Detector Pool's Quick Guide to Calibrated PIN diodes

Description of the Photodiode

The APS Detector Pool has three calibrated PIN diode detectors available for use.

- DP00256 is a Si PIN diode (Hamamatsu S3584-06) with an active area of 28 x 28 mm^2 and a depletion layer thickness of 0.3 mm. The diode was calibrated by Physikalisch-Technjsche Bundesanstalt (PTB, Germany's national metrology institute) on May 9, 2007.
- DP00328 is a Si PIN diode (Hamamatsu S3584-06) with an active area of 28 x 28 mm^2 and a depletion layer thickness of 0.3 mm. The diode was calibrated by Physikalisch-Technjsche Bundesanstalt (PTB, Germany's national metrology institute) on June 16, 2010.
- DP00325 is a Si PIN diode (Hamamatsu S3590-06) with an active area of 10 x 10 mm^2 and a depletion layer thickness of 0.3 mm. The diode was calibrated by Physikalisch-Technjsche Bundesanstalt (PTB, Germany's national metrology institute) on June 16, 2010.

Incident radiation generates electron-hole pairs in the silicon which cause an electric current to flow across the junction. The diode is installed in a special housing with a light-tight window and a connector. See References and PTB Calibration Report for measurement details. Spatial variations along the diode at 8keV were found to be well below 1%. At higher photon energies, especially above the Ag K edge (25.5 keV), responsivity varied at the edges of the diode, with some areas showing as much as 10% higher responsivity. More details about the calibration method and results are available from Detector Pool personnel. The PIN diode detector is typically used as a beam flux monitor, often for calibration purposes (e.g. tuning of monochromator).

Figure 1a: Detector with cover

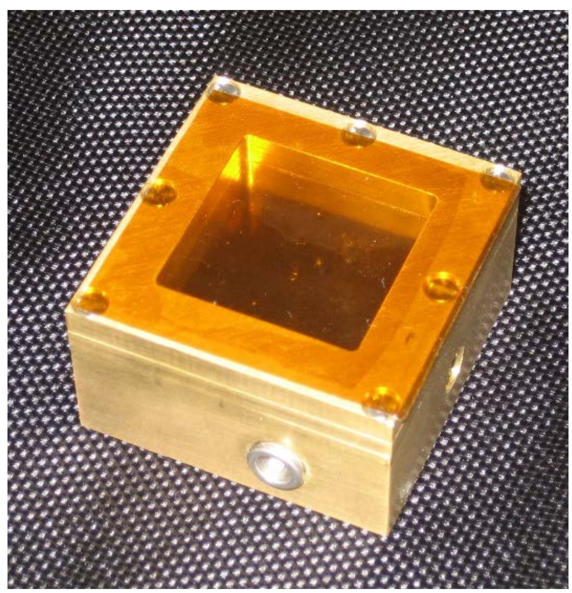


Figure 1b: Detector without cover

Safety and Handling Concerns

The Beryllium window is very thin and fragile (25 microns thick). Therefore, it is important to ensure that nothing comes into contact with it. Also, Beryllium particles are extremely toxic. If breakage of a Be window does occur it is important not to inhale, swallow, or allow the particles to come into contact with skin, open cuts, or eyes. If contact occurs seek medical attention immediately.

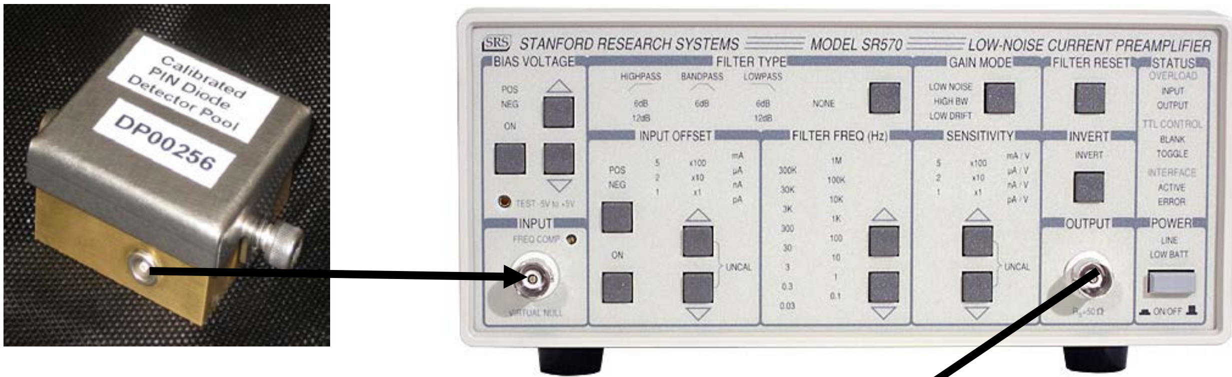
The radiant power used for calibration was between 0.1 μW and 3μW (PTB). Accordingly, we recommend that you keep the maximum total beam intensity around 3 μW in a 1 mm x 1mm area. Table 1 shows the maximum recommended count rate per mm^2 at various photon energies.

Photon Energy (keV)	Maximum Count Rate (cps/mm^2)
8	2.34×10^9
10	1.87×10^9
12.5	1.50×10^9
15	1.25×10^9
20	9.36×10^8
25	7.49×10^8
30	6.24×10^8
35	5.35×10^8
40	4.68×10^8
45	4.16×10^8
50	3.74×10^8
55	3.40×10^8
60	3.12×10^8

Table 1: Maximum recommended count rate at various photon energies

Typical Operation

The PIN diode can be read out in much the same manner as an ion chamber. However, the PIN does ***not*** need bias voltage. A common way to operate the detector is to connect the detector output to a current preamplifier input (e.g. SR570), the output of which is connected to a voltage readout device (e.g. voltage to frequency converter such as the NOVA N101VTF, or an ADC). Output from the VTF can be connected to a scaler. Note that the dark current should be subtracted from your x-ray measurements. The dark current will vary with gain setting.



Lemo to BNC connector cable

Voltage Readout Device (e.g. VTF), Scaler

Figure 2: Suggested detector to electronics connections

Adjust the gain and filtering of the SR570 accordingly. Suggested configurations:

Bias Voltage: Off
Filter type: NONE
Input offset: NONE
Gain Mode: LOW NOISE
Sensitivity: 1 μA/V (Vary as needed)
Invert: INVERT (to inverse the polarity of output voltage)
The gain on the VTF should be set to 1.

Calculation of Count Rate

The output voltage should be proportional to the input X-ray flux. The size of the output current from the diode versus the incident photon intensity is provided in the calibration report. Tables 2, 3, and 4 show the calibration data provided by PTB. Figure 3 shows the associated calibration curve (differences in data were slight, so that the calibration curve looks approximately the same for each diode). The method of calculating photons/sec/pA values (tables 2, 3, and 4) is shown on page 6, below Figure 3.

Photon Energy(keV)	Responsivity(A/W)	Uncertainty(A/W)	Photons/sec/pA*
8.0	0.270	0.003	2890
10.0	0.265	0.003	2355
12.5	0.233	0.002	2143
15.0	0.183	0.002	2274
17.5	0.137	0.001	2603
20.0	0.102	0.001	3060
22.5	0.0761	0.0008	3645
25.0	0.0575	0.0006	4342
27.5	0.0538	0.0005	4219
30.0	0.0424	0.0004	4907
35.0	0.0268	0.0002	6654
40.0	0.0181	0.0002	8621
45.0	0.0127	0.0002	10921
50.0	0.0092	0.0001	13568
55.0	0.0070	0.0001	16212
60.0	0.0055	0.0001	18914

Table 2: Spectral responsivity of detector DP00256 and measurement uncertainty.
*Values were calculated as shown below.

Photon Energy(keV)	Responsivity(A/W)	Uncertainty(A/W)	Photons/sec/pA*
8.0	0.269	0.003	2900
10.0	0.262	0.003	2382
12.5	0.231	0.002	2162
15.0	0.181	0.002	2299
17.5	0.137	0.001	2603
20.0	0.101	0.001	3090
22.5	0.0753	0.0008	3684
25.0	0.0576	0.0006	4334
27.5	0.0499	0.0005	4548
30.0	0.0393	0.0004	5294
35.0	0.0248	0.0002	7191
40.0	0.0168	0.0002	9288
45.0	0.0117	0.0002	11855
50.0	0.0086	0.0001	14515
55.0	0.0065	0.0001	17459
60.0	0.0051	0.0001	20397

Table 3: Spectral responsivity of detector DP00325 and measurement uncertainty.
*Values were calculated as shown below.

Photon Energy(keV)	Responsivity(A/W)	Uncertainty(A/W)	Photons/sec/pA*
8.0	0.268	0.003	2911
10.0	0.262	0.003	2382
12.5	0.231	0.002	2162
15.0	0.181	0.002	2299
17.5	0.136	0.001	2622
20.0	0.101	0.001	3090
22.5	0.0744	0.0008	3729
25.0	0.0568	0.0006	4395
27.5	0.0528	0.0005	4299
30.0	0.0415	0.0004	5013
35.0	0.0267	0.0002	6679
40.0	0.0181	0.0002	8621
45.0	0.0126	0.0002	11008
50.0	0.0092	0.0001	13568
55.0	0.007	0.0001	16212
60.0	0.0054	0.0001	19264

Table 4: Spectral responsivity of detector DP00328 and measurement uncertainty.
*Values were calculated as shown below.

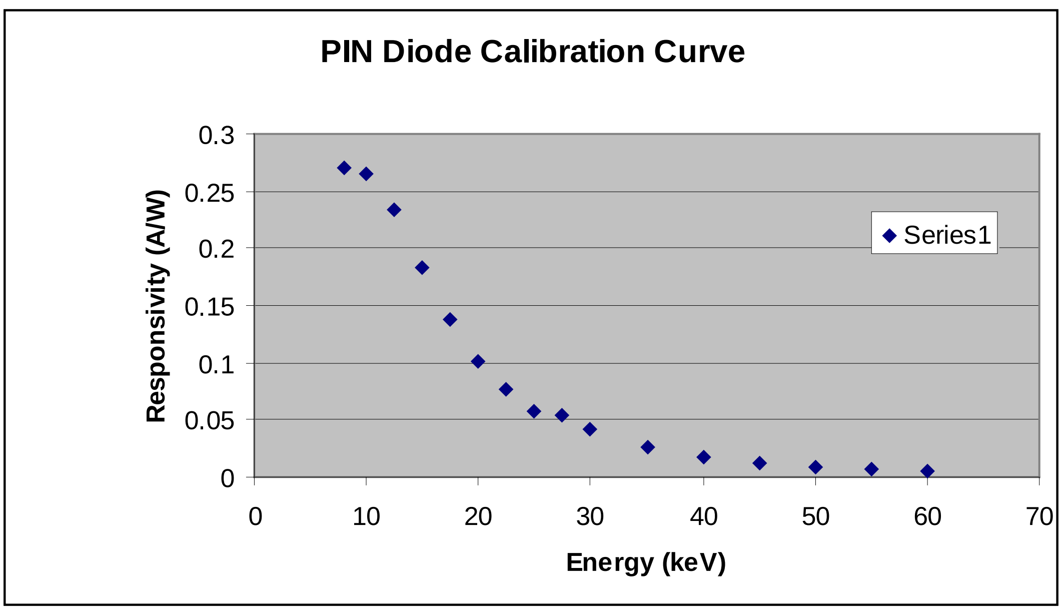


Figure 3: Calibration curve

PTB provided responsivity values in A/W. These values were translated to photons/second/picoamp as follows:

Known: 1eV = 1.6 x 10^{-19} J

Energy of an 8keV photon:

$$8000\text{eV} \times \frac{1.6 \times 10^{-19}\ \text{J}}{1\text{eV}} = 1.28 \times 10^{-15}\ \text{J}$$

Given: responsivity value shown in table 2
Known: 1 W = 1 J/s

$$\frac{0.27\text{A}}{1\ \text{J/s}} \quad \frac{1.28 \times 10^{-15}\ \text{J}}{1\ \text{photon}} = 3.46 \times 10^{-16}\ \text{A/photon/s}$$

Convert to pA:

$$3.46 \times 10^{-16}\ \text{A/photon/s} \quad \times \quad 10^{12}\ \text{pA/1A} = 3.46 \times 10^{-4}\ \text{pA/photon/s}$$

Reciprocal: **2890 photons/s/pA**

This calculation was repeated for each photon energy, using the responsivity data provided. Figure 4 shows a plot of keV photons per second per picoamp for each photon energy shown in table 2. Differences in data were slight, so that the plots look approximately the same for each diode.

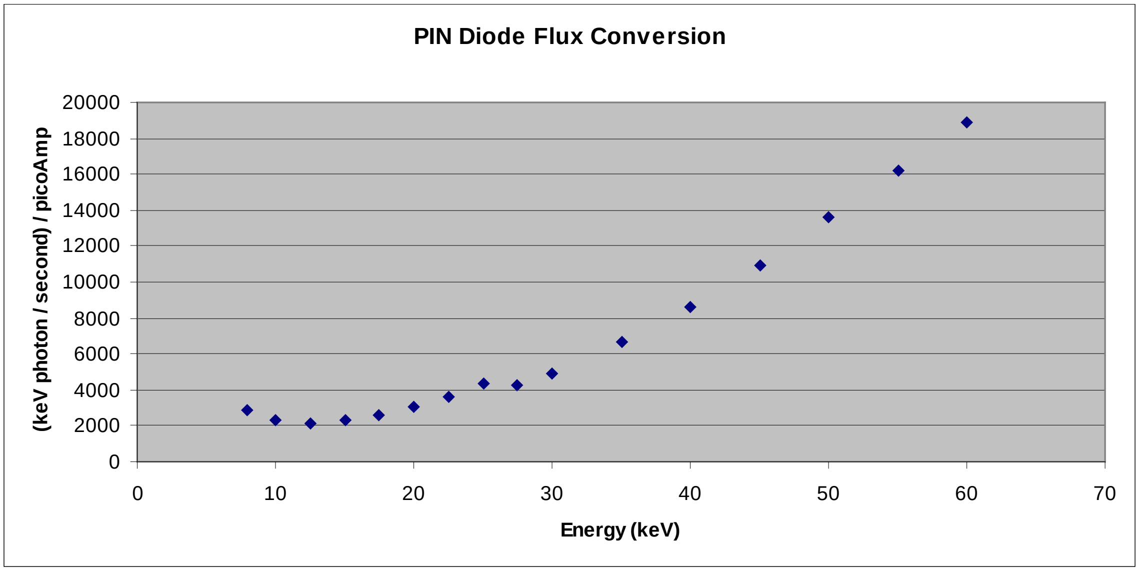


Figure 4: Number of keV photons per second per picoamp as a function of photon energy

Verification of Calibration

As an initial test of the calibration provided by PTB, calibrated PIN diode detector DP00256 was compared to a Cyberstar NaI photomultiplier tube with a thickness of 5mm. Tests were conducted in the XSD-BTS x-ray lab using x-rays from a copper x-ray tube. As a result, we expect the dominant x-ray signal to contain 8keV photons. The Cyberstar 2000 datasheet (Oxford Danfysik) confirms that the 5mm Cyberstar NaI has 99% efficiency in detecting 8keV photons. In addition, both detectors have beryllium windows of similar thickness. Thus, the transparency can be assumed to be comparable. On this basis, we believe that the 5mm Cyberstar NaI provides a reasonable means for comparison. Data were collected as follows:

- The count rates measured by the two detectors were compared at x-ray tube voltages of 10kV, 20kV, 30kV, 40kV, and 50kV.
- At each voltage, count rates of approximately 10K, 50K, 100K, 150K, and 200K were established with the Cyberstar NaI and recorded to ~200 count accuracy.
- The Cyberstar NaI was moved out of the beam and the calibrated PIN diode was moved into the beam. Count rates were measured by the following methods:
    - Joerger scaler measurement of counts with and without beam, to account for electronic noise
    - Voltmeter measurement on the SR570 output to confirm that the observed relationship between Joerger scaler displayed count rate and voltage held true.

The observed voltage was converted to a current in pA, then to photons/s as per the following example:

SR570 setting: 20 pA/V
(Measured voltage) – (Dark current voltage) = .185 V

20pA/V x .185V = 3.7pA
For this example, we multiply 3.7pA x 2890 photons/s/pA (responsivity for 8keV photons) = 10693 photons/s
For this datapoint, the Cyberstar NaI had measured ~10500 counts.

Reasonable agreement was observed for all datapoints, with the calibrated PIN diode generally registering slightly higher counts than the Cyberstar NaI. For more information, or to view the dataset in its entirety, please contact Detector Pool personnel.

References:

<u>General</u>

Oxford Danfysik – Synchrotron Components Catalogue 2004, "CBY Cyberstar Scintillation Counter X2000" (Datasheet)

R. L. Owen, J. M. Holton, C. Schulze-Briese and E. F. Garman, ***Determination of X-ray flux using silicon pin diodes,*** *J. Synchrotron Rad.* (2009). **16**, 143-151 (URL: http://scripts.iucr.org/cgi-bin/paper?xh0002)

PTB Calibration
H. Rabus, V. Persch, and G. Ulm, ***Synchrotron-Radiation Operated Cryogenic Electrical-Substitution Radiometer as High- Accuracy Primary Detector Standard In the Ultraviolet, Vacuum Ultraviolet and Soft X-ray Spectral Ranges***, Appi. Opt. 36, 5421-5440 (1997)

A. Gottwald, U. Kroth, M. Krumrey, M. Richter, F. Schoize and G. Ulm, ***The PTB high-accuracy spectral responsivity scale in the VUV and X-ray range,*** Metrologia 43, S125 — S129 (2006)

M. Krumrey, L. Büermann, M. Hoffmann, P. Muller, F. Schoize and G. Ulm, ***Absolute responsivity of silicon photodiodes in the X-ray range***, AIP Conf. Proc. 705, 861 - 865 (2004)