# Introduction

To begin with, we have chosen this topic due to the fact that silicon radiation detectors are one of the main type of particle detectors used in the radiation detection industry nowadays. Hence, it is crucial for an engineer in this field to know the history of silicon production as well as the development process and concrete examples of the different types of detectors.

# History of silicon radiation detectors

According to *Rehak (2003),* silicon is the main material which is used in electronics and radiation detection industries. Moreover, there was a rapid development in the field of silicon radiation detectors in the last decade, which could be noted as a considerable progress after 1982, when planar technology was invented. [1.] Furthermore, according to *Orava et al (2007),* even today new development activity is initiated with introduction of 3D detector technologies, active edge silicon processing and other perspective inventions in the field. [3.] It has to be said that there is always interaction between electronics industry and silicon radiation detectors because they both use silicon as the main component. The main point is that silicon used for radiation detectors should have 3-4 times more resistivity and lower density of traps than the one used for electronics. [1.]

Interestingly, almost all radiation detectors before 1982 were lithium-drifted (Figure 1). Lithium doping was used in order to increase the thickness of the detector and thus to decrease the capacitance and apply reasonable voltages which would lead to lower noise levels.

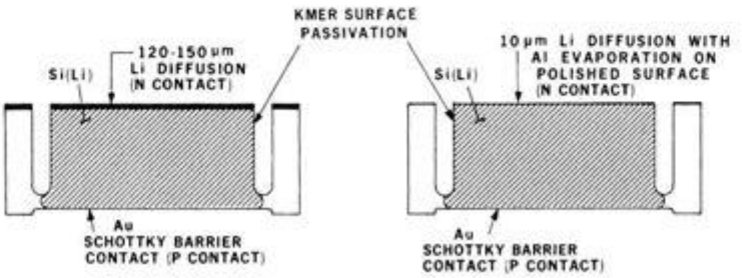



Figure 1. Lithium drifted silicon detector. Reprinted from Rehak (2003) [1,2494].

However, the main disadvantage was the instability of the surfaces along the field of the detector and working temperature of about 77K. Obviously, silicon radiation detectors which could be used at room temperature were drastically needed. [1.]

Planar technology was introduced in 1982, which led to the rapid progress in development of the silicon detectors. Among others, strip detectors were invented and matched to meet the requirements of the Large Hadron Collider (LHC) developed at The European Organization for Nuclear Research (CERN). Main advantages were lower noise, smaller capacitance, room working temperature, easier production, reduced cooling requirements and larger area coverage. [1;3]

## Strip silicon radiation detectors

Strip silicon detectors consist of n type material while having p type aluminium strips on the surface which are separated by a thin insulator. At the same time there is an electric field between the p strips and the n type material. When a radiation particle passes the detector, silicon atoms are ionized and free electrons leave these atoms with an electron vacancy (holes). After they reach the p type strip they are collected and then create a charge on the aluminium strip which is possible to be measured with special electronics.

*Orava et al (2007)* proposes a new type of the strip silicon detector (Figure 2) which implements cross-connected short strips interlaced by long strips. The main advantage is that better measuring resolution is achieved, which requires much less accuracy [3].

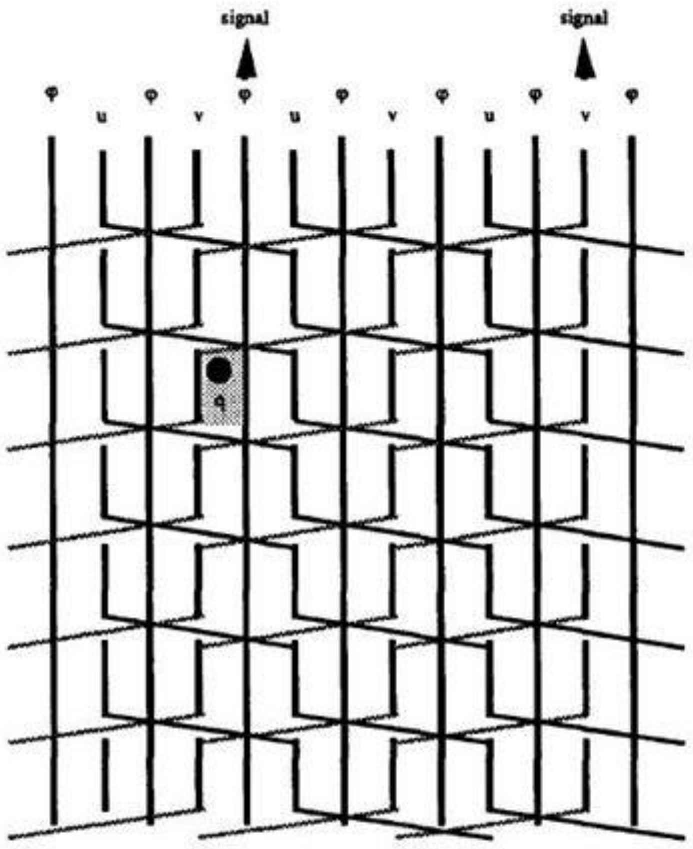



Figure 2. Layout of the single sided stereo angle silicon strip detector. Reprinted from Orava et al (2007) [3,227].

Furthermore, detector is designed in a way that every second strip is long while short strips are crossing them which helps to register particles at better angles to the surface of the sensor. Consequently, the high efficiency and proper special resolution are achieved. [3].

## Materials and manufacturing technologies

Strip silicon detectors consist of n type material while having p type aluminium strips (which are used to collect the charge) on the surface which are separated by a thin insulator.The crystalline structure is diamond cubic (FCC). Polysilicon consists of small Si crystals randomly oriented.

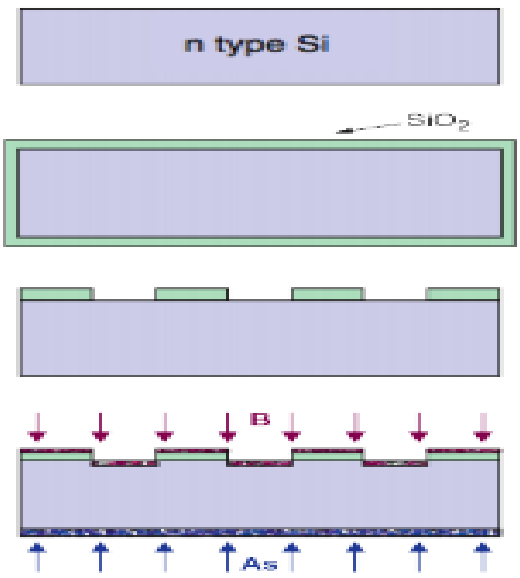
There are two types of material used for package of detector: ceramic or polymer. Some materials are more favorable than others due smaller capacitance, lower noise, room working temperature, easier production, reduced cooling requirements and larger area coverage.

Typical manufacturing process steps (Figure 13):

1. Starting Point: single-crystal n-doped wafer. Wafer is a very thin slice of silicon crystal which is used to produce the actual detectors.
2. Surface passivation by SiO2-layer. E.g. growing by (dry) thermal oxidation at 1030 °C.
3. Window opening using photolithography technique with etching, e.g. for strips
4. Doping using either

   - Thermal diffusion (produce a thin layer of oxide on the surface of a wafer)
   - Ion implantation (introduction of dopants in a semiconductor by accelerating ions)

5. After ion implantation: Curing of damage via thermal annealing at approx. 600°C, (activation of dopant atoms by incorporation into silicon lattice)
6. Metallization of front side: sputtering or CVD (chemical vapor deposition) to produce thin film
7. Removing of excess metal by photolithography: etching of non-covered areas
8. Full-area metallization of backplane with annealing at approx. 450°C for better adherence between metal and silicon
9. Wafer dicing (cutting) [12].



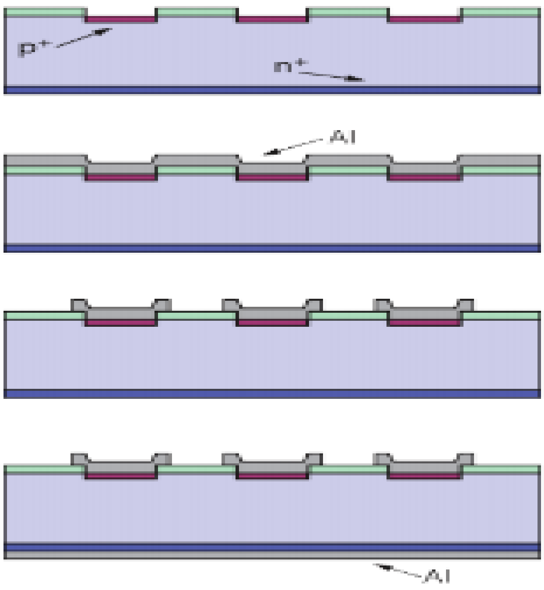



Figure 13. Manufacturing process steps. Reprinted from : http://indico.cern.ch/event/124392/contribution/0/material/slides/0.pdf [12].

## Silicon radiation detectors characteristics

As an example, we have considered datasheets of 2 sensors. Those are DT Standard Photodiode Products [7] and First Sensor PIN PD [8].

Radiation detectors are usually very high sensitive, though the exact value is not defined. It can be improved by depressing noise signals which appear from e.g. light. Manufacturing material's quality is very important in sensitivity rise.

Although It is impossible to set the exact mathematical equation to introduce the transfer function of the sensors (nor do the datasheets give any transfer functions), it can be defined after measuring and analyzing spectrum.The maximum efficiency for both sensors is achieved at 10 keV energy level (Figure 3, Figure4).

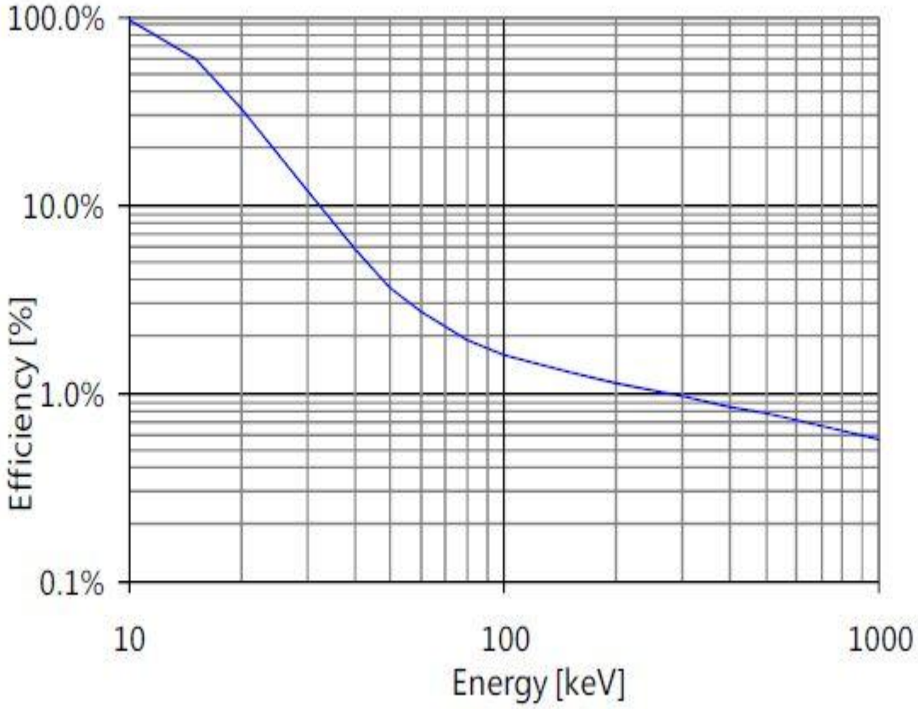



Figure 3. X-ray Efficiency vs. Energy in XRB series Diodes. Reprinted from http://www.deetee.com [7].

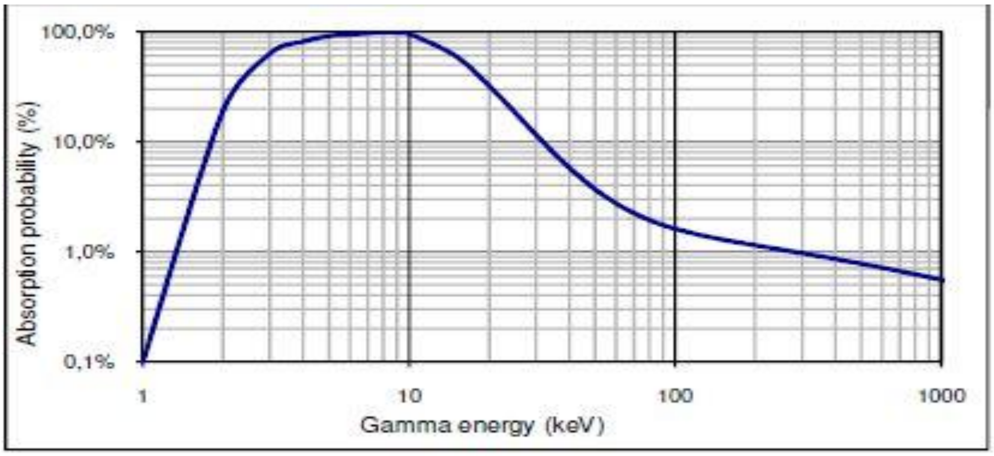



Figure 4. Absorption of gamma radiation. Reprinted from http://www.marubun.co.jp [8].

To evaluate radiation sensor it is important to consider its major characteristics:

1. Active area
2. Dark current
3. Capacitance
4. Shunt resistance

To understand those characteristics, there is a short explanation for each. Active area is a part of a sensor which contains the transistors, resistors and capacitors, and perform the actual detection and storage operations. Dark current is a small current which flows through the sensor because of the random generation of the disordered location of electrons and holes in the depletion region. Capacitance is an electrical characteristics which appears by applying an electrical charge to two conductive objects with a time period between them. Shunt resistance is a low-resistance connection between two points that forms an alternative path for a portion of the current.

Moreover, it is necessary to notice the operation characteristics to avoid the breakage of the sensor. Operating voltage and temperature, as well as storage temperature are crucial (Figure 5, Figure 6).

**Characteristics**

| Type | Active Area | | Abs. Eff. | Depletion | | Shunt Resistance | | Dark Current | | |
|---|---|---|---|---|---|---|---|---|---|---|
| series, size, shape, package (see below) | dimensions<br>mm | area<br>mm² | 20 keV x-rays<br>% | maximum thickness<br>µm | voltage<br>V | typical $V_R$=10mV<br>MΩ | minimum $V_R$=10mV<br>MΩ | typical $V_R$=70V or 125V<br>nA | maximum $V_R$=70V or 125V<br>nA | t V f= |
| XRB 100s-CB380 | 10.0 x 10.0 | 100 | 32 | 380 | 70 | 8.4 (g) | 6 | 5.5 (g)[1)] | 10.0 (g)[1)] | |

Figure 5. XRB 100s-CB380 characteristics. Reprinted from http://www.deetee.com [7].

| Symbol | Characteristic | Test Condition | Min | Typ | M |
|---|---|---|---|---|---|
| | Active area | | | 10 x 10 | |
| | Active area | | | 100 | |
| | Energy range of detectable radiation | Gamma radiation | 5 | | 1( |
| $I_D$ | Dark current | $V_R$ = 12 V | | 5 | |
| $T_K(I_D)$ | Temperature coefficient | $V_R$ = 12 V; change of dark current | | 13 | |
| C | Capacitance | $V_R$ = 0 V; f = 10 kHz | | 500 | |
| | | $V_R$ = 12 V; f = 10 kHz | | 80 | |
| $t_R$ | Rise time | $V_R$ = 12 V; E = 10 keV; $R_L$ = 50 Ω | | | 5 |
| | Shunt Resistance | $V_R$ = 10 mV | | 40 | |
| | Noise current | $V_R$ = 12 V | | 6.1 E-14 | |
| $V_{BR}$ | Breakdown voltage | $I_R$ = 2 µA | 50 | 80 | |

Figure 6.First Sensor PIN PD characteristics. Reprinted from http://www.marubun.co.jp [8].

## Interface electronic circuits

As almost all other sensors, radiation detectors need to be interfaced before being able to process the data. An interface or a signal conditioning circuit has a specific purpose: to bring the signal from the sensor up to the format which is compatible with the load device [10]. Cremat Inc. radiation detection electronics can be used with a wide range of detectors, including compound semiconductor radiation detectors, scintillator-photodiode detectors, avalanche photodiodes etc [9].

Typical interface electronic circuit using Cremat amplifiers is presented in Figure 7.

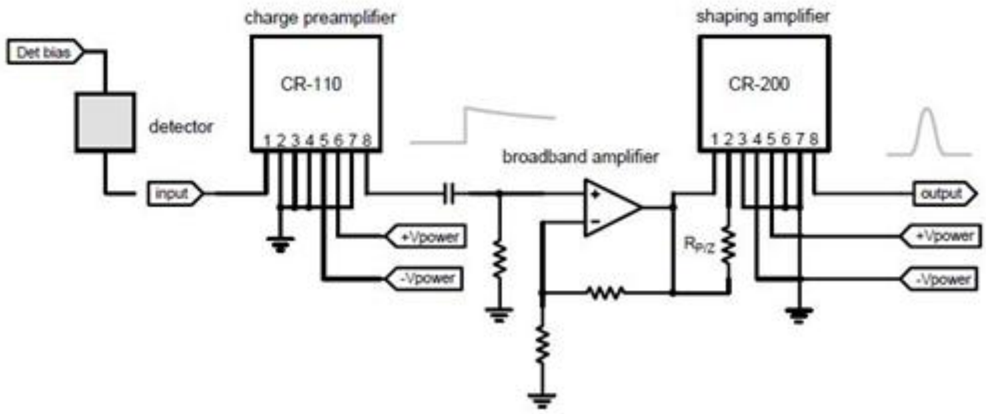



Figure 7.General shematic. Copied from http://www.cremat.com [9].

The Cremat's CR-110 is a single channel charge sensitive preamplifier module intended for use with various types of radiation detectors including semiconductor detectors. Bias voltage can be used if required. Radiation is detected as a series of pulses, resulting in fast bursts of current (from 1ns to few µs) flowing into preamplifier input. After the series of amplifiers it flows into the Cremat's CR-200 Gaussian shaping amplifier. The CR-200 is a single channel shaping amplifier, which is processing the signals from charge sensitive preamplifiers. It accepts a step-like input pulse and produces an output pulse shaped like a Gaussian function (Figure 8). [9.]

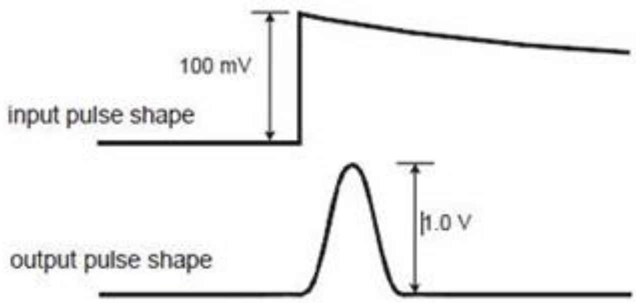


Figure 8. CR-200 input and output pulse shapes. Copied from http://www.cremat.com [9].

The main aim of this is to filter the noise from the signal and to provide a quickly restored baseline. The CR-200 shaping amplifiers have low output impedance (<5 Ohms) and can source/sink 10 mA of output current. CR-110 output impedance is 50 Ohms.[9.]

The whole circuit is presented as commercially available PCBs: CR-150 evaluation board and CR-160 Gaussian shaping amplifier evaluation board  (Figure 9, Figure 10).

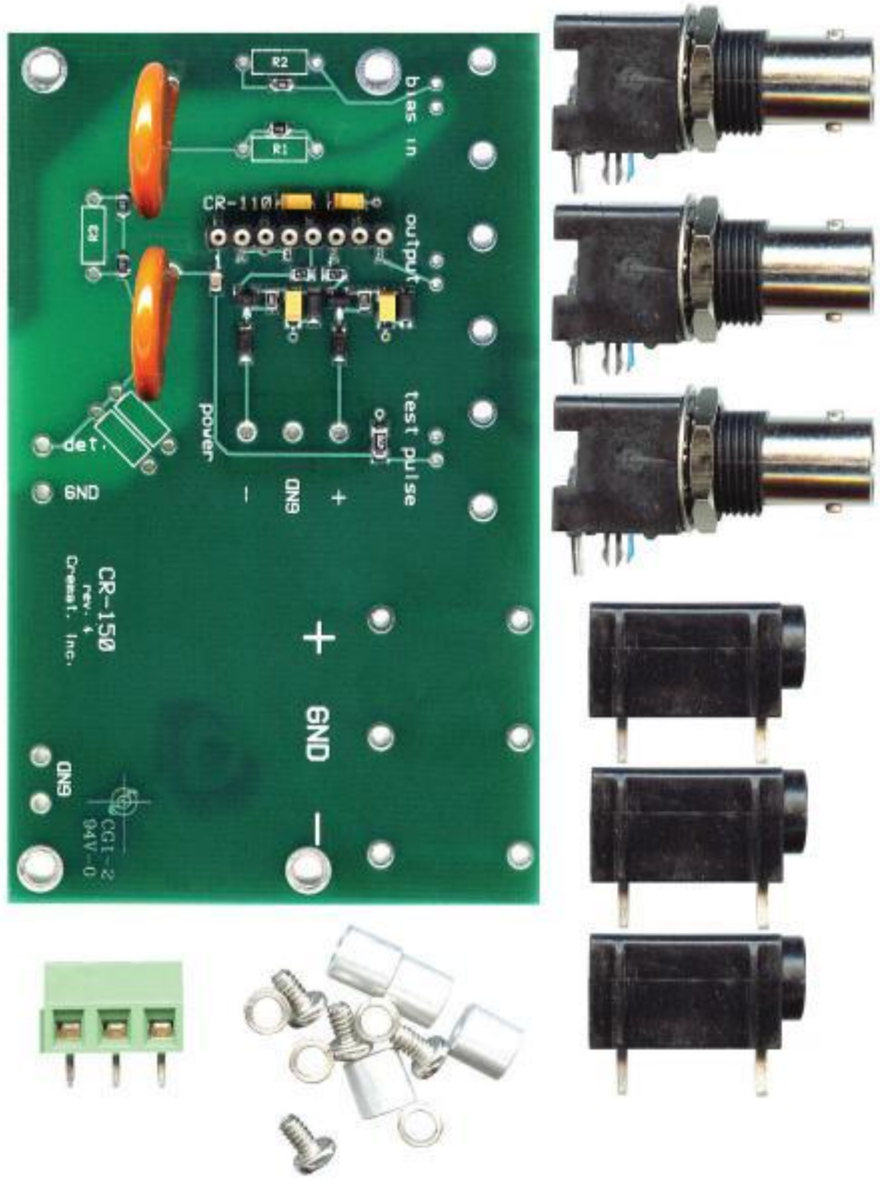



Figure 9. CR-150 evaluation board. Copied from http://www.cremat.com [9].

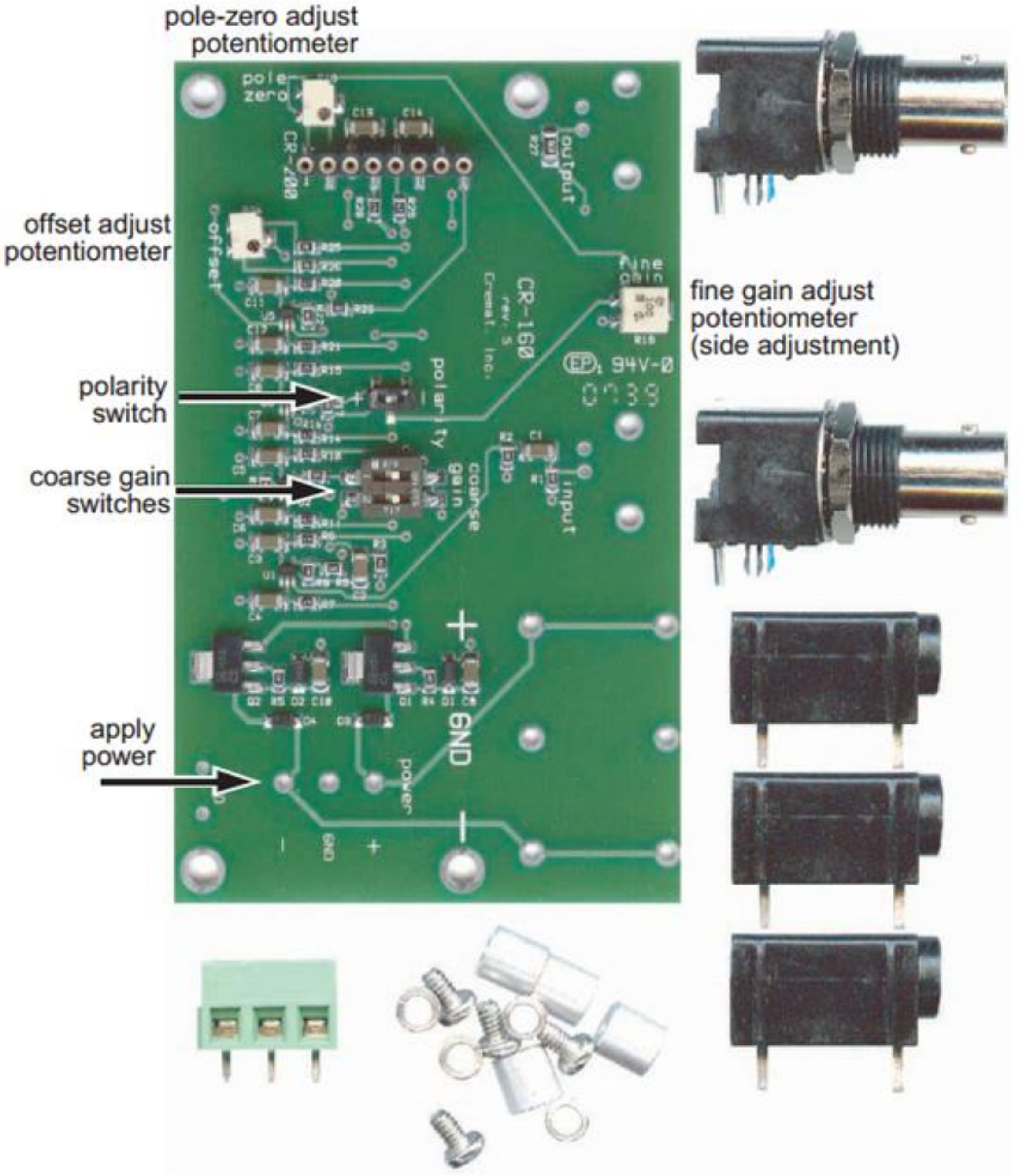



Figure 10. CR-160 Gaussian shaping amplifier evaluation board. Copied from http://www.cremat.com [9].

The CR-160 includes an adjustable low-noise wide-band amplifier having gains adjustable from 0 to 100. Combined with the CR-200-X gain of 10, this allows an overall gain of 0 to 1000. Furthermore, an inverted-polarity signal is available, as well as adjustments for pole-zero correction and DC offset.[9.] In order to calibrate the sensor there is a number of potentiometers: Fine Gain to adjust the gain from 0 to 100; Pole-Zero to adjust the baseline of the output; Offset Adjustment; Signal Polarity;

The whole system has analog nature without any conversion to digital format. A/D conversion is typically happening in PC or various embedded systems. For instance, pulse height analyzer (PHA) is an instrument used in nuclear and elementary particle physics research which accepts electronic pulses of varying heights from particle and event detectors, digitizes the pulse heights, and saves the number of pulses of each height in registers or channels for later spectral analysis.

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