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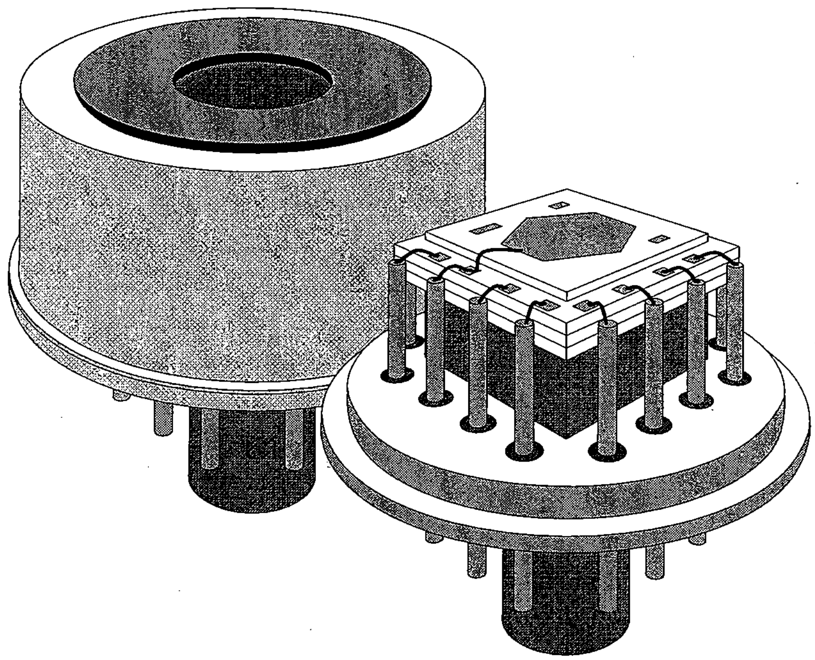
Silicon Drift Detector with On-Chip Electronics for X-Ray Spectroscopy



- high energy resolution ⇒ FWHM < 175 eV @ 5.9 keV
- high speed of operation ⇒ input count rate > 10^5 cps
- integrated FET ⇒ low noise, no pickup, no microphony
- cooled by Peltier element ⇒ no liquid nitrogen
- hermetic TO8 package ⇒ portable, compact setup
- power supply & amplifier board ⇒ easy operation

Concept of the Silicon Drift Detector

The basic form of the Silicon Drift Detector (SDD) was proposed in 1983 by Gatti and Rehak [1]. It consists of a volume of fully depleted silicon in which an electric field with a strong component parallel to the surface drives signal electrons towards a small sized collecting anode. In an advanced layout for spectroscopic applications the electric field is generated by a number of increasingly reverse biased field strips covering only one surface of the device (fig. 1) [2]. The radiation entrance side is the non-structured p+-junction on the back side, giving a homogeneous sensitivity over the whole detector area.

The outstanding property of this type of detector is the extremely small value of the anode capacitance, which is practically independent of the active area. This feature allows to gain higher energy resolution at shorter shaping times compared to conventional photodiodes and Si(Li) detectors, recommending the SDD for high count rate applications.

To take the full advantage of the small output capacitance the front-end transistor of the amplifying electronics is integrated on the detector chip and connected to the anode by a short metal strip [3]. This way the stray capacitance of the connection detector - amplifier is minimized, and moreover noise by electrical pickup and microphonic effects are avoided. The collecting anode is discharged from signal electrons in a continuous mode. Thus the SDD can be operated with dc voltages only, and there is no detector dead time caused by a clocked reset mechanism.

Due to the elaborated process technology used in the SDD fabrication the leakage current level is so low that the drift detector can be operated with good energy resolution at room temperature, too (FWHM < 300 eV @ 5.9 keV). With moderate cooling by a single stage Peltier element the SDD's energy resolution (FWHM < 175 eV @ 5.9 keV) can already be compared to that of a Si(Li) or Ge detector requiring expensive and inconvenient liquid nitrogen cooling.

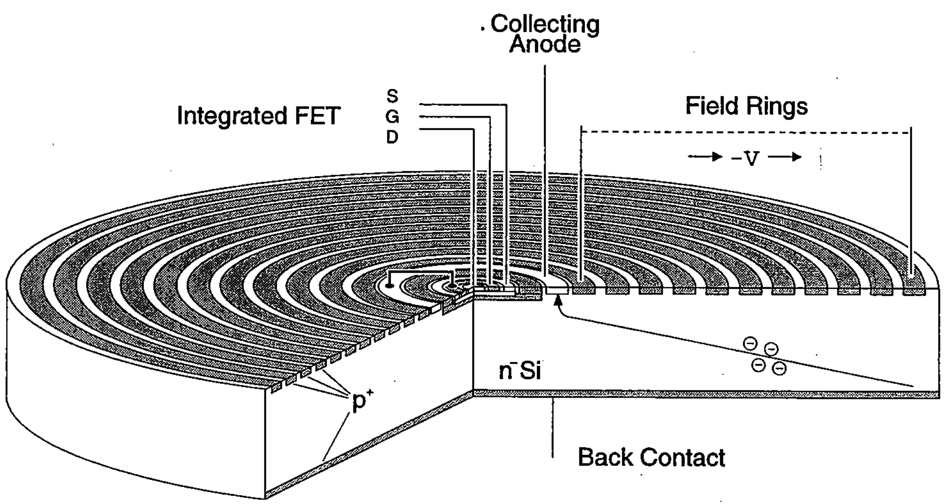


Fig 1. Schematic view of a cylindrical Silicon Drift Detector.

Performance & Characteristics

The active area of the SDD is 5 mm^2. As the device is fully depleted the total thickness of 300 µm is sensitive to the absorption of X-rays. This feature translates to a detection efficiency > 90% at 10 keV and > 50% at 20 keV while at the low energy end the detection efficiency is limited by the transmission of the Be entrance window (see below).

The spectrum of a ^{55}Fe source recorded with a SDD at Peltier temperature (appr. -10°C) with Gaussian shaping of 0.5 µsec shows an energy resolution in terms of FWHM of the Mn-Kα line at 5.9 keV typically better than 175 eV. Selected chips have a FWHM < 160 eV, as shown in Fig. 2. The peak-to-background ratio is typically 700, with a special collimator it is > 3000.

Due to its extremely small overall capacitance the SDD can be operated with very short shaping times and consequently at extremely high count rates. Fig. 3 shows the measured FWHM at 5.9 keV as function of the input count rate. Spectroscopic measurements are possible up to count rates close to 10^6 cps!

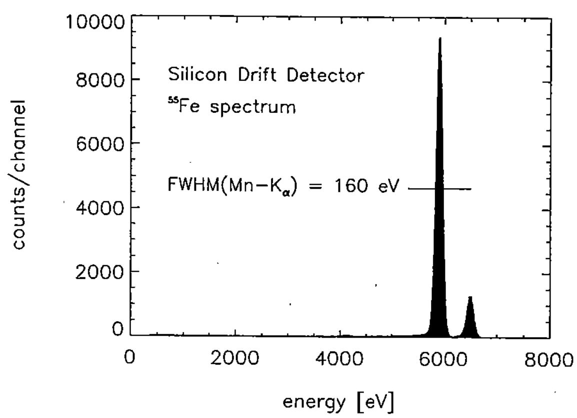


Fig 2. ^{55}**Fe spectrum recorded by a SDD with Peltier cooling (-10°C).**

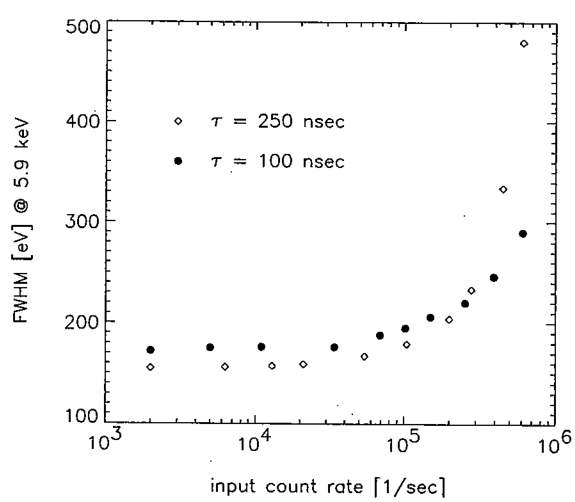


Fig 3. Energy resolution of the SDD at different input count rates.

Package

The detector chip and the Peltier cooler are enclosed in a standard TO8 package with a diameter of 15 mm and a height of 16 mm (see title page). The housing is hermetic sealed in nitrogen atmosphere, a leak test with specification MIL 883C meth. 1014 is performed.

The X-ray window being an 8 µm DuraBe foil mounted on a Zr collimator is implemented in the TO8 cap. The transmission curve of the DuraBe window is shown in fig. 4 . The Zr collimator has a circular opening of 4.5 mm^2 and reduces the probability of split events at the edges of the sensitive area. By the choice of the material undesired fluorescent lines are avoided. For special applications in clean (vacuum, dry air) and dark environment a windowless detector module can be supplied, too.

To dissipate the heat of the Peltier cooler's hot side a pin with a standard M4 thread is soldered to the TO8 bottom part. The dimensions of the package are shown in fig. 5.

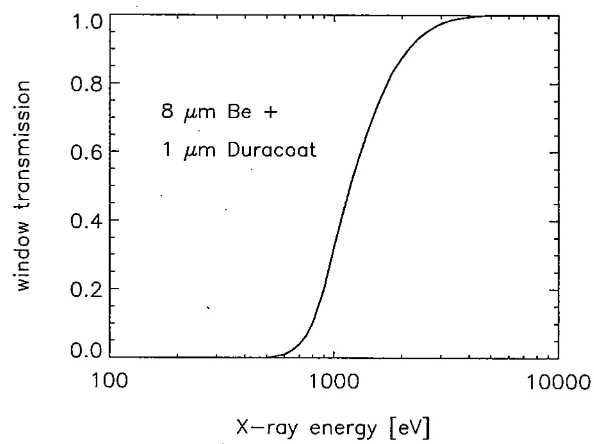


Fig 4. Transmission of the 8 µm DuraBe foil [3].

Cooling

The temperature of the detector chip is controlled by a single-stage Peltier element. At usual working conditions the chip is cooled by $\Delta T \approx 35\,K$ relative to the hot side of the Peltier element. The final temperature of the chip is reached within seconds after the cooler power has been applied. The hot side of the Peltier element is mounted on a copper pin which should be connected to an external heat sink via a M4 thread by the user. The dimensions can be seen in fig. 5. A second Peltier stage to cool down the first Peltier's hot side can be easily implemented externally.

The temperature of the detector chip and the correct setting of the Peltier power may be constantly monitored by a temperature diode integrated on the detector chip. The voltage drop across the diode can be measured on the electronics board. Its differential temperature dependence is given by the relation:

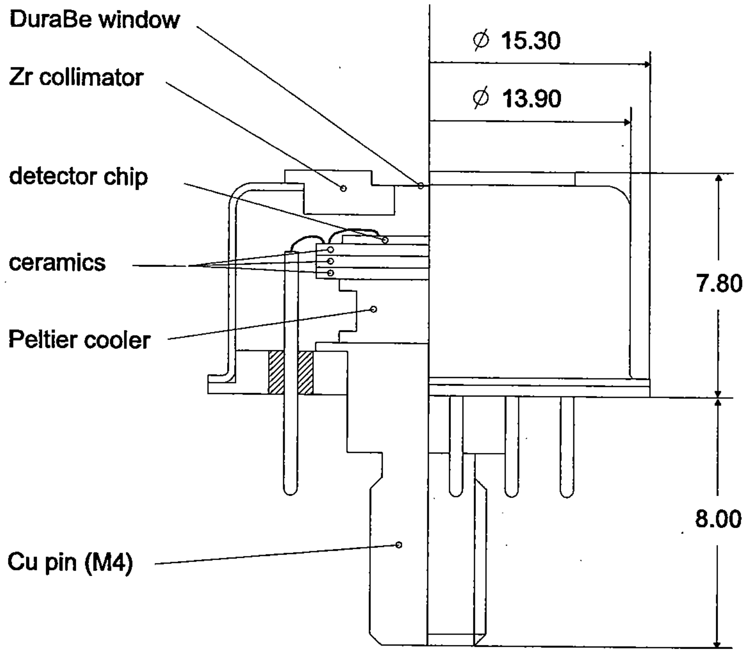


Fig. 5.
Dimensions of the TO8 detector package.

$$dV/dT = 10\cdot(-3\ mV/K).$$

The term in brackets is an intrinsic property of silicon diodes biased in forward direction, the factor 10 is an amplification of the voltage drop by the electronics board.

Signal Output Line

In the SDD the first stage of amplification is realised by the integrated FET. The output signals from the on-chip FET are fed into a charge sensitive amplifier (AMPTEK A250). The sensitivity of the A250 is roughly 0.015 mV per signal electron. The A250 is equipped with a line driving unit so that 50 ? coaxial cables of lengths of several meters can be used. The output is connected via a LEMOSA coaxial connector.

The signals from the A250 can directly be fed into a standard spectroscopy amplifier with Gaussian characteristic and filter time constants in the range 100 nsec ... 2 µsec (e.g. ORTEC 450, Silena 7614). The signal output line is shown in the block diagram of fig. 6.

The choice of the filter time constant depends on the kind of measurement. For optimum energy resolution at Peltier temperature (appr. -10°C) the shaping time should be 0.5 µsec ... 1 µsec. For spectroscopy or counting applications at extremely high rates (> 10^5 cps) the shaping time should be as short as 100 nsec to avoid signal pileup (see fig. 3).

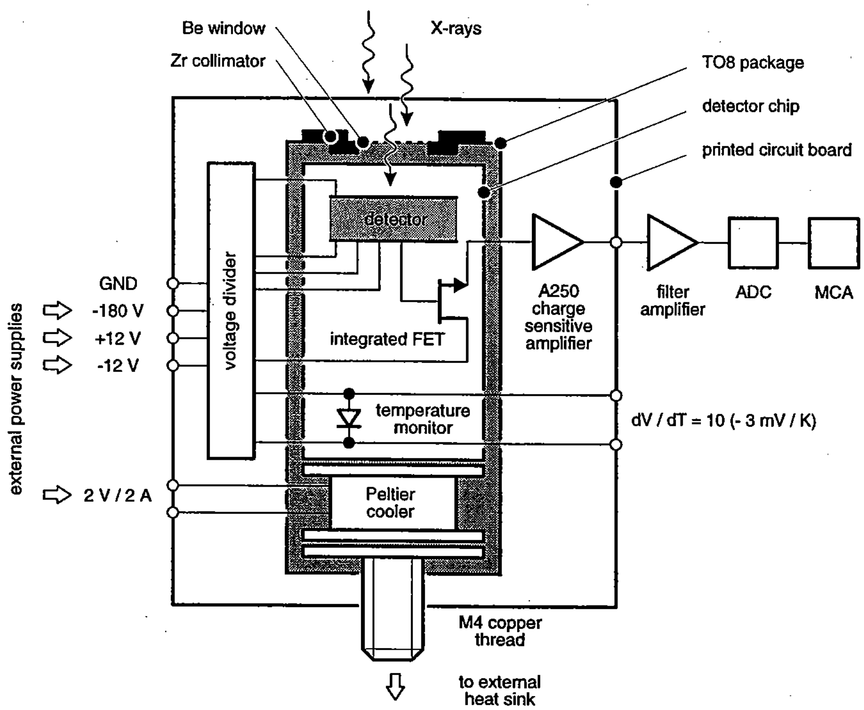


Fig 6. Block diagram of the SDD module and related electronics.

Supply Voltages

All voltages and currents needed for the operation of the detector, the temperature monitor, and the A250 are derived from the external dc supply voltages ±12 V and -180 V by a voltage divider (fig. 6). The ±12 V are provided through a 9 pin SUB-D connector (pin 4: +12 V, pin 9: -12 V) and can be directly taken from the PREAMP POWER connector of most spectroscopy amplifiers (e.g. ORTEC 450, Silena 7614). The -180 V and GND are provided through standard pin connectors. All detector voltages are adjusted for optimum operation by KETEK.

The Peltier cooler is powered separately by a 3 V/1 A supply, also connected through standard pins. The correct Peltier current is defined by KETEK and must be adjusted by the user.

Power Supply & Amplifier Board

The TO8 detector module, the voltage divider, the charge sensitive amplifier, and all connectors are mounted on a printed circuit board (PCB) with the physical dimensions 100 mm x 53 mm. In case of space constraints it may be useful to have the detector and the related electronics separated. For this reason the PCB can be cut in an 'elctronics board' (75 mm x 53 mm) and a 'detector board' (25 mm x 33 mm) connected by a flexible multi-wire cable (fig. 7). The maximum allowed cable length depends very much on the environment and shielding and must be adjusted individually for each application. The electronics board and the connection to the detector board must be shielded. For special requirements the electronics board can be adapted by KETEK according to the needs of the experiment.

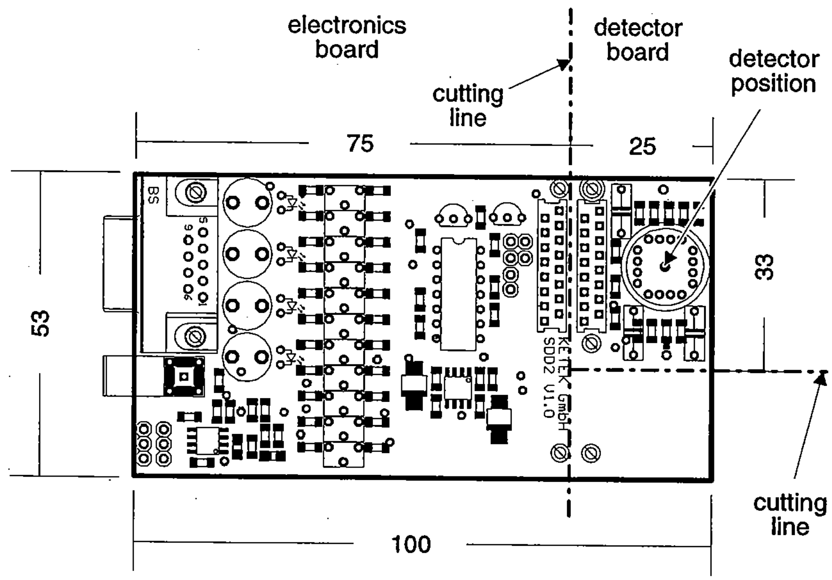


Fig 7. Dimensions of the power supply & amplifier board.

References

[1] E. Gatti, P. Rehak, *Semiconductor drift chamber - an application of a novel charge transport scheme*, Nucl. Instr. and Meth. 225 (1984) 608-614

[2] J. Kemmer, G. Lutz, *New detector concepts*, Nucl. Instr. and Meth. A 253 (1987) 365-377

[3] P. Lechner et al., *Silicon drift detectors for high resolution room temperature X-ray spectroscopy*, Nucl. Instr. and Meth. A 377 (1996) 346-351

[4] product information by MOXTEK Inc. (1993)

Technical Questions

are welcome to:

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Silicon Drift Detector

Power Supply & Amplifier Board

- Specifications -

Detector	Type	Silicon Drift Detectorwith on-chip FET
	sensitive area	5 mm^2 (chip) 4.5 mm^2 (collimator)
	sensitive thickness	300 µm
	energy resolution [FWHM @ 5.9 keV, -10°C , 1 kcps]	175 eV (typical) < 160 eV (selected)
	[FWHM @ 5.9 keV, 20°C , 1 kcps]	300 eV (typical) < 250 eV (selected)
	peak-to-background @ 5.9 keV	600 (standard) > 3000 (special collimation)

Package	Type	TO8
	Diameter	15.3 mm
	Height	16 mm
	entrance window	DuraBeryllium 8 µm
	Option	Windowless

power supply & amplifier board	size (total)	100 x 53 mm^2
	size (electronics board, optional)	75 x 53 mm^2
	size (detector board, optional)	25 x 33 mm^2

supply voltages	detector & amplifier supply	±12 V / 40 mA (9 pin SUB-D) -180 V / 10 mA (standard pin) GND (standard pin)
	Peltier power	3 V / 1 A (standard pins)

outputs	charge sensitive amplifier (A250)	0.015 mV/electron (LEMOSA coaxial connector)
	temperature monitor	10·(-3 mV/K) (standard pins)

operating conditions	Temperature	-100°C < T < 80°C
	Pressure	0 < p < 1.7 atm

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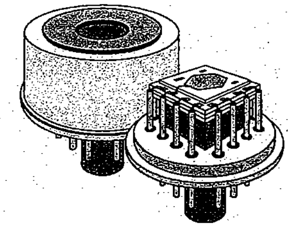
5 and 10 mm^2 Silicon Drift Detector *

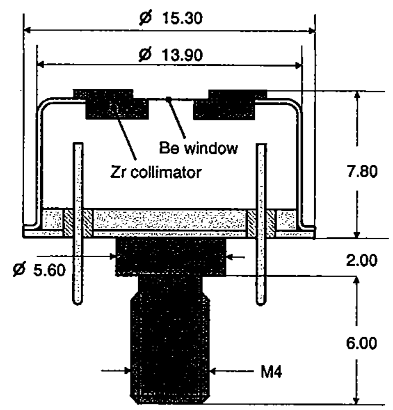
Packaged in TO8 housing with Peltier Cooler and Temperature Monitor



* *protected by international patents*

The silicon drift detector (SDD) produced by KETEK GmbH is a state of the art high resolution room temperature detector. The overall capacitance associated to the detector anode is minimized by the particular geometry of the device and by the integration of the first stage of the front end electronics, a FET working in source follower configuration. Microphonisms are avoided that way and the overall electronic noise is kept to a negligible value.
Our SDD is available with 5 or 10 mm^2 active area. Both versions are packaged in a standard 16 PIN TO8 housing, with integrated thermocooler and temperature monitor. The SDD shows an excellent energy resolution already at temperatures of the order of -10°C.
The extremely short shaping time makes the SDD the optimum solution for high throughput application. Count rates up to 10^6 cps have been measured.

Device characteristics	
Active chip area:	5 mm^2 or 10 mm^2
Sensitive detector thickness:	300 μm, completely depleted
Detector housing:	TO8
TO8 Entrance window:	8 μm DuraBeryllium *(standard)*
TO8 Collimator:	Zr, ∅ 2.4 mm *(std., for 5 mm^2 SDD)* Zr, ∅ 3.4 mm *(std., for 10 mm^2 SDD)*
Cooling system:	Peltier element
Input power:	<1.5 W
Temperature monitor:	pn-junction integrated on detector chip
Typical Chip temperature:	-10°C down to -20°C for an ambient temperature of 20°C
Typical Shaping Time:	0.5 μs
Count-rate capability:	up to 10^6 cps



Dimensions: mm

Selection Chart

Type	Energy Resolution[a]	Peak to Background[b]	Reccommended energy range	Size	Price EURO	Size	Price EURO
SDD-170400	175 eV (typ.)	400 (typ.)	1 keV – 30 keV	**5 mm^2**	2.800 €	**10 mm^2**	3.850 €
SDD-150500[c]	150-160 eV (guar.)	400-600 (guar.)	1 keV – 30 keV	**5 mm^2**	3.850 €	**10 mm^2**	5.000 €
SDD-140500[c]	140-149 eV (guar.)	400-600 (guar.)	1 keV – 30 keV	**5 mm^2**	4.350 €	**10 mm^2**	5.750 €

(typ.), i.e. typical performance values
(guar.), i.e. values guaranteed

[a] *Energy resolution* is measured in terms of Full Width at Half Maximum (FWHM) of the Mn Kα line, at -10°C, 1-10kcps, optimum shaping time (typ. 0.5 μs).

[b] *Peak to background ratio* is the relation of the peak value of the spectrum of Mn Kα (5.895 keV) and the mean floor value between 800 eV and 1200 eV, measured at -10°C, 1-10kcps, optimum shaping time (typ. 0.5 μs).

[c] *Radiation hardness* of the silicon drift detector is continuously controlled. Up to a total dose of 10^{12} absorbed photons on the SDD active area typical variation of the energy resolution in terms of FWHM are less than 2% and P/B ratio variation are less than 10%. For the detector type SDD-150500 and SDD-140500 these values are guaranteed.

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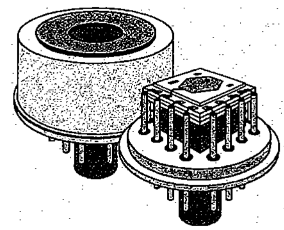
Printed Circuit Board for SDD2/5

(ver. 2000-04)



Provides all voltages needed for the detector operation Includes A250 preamplifier with 50 Ω cable driver.

For a proper operation of the SDD, Peltier element, temp. monitor, up to 11 different voltages and constant current sources are needed. For test purposes of our SDD we provide a simple Printed Circuit Board (PCB), including a voltage divider for the detector biasing and a voltage preamplifier (A250) with 50 Ω cable driver.

PCB characteristics and price	
PCB input bias:	3 voltage sources: +12 V -12 V -180 V 1 current source: 1A (max), 5V
Output:	Preamplified signal (50 Ω), LEMO
Features:	• Detector bias • Temp. monitor bias • Peltier element bias • Detector signal preamplification
Price:	1.550,00 EURO