2.7 W |
| Red | 6 V | 33.3 mA | 1.633 A | 3.9 V | 2.388 ohms | 6.3 W |
| BLUE | 6 V | 66.66 mA | 980 mA | 2.99 V | 3.06 ohms | 2.93 W |
| IR | 4 V | 66.66 mA | 3.266 A | 2.6 V | 0.795 ohms | 8.4 W |
| UV | 6 V | 20 mA | 980 mA | 3 V | 3.06 ohms | 2.94 W |

**Table 2.** Calculations for each LED

## 2.4 Stabilization problem:

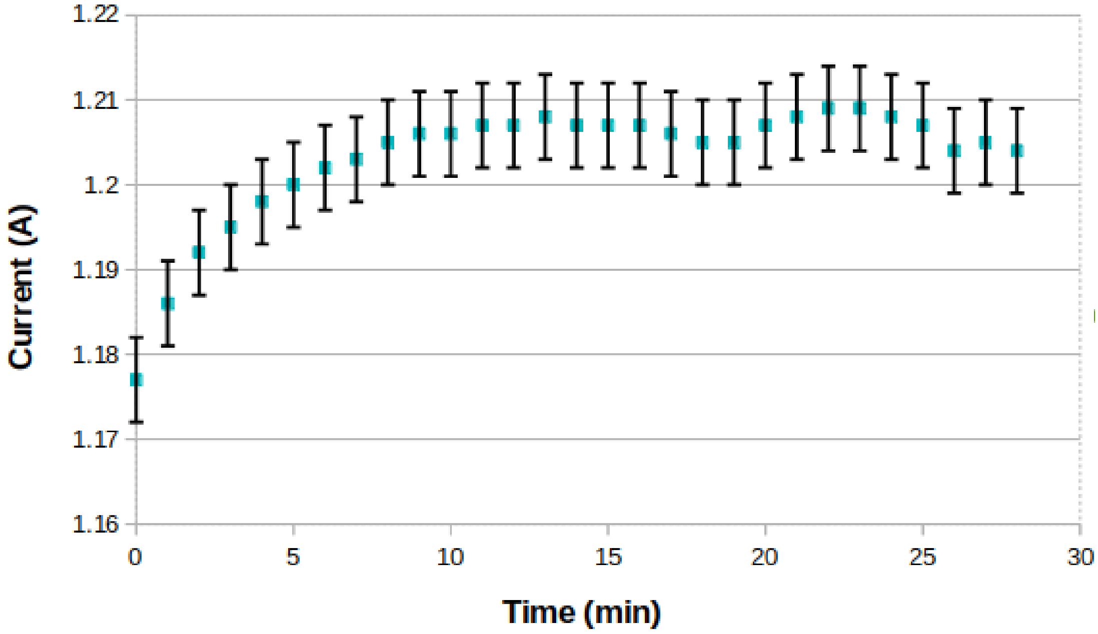



**Fig.6** : Drift current versus time.

By observing Fig 6, the current is not stable ,it is changing with time . That means that the voltage provided by the DC generator to the circuit is not constant ,also it is having ripples .Besides this the light output of LED is temperature dependent ,the cooler the environment, the higher an LED's light output will be and in warmer environments and at higher currents, the temperature of the semiconducting element increases,higher temperatures generally reduce light output. Also, as we can see that the first 10 minutes the current is changing without a certain range and this is so clear by adding the error bars which are Systematic Errors which usually come from the measuring instruments themselves , they produce consistent errors : a proportion of the true value, or like here as a fixed amount (0.005) due to that the accuracy of the instrument is to 3 digits after the decimal point . So, If you repeat the experiment, you'll get the same error, but after the first 10 min the current is likely stable which indicates that when we begin to take data, we should take it after 10 min of initializing the system , so that the output light will not change much , and the images created in the end will have much less noise.

### 2.4.1 LD1084 : 5 A low-drop positive voltage regulator adjustable as a Solution.

So , in order to solve this stability problem , we used an low-dropout or LDO regulator is a DC linear voltage regulator that can regulate the output voltage even when the supply voltage is very close to the output voltage. It is used to maintain a steady voltage . Linear regulators have very low output voltage ripple,and low noise because there are no elements switching on and off frequently.

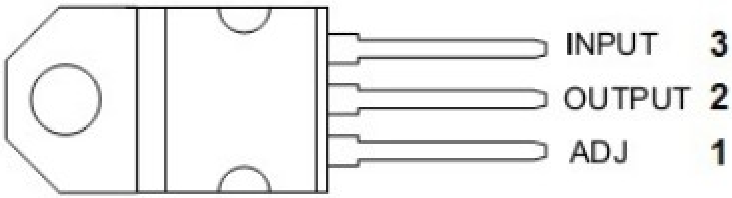



**Fig.7:** Pin configuration of LD1084 ;5 A low-drop positive

voltage regulator adjustable.

There is also adjusting a voltage divider system to maintain a constant output voltage in Fig.8 : a variable resistor R2 and fixed resistance R1 are connected to it to control the value of output voltage continuously.

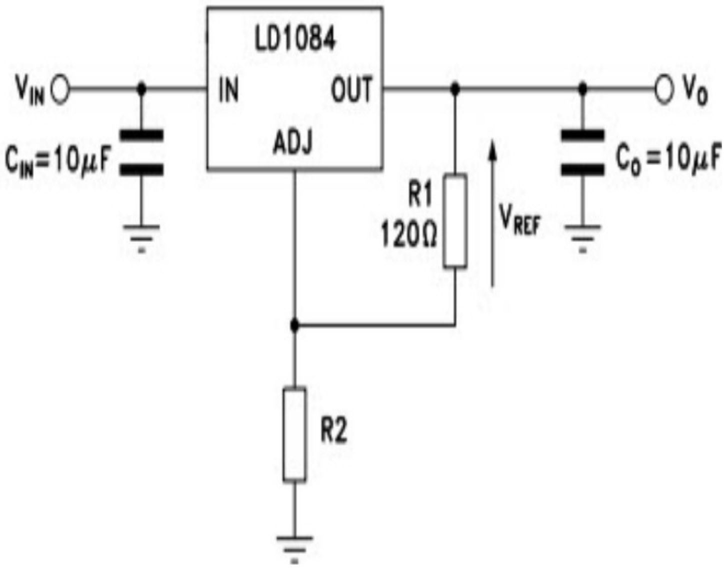



**Fig.8:** Voltage divider network connection to LD1084

The output voltage is given as:

$$V_{\text{OUT}} = \left(1 + \frac{R_1}{R_2}\right) V_{\text{REF}}$$

The voltage regulator is continually dissipating the difference between the input and regulated voltage as waste heat. In order to dissipate this heat ,it must be mounted separately on a heat sink like in Fig 8. Heat sink is a passive heat exchanger that transfers the heat generated by an electronic device to a fluid medium, often air,where it is dissipated away from the device, thereby allowing regulation of the device's temperature at optimal levels so that the temperature will not increase.

The power loss is given as:

$$P_{\text{LOSS}} = (V_{\text{IN}} - V_{\text{OUT}})\, I_{\text{OUT}}$$

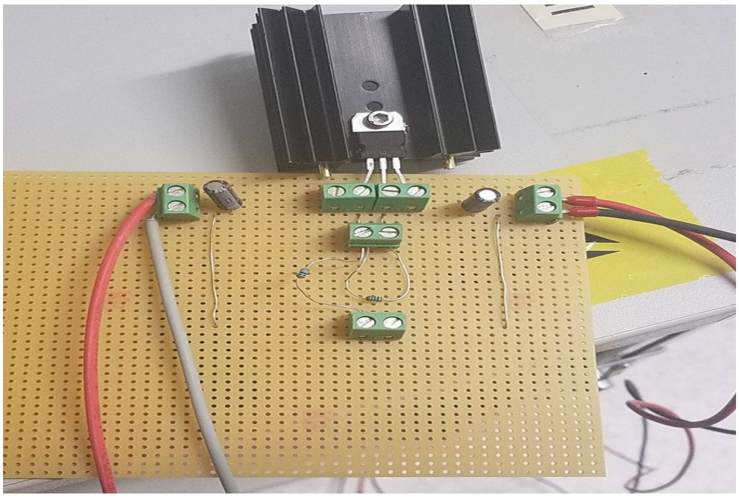


**Fig.9** Hardware circuitry of the voltage regulators

It requires also external capacitors connected from the output lead to the ground in order to maintain regulator stability .

### 2.4.2 Plot of Drift current versus time after using the regulator with The previous current :

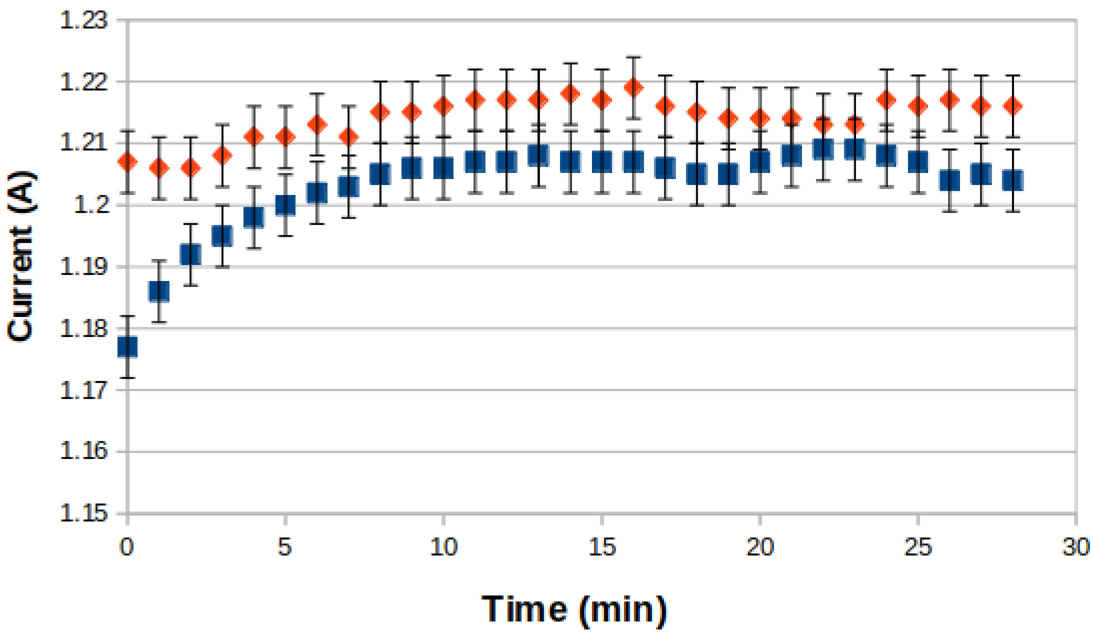



**Fig. 10**: Plot of the current versus integration time in two different circuitry.

By observing Fig.10 ,we will notice the dirft current (the red scatter points) using the voltage regulator is more stable than the current produced (blue scatter points ) without using the voltage regulator.

The varying range of the new cuurent =0.02 A.

The varying range of the old cuurent =0.05 A.

But , in the end we have to wait like 1 hour until the current will be more stable .

## 3 Photon-transfer curve

Photon -transfer technique also can be applied as a standard method for evaluating the CCE performance of CMOS transistors and to calculate how many photon/electron were incident on the sensor,and how much the noise is, to able to use PERCIVAL as counting -photon detector.

It also provides us key sensor characteristics, such as noise, Quantum Efficiency (QE), gain,and full well.

"It is a curve of noise σs (DN) as a function of signal S (DN) “: The input to the sensor is given in units of incident photons , and the final output is achieved by encoding each pixel's signal into digital number of 13 bits . where S (DN) represents the average signal (DN) over all affected pixels for a certain time delay ,and σs (DN) is the standard deviation of the signal S.

So, in order to produce PTC / PIXEL : The integration time of the sensor has to be varied in both dark and light conditions to perform an integration sweep over all ranges until all pixels are saturated. After this,we will take the mean of the signal of all images for each integration time taken for a specific pixel and also the standard deviation of the signal as a noise for the pixel . And we will repeat this process for different integration time to construct PTC plot as shown in Fig.11.

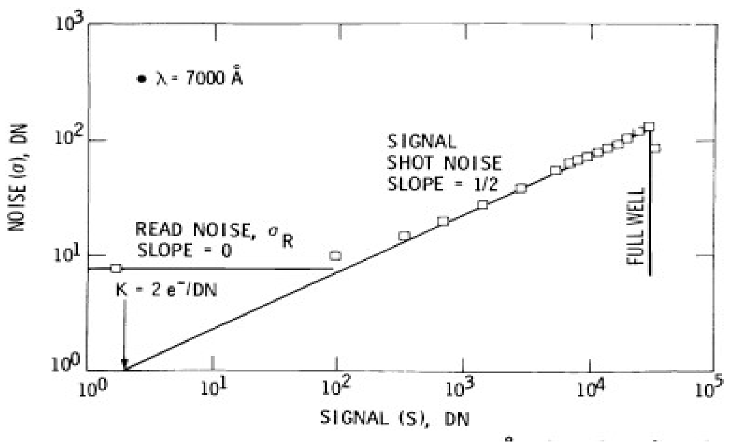



**Fig.11** :Photon-transfer curve.

## 3.1 Conditions for PTC calibration :

Components Specifications :

1. Large and Stable light source of LEDs which is nearly done by using the voltage regulator with a heat think. Then put it in a closed dark box which is connected by a large tube .
2. In order to get high degree of uniformity and homogeneity we need a large diffuser that covers all the sensor area , which scatters light in all directions so that the light is uniform on the sensor .
3. Varying either the optical densities of the filter or the integration time several times in order to control the photon flux intensity incident on the sensor.

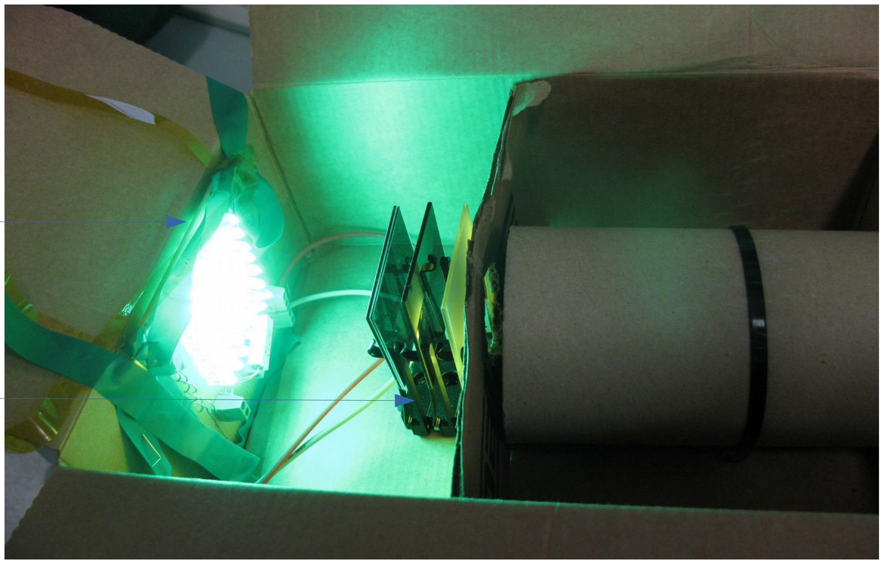



**Fig.12** Integrating The optical components with the detector

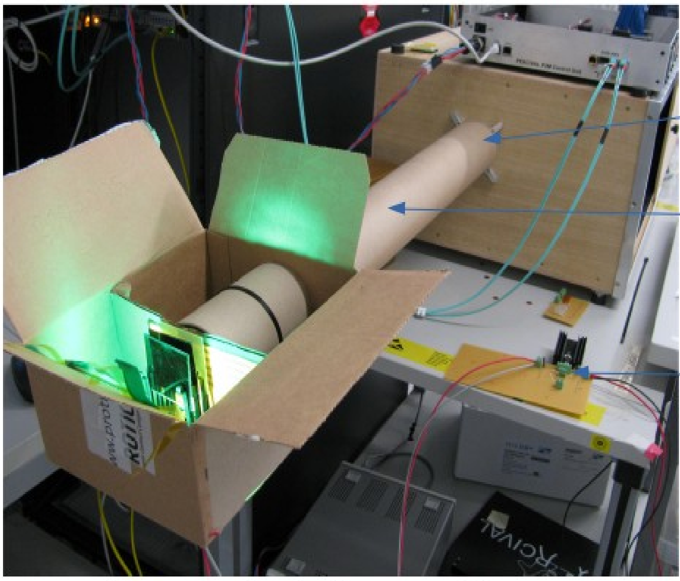



**Fig.13** Mechanical set-up of the system.

### 3.2 LIGHT CONDITIONS (WITH GREEN LEDs):

Varying integration time and fixing the optical densities of the filters:

- 12ms → 244 ms ,by step = 8ms ,to get in the end 30 integration delays .
- Number of frames / Integration time = 10 Frames,Total number of frames = 300.

**For 12 ms integration time:**

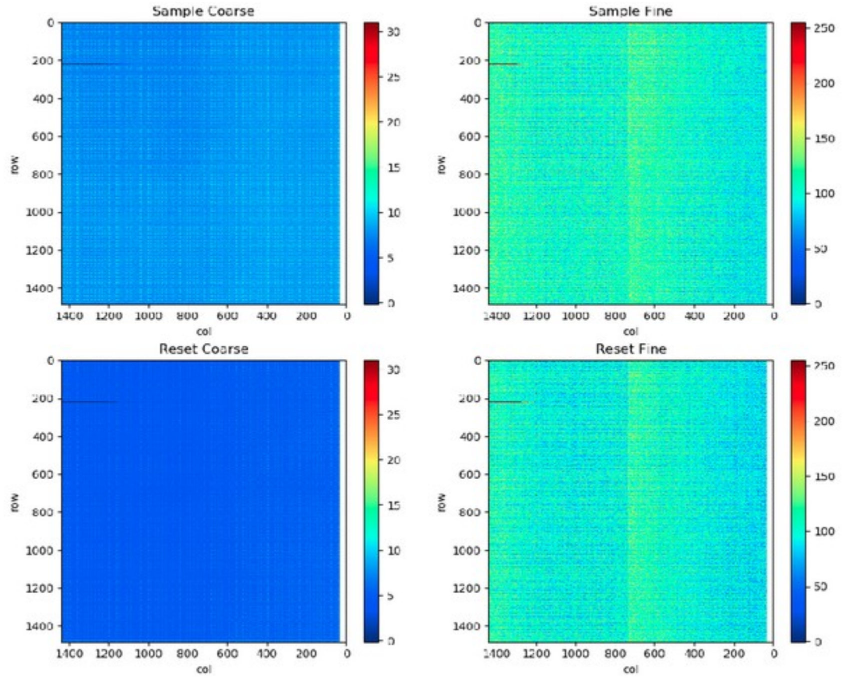



**Fig.14:** The images taken for 12 ms.

We usually have two groups of images divided into three categories :

The 2 groups are:

- The Sample : Taking data within an integration time which is 12 ms.
- The Reset : Taking images within an integration time much lower than 12ms , as before arriving the photons to the sensor in order to know what was the state of the sensor, which is the same images for all the integration time.

The Three categories are :

- The gain represented by 2-bits ,but we did not use it in our measurements.
- The coarse represented by 5-bits, having the max value is 31 ADU.
- The fine represented by 8-bits,having the max value is 255 ADU.

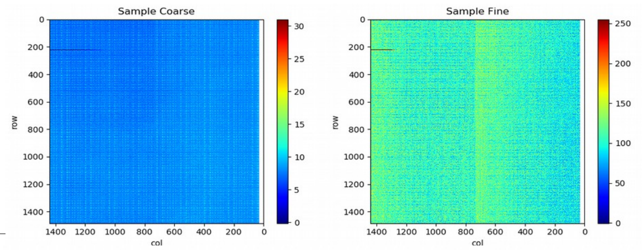
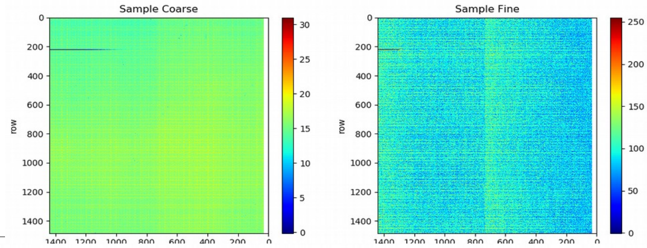
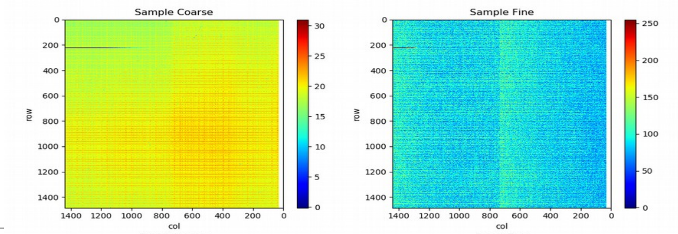
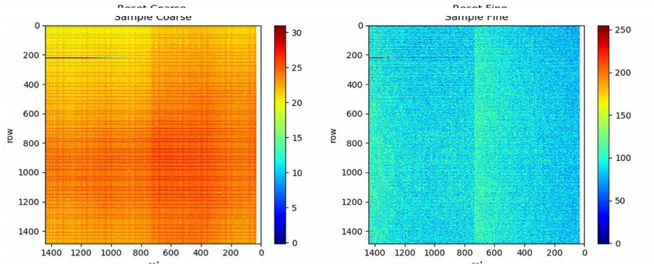
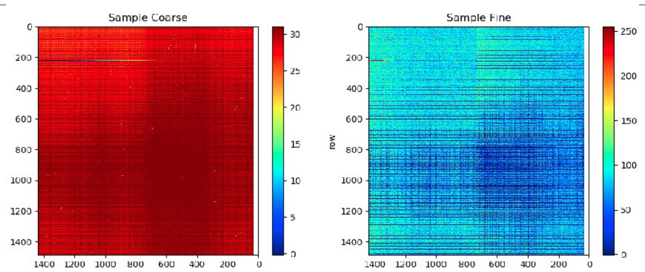
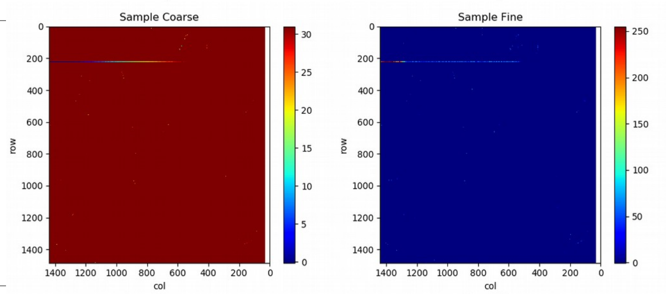
| Integration Time (ms) | Sample Coarse Sample Fine |
|---|---|
| 1. 12 |  |
| 2. 60 |  |
| 3. 84 |  |
| 4. 108 |  |
| 5. 156 |  |
| 6. 244 |  |

**Table 3.**Images taken at different integration time.

- ➔ Repeating same previous procedures for dark conditions.

- ➔ By combining the coarse and fine in one image : Sample_light.

### 3.3 Calculations for plotting the generated signal while increasing Time delays:

Data_light :D.L

Sample_light:S.L

Reset_light : R.L

Mean of the data_light : $\overline{D.L}$

Variance of the data_light : $\sigma^2 L$

Signal : S

Data_dark :D.D

Sample_dark :S.D

Reset_dark :R.D

Mean of data_dark: $\overline{D.D}$

Variance of the data_dark: $\sigma^2 D$

Corrected_Variance : $\sigma^2 C$

1. $D.L = S.L - R.L$
2. $D.D = S.D - R.D$
3. $S = D.L - D.D$
4. $\sigma^2 C = \sigma^2 L - \sigma^2 D$

### 3.3.1 Signal versus integration time Plot :

by observing the Fig.15 :

- we distinguish that there is linear regression between the integration time and the signal in a particular range , so that the number of electrons generated increases by increasing the integration time (increasing photon flux)n linearly.

- Also, pixel is saturated in another range , and we can know from the plot the max number of electrons that can be stored in the pixel.

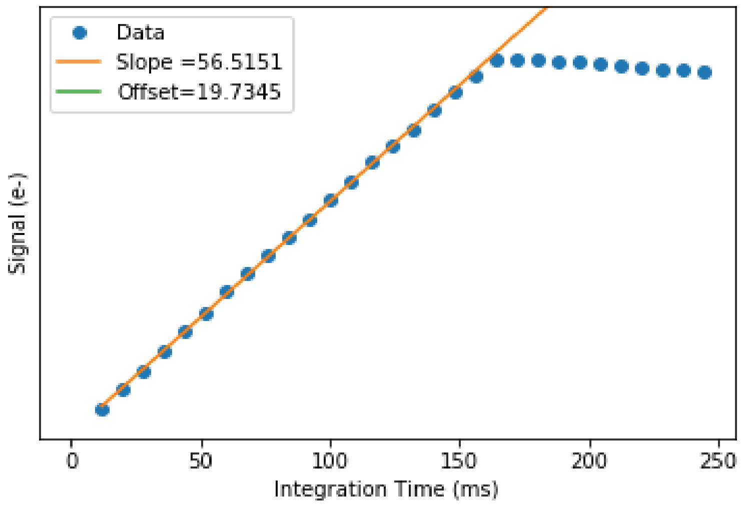


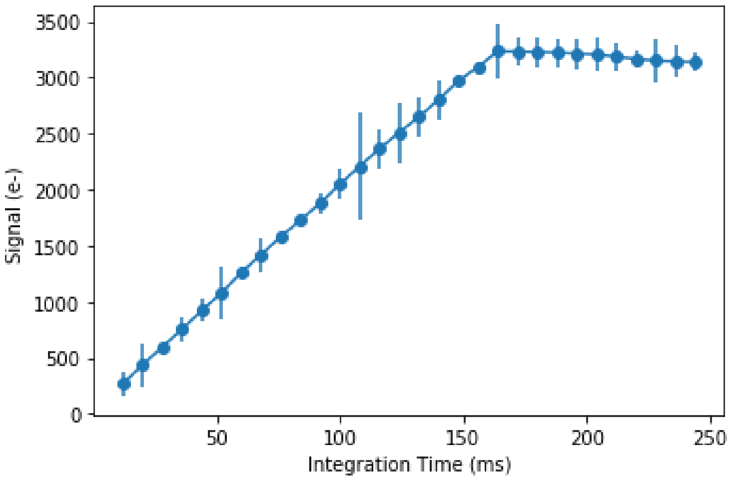

**Fig.15** : Plot between the integration time and the signal.

### 3.3.2 Adding error bars to the plot in Fig.16:

Here, the error bars are the corrected_variance . We will notice that the error bars have larger value for few integration delays plot is not accurate

This is due to two possibilities :

1. low statistics of taking small number of frames per each integration time,which explains this inaccuracy.



2.The unstability of the light source .

**Fig.16** : Adding corrected_variance as error bars to the plot

## 4 Conclusion

I had been able to improve PERCIVAL calibration and installation set-up by using large stable LED as our synchrotron radiation and integrating it with the optical components to be able test the detector behavior and analyse it .We had much better images in the form of homogeneity and uniformity for this set-up, we have had a linear relationship between the number of electrons generated and increasing the integration time. But, by adding the error bars to the plot ,it was not accurate.That is why we could not plot the PTC curve.
So ,the next stage is to increase the statistics by increasing the number of frames taken per each integration time to 300 images in order to have better results. Besides this, in order to have more improvements in the data ,we need to have new designs for the LED array circuitry to make it more stable,and maybe to test it with the other LEDs.

## 5 Acknowledgments

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Special thanks to DESY Summer Student Programme 2019 organising team for given me the opportunity to be a part of it.

## 6 References

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