DEUTSCHES ELEKTRONEN-SYNCHROTRON DESY

DESY 84-063
July 1984

A COMPACT AND INEXPENSIVE RADIATION MONITORING DEVICE

by

H. Moser, H. Grassman, H. Wegener
Physikalisches Institut der Universität Erlangen-Nürnberg, Erlangen, FRG

V. Fonseca, E. Lorenz
Max-Planck-Institut für Physik und Astrophysik, München, FRG

A. Scheer
Physikalisches Institut der Universität Würzburg, FRG

ISSN 0418-9833

NOTKESTRASSE 85 · 2 HAMBURG 52

DESY 84-063
July 1984

ISSN 0418-9833

A COMPACT AND INEXPENSIVE RADIATION MONITORING DEVICE

H. Moser[1], H. Grassman[1], V. Fonseca [2,4], E. Lorenz [2], A. Scheer [3],
H. Wegener[1]

ABSTRACT

A simple radiation monitoring device consisting of a small CsI(Tl) crystal coupled to a large area silicon photodiode will be described. For maximum stability the photodiode is operated as a photoelement and connected to a current amplifier with picoampere sensitivity. The device is very compact and insensitive to magnetic fields. With careful construction the device can be made sensitive down to 0.2 μRad/s.

*Work supported in part by the Bundesministerium für Wissenschaft und Forschung.

---

1) Physikalisches Institut der Universität Erlangen-Nürnberg, Erlangen, FRG.

2) Max-Planck-Institut für Physik und Astrophysik, München, FRG.

3) Physikalisches Institut der Universität Würzburg, FRG.

4) Permanent address: Facultad de Ciencias Fisicas Universidad Complutense Madrid-3.

INTRODUCTION

In a recent high energy physics experiment at the DESY storage ring DORIS, it was necessary to monitor the instantaneous radiation levels during various phases of the storage ring operation. Also it was necessary to make measurements in very confined areas adjacent to strong magnets. A simple device has been constructed, consisting of a small scintillator coupled to a large area silicon photodiode, to fulfill these requirements.

DESCRIPTION OF THE DEVICE

The device consists basically of

- i) a high Z scintillator
- ii) a large area photodiode
- iii) a FET operational amplifier
- iv) a voltage measuring device (DVM, recorder...)

Fig. 1 shows the basic block diagram. A small scintillating crystal of CsI(Tl) with dimensions 2x2x(0.5-2) cm^3 is coupled to a 1 cm^2 area photodiode. In order to achieve high stability, the photodiode is operated as a photoelement. The photocurrent for low radiation levels is expected to be very weak, therefore the signal has to be amplified by a low drift operational amplifier. The amplifier is operated as a picoammeter. The output of the amplifier is connected to a digital voltmeter or a recording device. The entire unit can be mounted inside a small shielded box. Fig. 2 shows a layout of such a unit.

PREPARATION OF THE SCINTILLATOR

In an e^+e^- storage ring environment, the main radiation background is from γ's and electrons over a very wide energy spectrum. This wide energy range extending from the keV to the GeV energy makes exact monitoring nearly impossible. Nevertheless a knowledge of relative radiation changes is very important. For reasons of good γ-absorption, a high Z-scintillator has to be used. Thallium activated CsI has been found to be particularly useful. CsI has a very high light yield of about 40,000 photons/MeV. The emission spectrum is very well matched to the spectral sensitivity of silicon photodiodes. Also the material is very rugged and only weakly hygroscopic. Unlike NaI, it is not necessary to encapsulate CsI. One can either obtain prepared crystals from various manufacturers or prepare one from bulk blocks. CsI(Tl) can be cut or milled easily to the appropriate size. The crystal is rather soft and a high quality polish is difficult, but for many applications in high energy physics this is unnecessary. In this case the crystal can be given a simple 'water' polish with a wet tissue. If necessary the surfaces can be protected against high humidity environments by a clear lacquer coating (Krylon spray paint). For enhancement of light collection the surfaces can be painted with white reflective paint or wrapped in white Teflon foil. Typical crystal sizes for a 1 cm^2 photodiode are 1x1x0.2 to 3x3x3 cm^3. For small crystals the sensitivity is proportional to the volume.

THE PHOTODIODE

A large area photodiode is used as a light sensitive element. Photodiodes have large dynamic ranges up to 10 orders of magnitude and survive excessive overloads without any damage. The Hamamatsu photodiodes S1337-BR1010, S1227-BR1010, S1723 or S1790 of 1 cm^2 area are all found to be useful. Although more expensive, the diode S 1790 is easier to couple to the crystal. In addition, its white case slightly increases the light collection due to back reflections. The diode can be coupled either with an air gap, grease or optical glue to the crystal. For prolonged use an air gap or optical glue coupling is advisable, the latter giving a substantially higher photoelectron yield.

THE AMPLIFIER

Depending on the radiation level, photocurrents in the 10^{-12} - 10^{-6} ampere range are expected (the diode is linear up to milliamps). For low level applications the picoampere signal has to be amplified. There exist a large variety of operational amplifiers for the construction of a simple picoamperemeter (for example the LF365N). For a sensitivity of less than 20 μRad/s a high quality amplifier with an FET input of very low drift and bias current has to be used such as the LH0052. The feedback resistors have to be selected for the appropriate operation range between 1 GΩ and a few MΩ. It is sometimes necessary to add a damping capacitor parallel to the feedback resistor to prevent oscillations. For dynamic compression a logarithmic feedback element might be used (1).

For the highest sensitivity a careful layout of the amplifier board and input connection is necessary to avoid leakage currents. It should be mentioned that CsI is a salt, and careless assembly can result in parasitic conductors at the amplifier input.

The monitor can be powered for short-term use by batteries. For continuous operation an external power supply is necessary.

THE DISPLAY

The output is a voltage proportional to the radiation level. A variety of display devices can be used such as voltmeters, plotters or ADC's coupled to rate meters and scalers giving both instantaneous rate and integrated flux.

CALIBRATION

As already mentioned, the device is not very precise. The device can be approximately calibrated with radioactive sources of known intensities (for example Zn, Cs^{137}, and Co^{60} whose intensities range from 100 μCi to 1 mCi). Angular effects due to the limited crystal size and due to the incomplete absorption for thin crystals have to be taken into account. A well designed monitor will have a conversion factor of about 20,000 photoelectrons per MeV deposited.

For a more precise determination of the conversion factor, the monitor can be operated as a nuclear counter after exchanging the amplifier against suitable electronics, i.e. a charge sensitive preamplifier, a shaping amplifier, and a pulse height recording system (2,3). This calibration method can only be used in connection with high quality PIN photodiodes.

DEFICIENCIES AND LIMITATIONS

The best commercially available operational amplifiers have an input offset current of 0.5 pA and equivalent drift, setting the lower limit of sensitivity to about 0.2 μRad/s for a 5 cm^3 crystal. For much lower radiation levels one can operate the crystal photodiode combination as a nuclear counter (2,3).

After prolonged operation in high radiation levels, degradations are expected. The crystal will be damaged. Firstly it is expected that the transmission will degrade. The effect will be more pronounced for long light paths inside the crystal. Therefore it is advisable to use small volume crystals for high radiation levels. Radiation damage can be cured with a heat treatment. CsI has substantial afterglow after high doses of radiation. Therefore the monitor will indicate higher than actual radiation levels shortly after high level exposure. It is expected that the FET in the preamplifier will also be affected by an integrated dose of 10^4–10^6 rad in environments of only photons and electrons. The photodiode should survive very high levels of radiation. For the monitoring of very high levels it is advisable to use BGO crystals instead of CsI and to use an operational amplifier built entirely with bipolar transistors. BGO has about 10% of the comparable light output of CsI and has a higher radiation resistance. BGO will self-recover from radiation damage within a few hours to weeks. CsI(Tl) has a positive temperature coefficient of 0.4%/°C at room ~0.2%/°C at room temperature for photodiode readout (4) while BGO has a negative coefficient of −1%/°C. The temperature coefficient of the diodes is negligible.

It should be mentioned that the photodiode itself responds to radiation like a nuclear semiconductor counter. Although of relatively low Z-material and small volume, large signals are generated by converted low energy γ quanta or traversing charged particles. The diode corresponds to about an additional layer of 1mm of CsI. One of the reasons for the high sensitivity of the diodes is linked to the long carrier lifetime in the high sensitivity n-layer. An alternative solution might be to use large area photodiodes made of low sensitivity material or very thin wafers, but no tests have been done.

An increase of the scintillator volume above a few cm^3 will not increase the lower limit of the sensitivity significantly. Due to the larger mismatch of the diode area and the crystal surface, the number of observable photoelectrons per MeV will decrease due to light losses from material self-absorption or after multiple surface reflections. One has to increase the number of diodes or very carefully prepare the reflectivity of the crystal surface not covered by the diodes.

EXAMPLE OF PERFORMANCE

Figure 3 shows a typical measuring curve of a run at the DORIS storage ring.

SUMMARY

A simple radiation monitoring device is described. The unit is very compact and insensitive to magnetic fields. The component price is around $100.

REFERENCES AND COMMENTS

1) The output voltage of the photodiode is proportional to the logarithm of the light intensity. Use of a high quality voltage amplifier will give an output signal proportional to the logarithm of the radiation level. The temperature dependence of the diode voltage is quite high and needs to be compensated for higher performance or large temperature variations.

2) H.G. Moser: Untersuchungen von Materialien kurzer Strahlungslaenge für Kalorimeter mit optischer Auslese. Diplomarbeit. University Erlangen (1984), unpublished.

3) H. Grassmann: Ein CsI(Tl) Test Kalorimeter bei Energien zwischen 1 GeV und 20 GeV. Diplomarbeit. University Erlangen (1984), unpublished.

4) For a photomultiplier readout a temperature gradient of 0.4%/°C has been observed. The discrepancy might be explained by different temperature dependence of the light intensity as a function of wavelength.

FIGURE CAPTIONS

Fig 1: Basic circuit diagram of the monitor device.
Fig 2: Layout of a typical monitor.
Fig 3: Example of a measuring curve during a typical 5 hour period of DORIS operation.

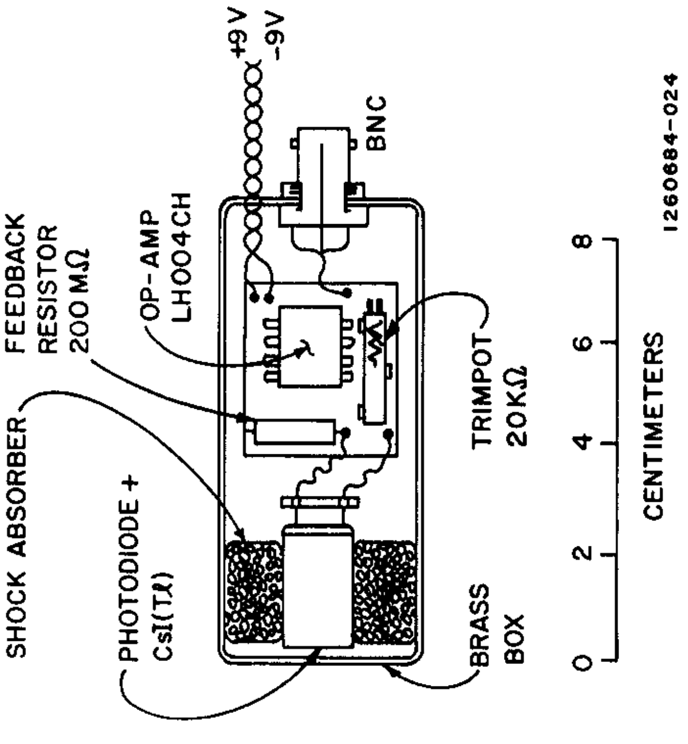
+9V
-9V
BNC
1260684-024
FEEDBACK RESISTOR 200 MΩ
OP-AMP LH0004CH
SHOCK ABSORBER
PHOTODIODE + CsI(Tl)
TRIMPOT 20KΩ
BRASS BOX
0
2
4
6
8
CENTIMETERS

Fig. 2

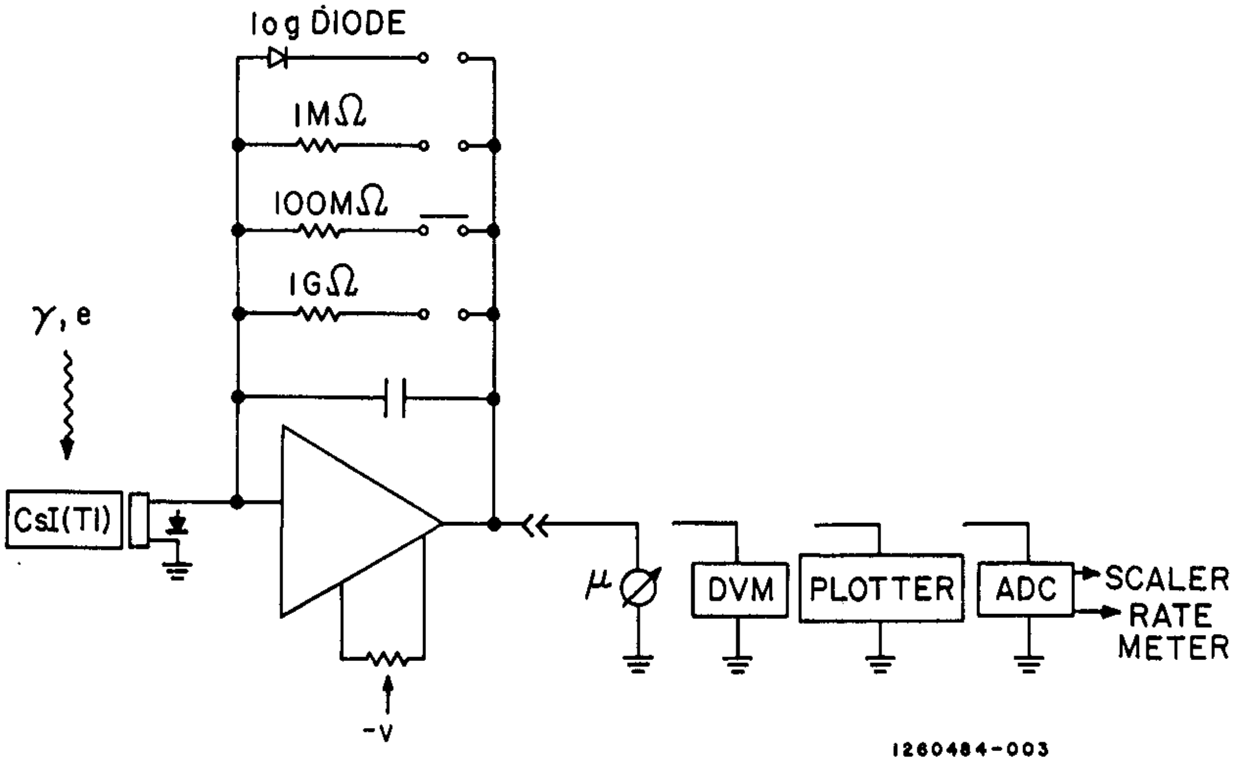
log DIODE
1MΩ
100MΩ
1GΩ
γ, e
CsI(Tl)
-V
μ
DVM
PLOTTER
ADC
SCALER
RATE METER
1260484-003

Fig. 1

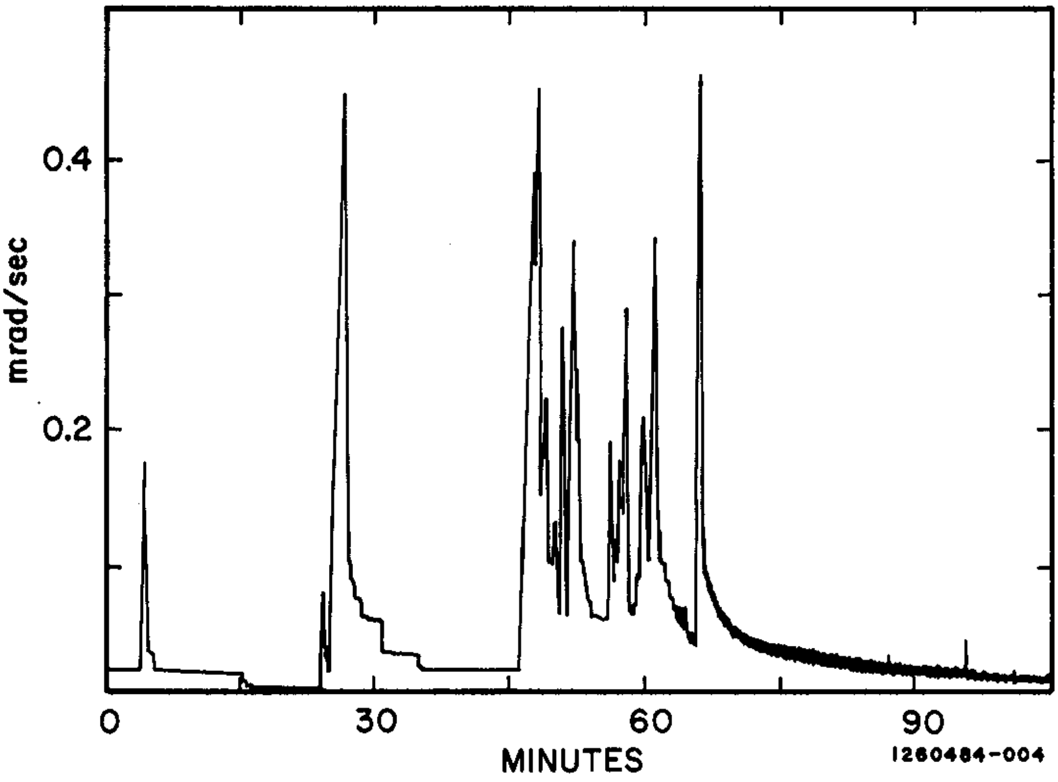

Fig. 3