Linear transmission via fiber optics of analog current-signals using the Optically-Coupled Current-Mirror (OCCM) architecture

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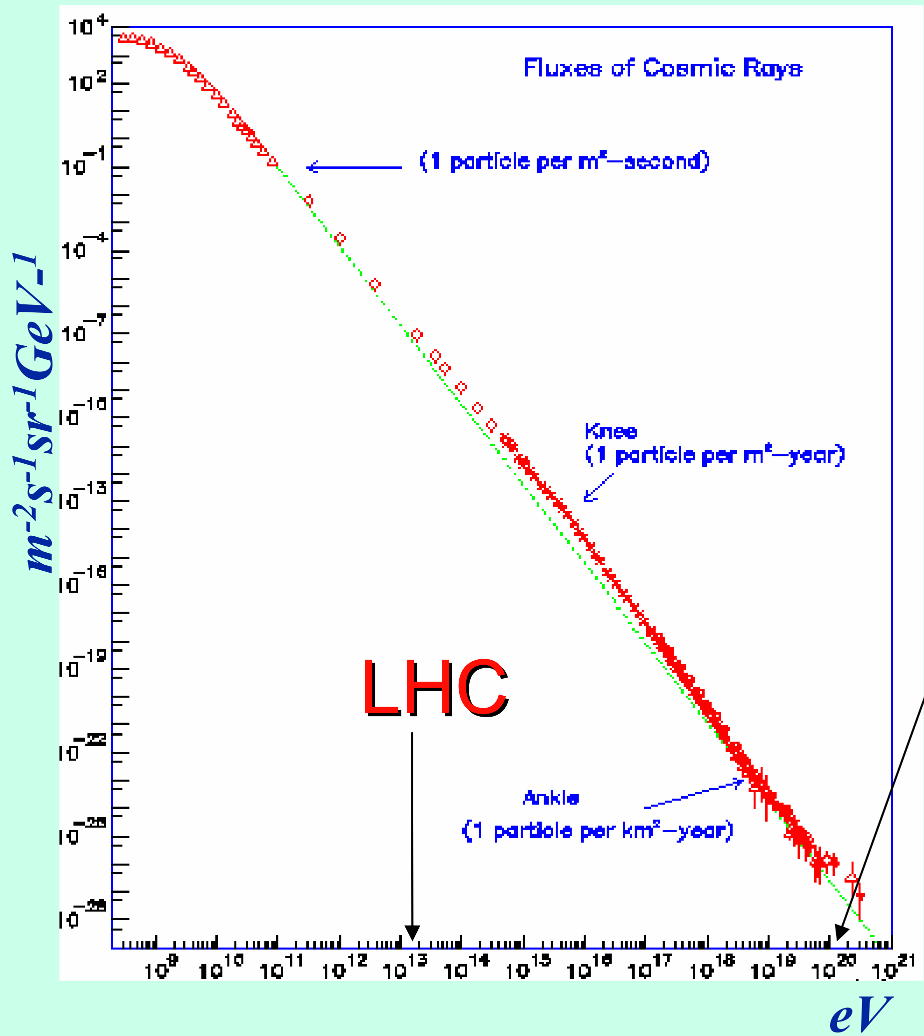
- Introduction.
- Galvanically decoupled DC amplifiers.
- The OCCM and its application with PMTs and ionizing detectors.
- Performance at cryogenic temperature.
- Status of a fiber optics link based on the OCCM.

The Pierre Auger Project:

looking for the highest energy cosmic rays

The Auger collaboration: about 300 researchers from 15 countries



UHECR fluxes:

-10^{19} eV: ~ 1/km^2. year

-10^{20} eV: ~ 1/km^2. century

For a 3000 km^2 site:

-10^{19} eV: ~ 3000 events / year

-10^{20} eV: ~ 30 events / year

The Pierre Auger Observatory: an hybrid detector

- **Objective:**

  to study the:
  - energy
  - flux
  - arrival directions
  - composition

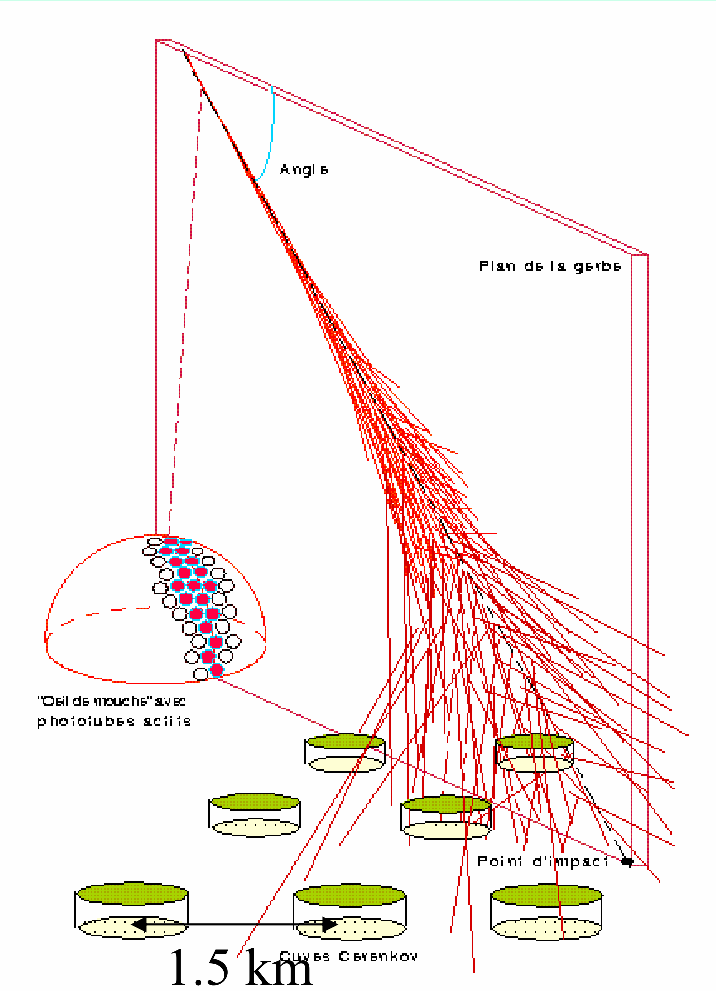
  of UHECR with E > 10^{18} eV with

  full efficiency above 10^{19} eV.

- **Proposed:**
  - full sky coverage (two extensive Observatories)
  - large aperture.
  - Hybrid detector techniques:

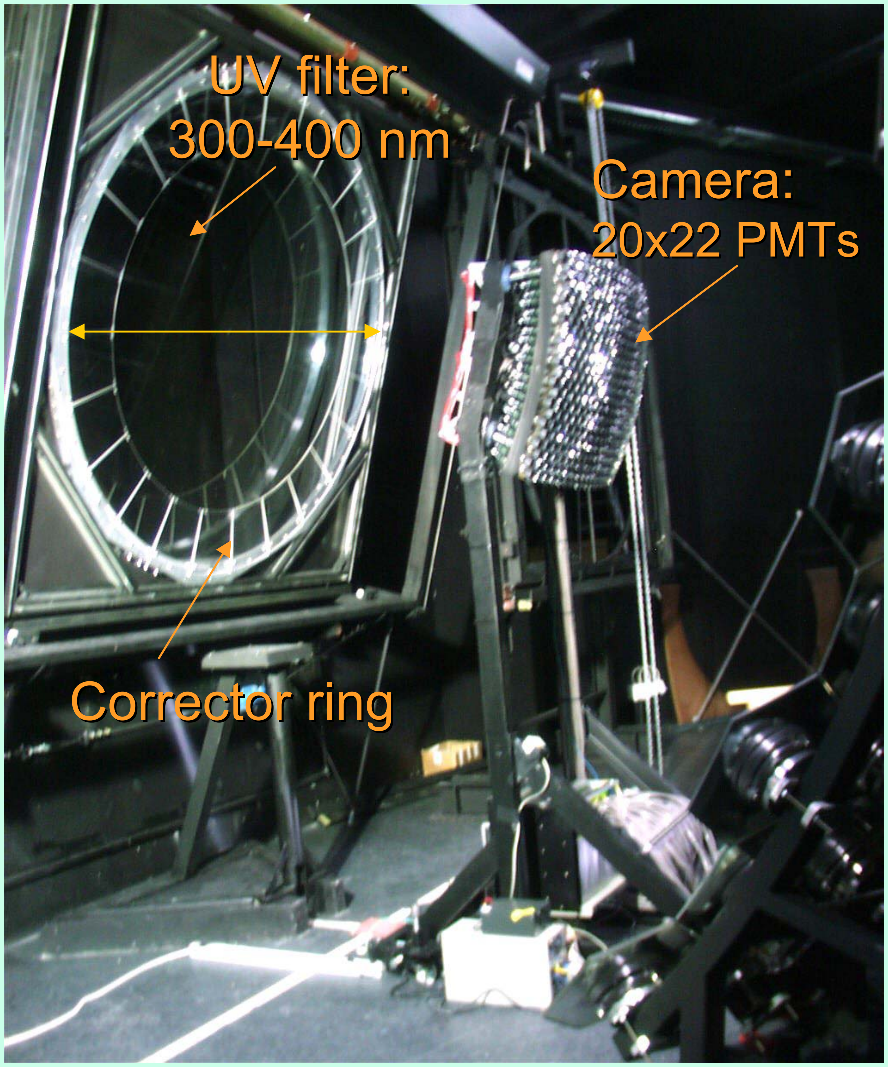
  -> atmospheric fluorescence detector (FD)

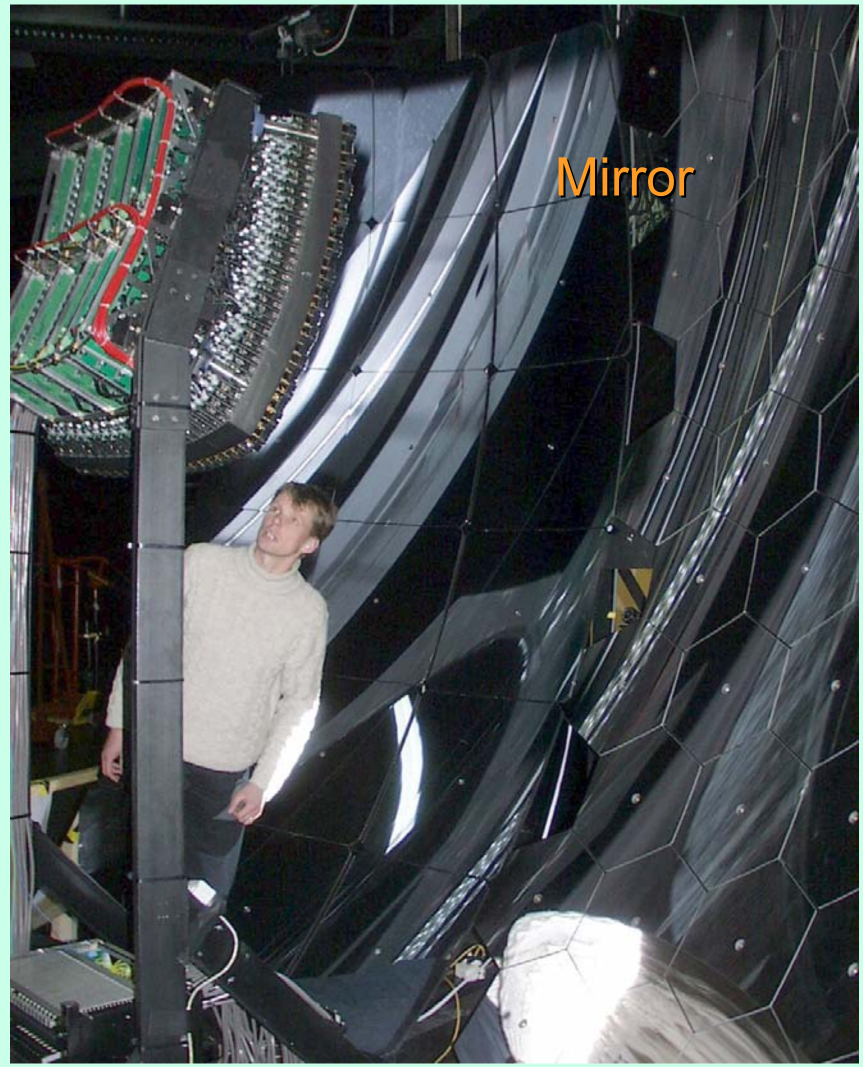
  -> surface array: water Cherenkov tanks (SD)



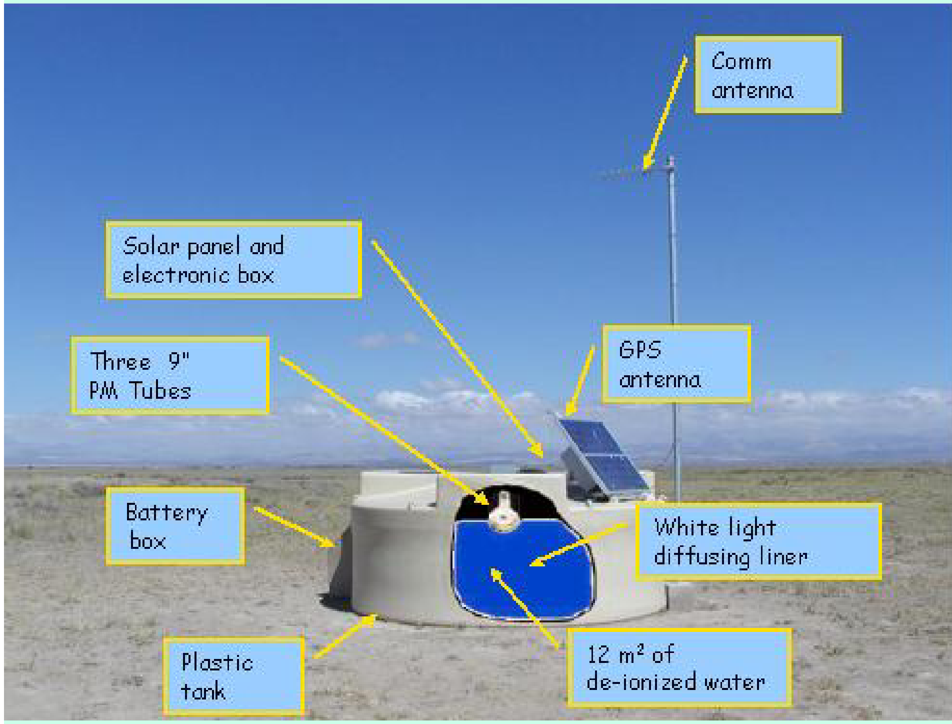
The telescopes of the Fluorescence Detector

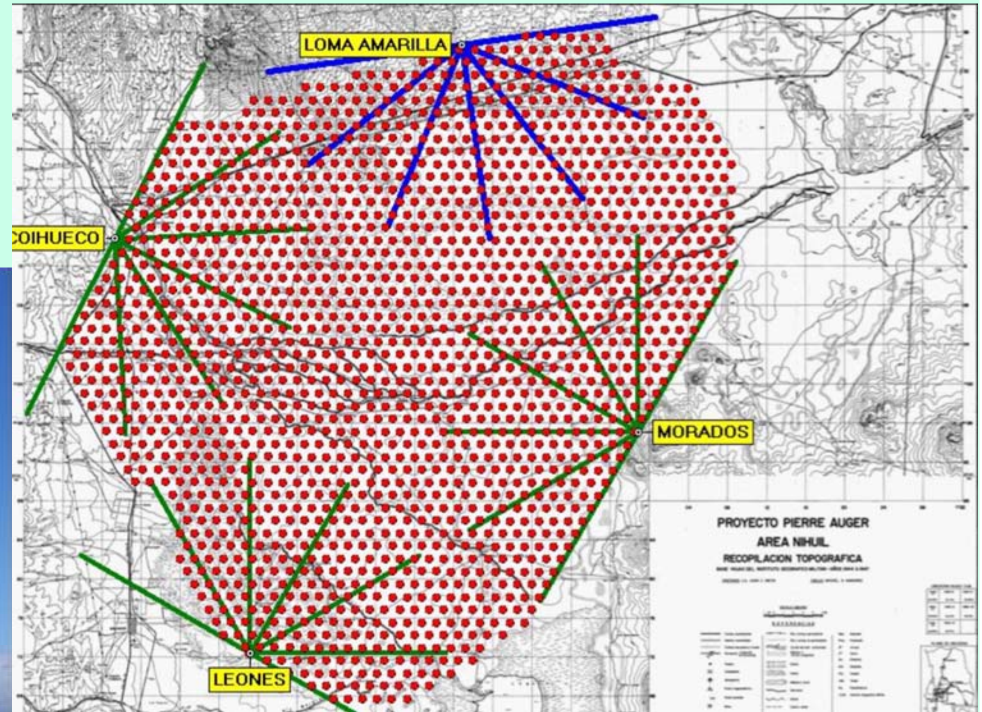
4 FD buildings with 6 telescopes each looking to the dark-sky night





The water-Cherenkov tank array





~ 60 km

1600 units spaced 1.5 km each other

Making the telescopes sensitive to star signals to control their absolute pointing and long-term stability

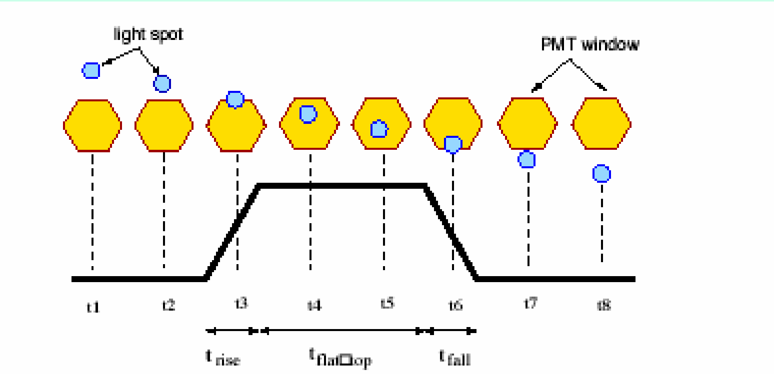
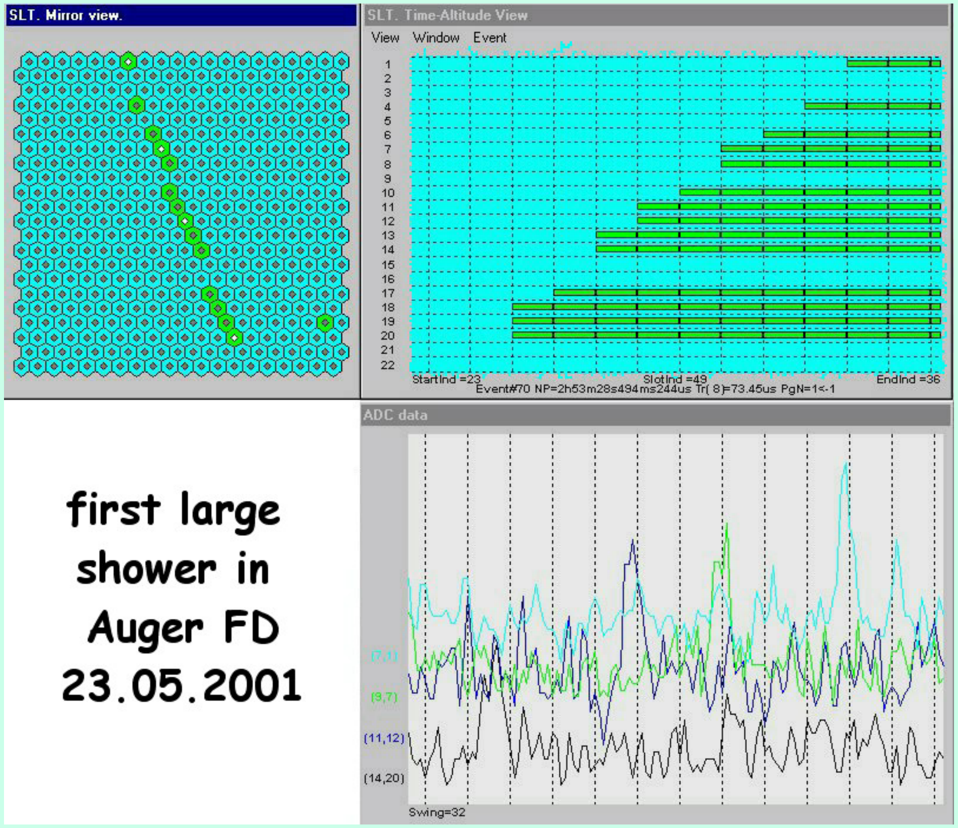


Figure 3-7. *Shape of the signal generated at a PMT of a FD Mirror*

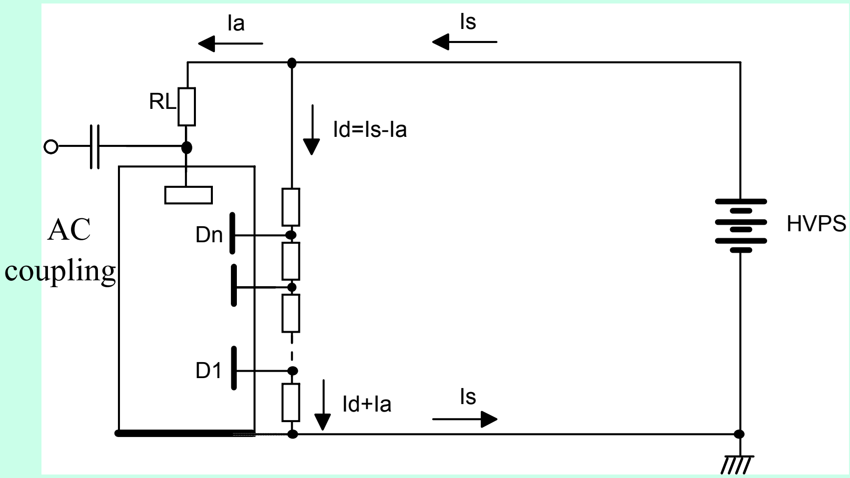
Fluorescence pulse width:
~ 0.3 -10 μs

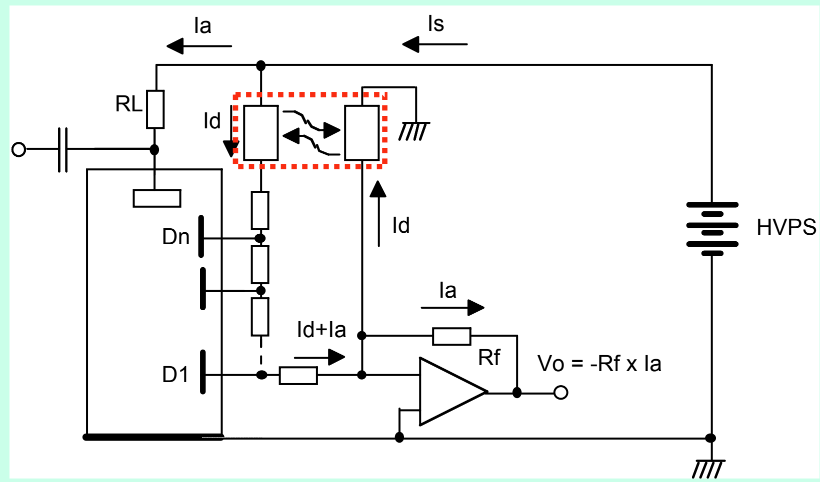
Star track width: 5 to 10 min



first large shower in Auger FD 23.05.2001

The currents in a PMT biased with positive HV



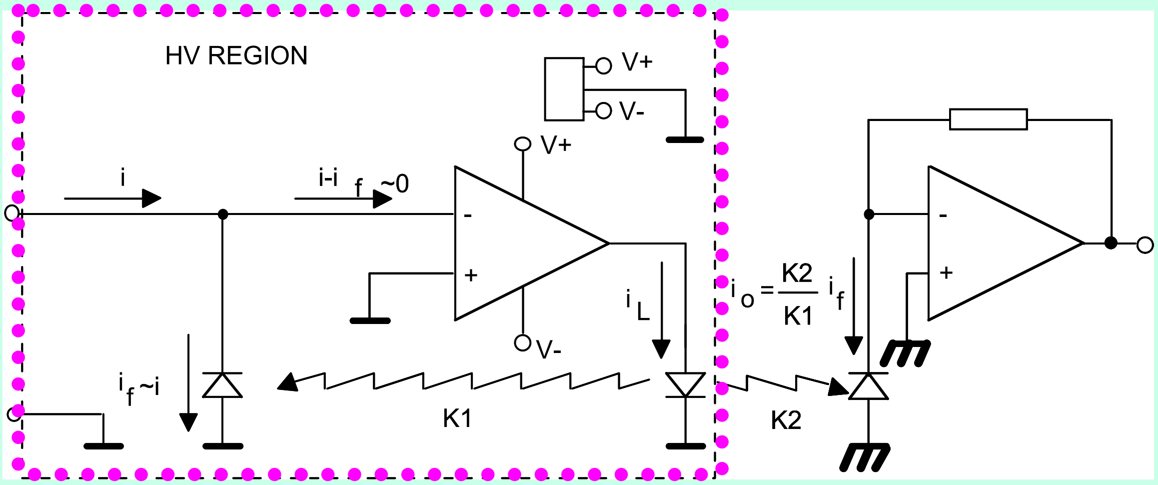


Mirroring Id to ground potential would allow to measure the DC or slowly varying anode current.

What to use to mirror the divider current ?

State of the art on Galvanically decoupled DC amplifiers:

- 1973, J. Sunderland's scheme:

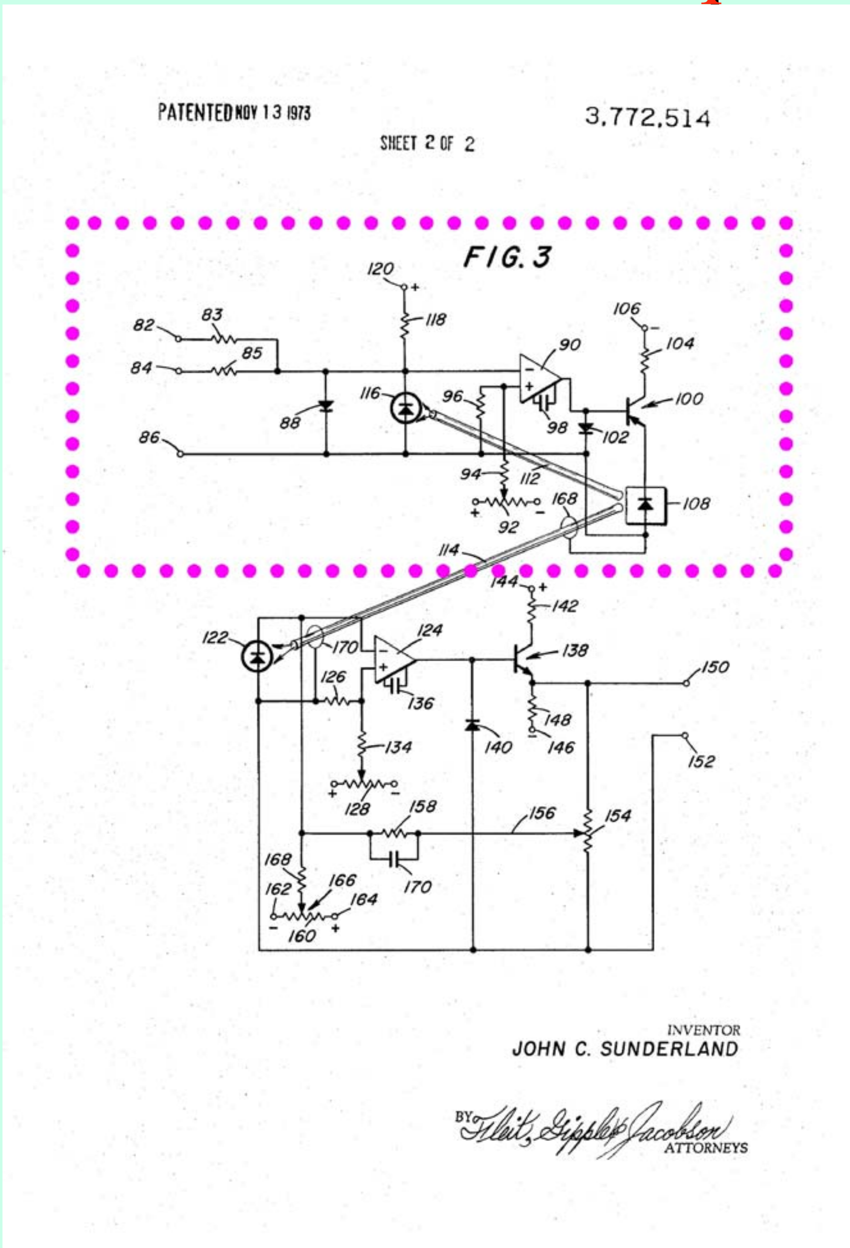


- LV power supply required at the HV, or isolated region.
- In the last 30 years many solutions were proposed to bring LV to that region.

- 1995, Hodson (*Texas Instrument*):
- Introduction of the Linear Optocoupler
- Still, LV was always required at the isolated or HV region.
- Unacceptable for Auger ! (24 x 440 PMTs)

QuickTime™ and a TIFF (Group 4 Fax) decompressor are needed to see this picture.

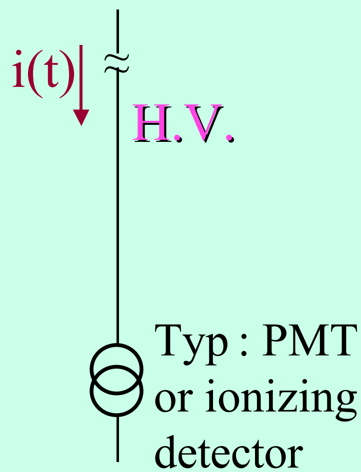
John C. Sunderland's patent



The Optically-Coupled Current-Mirror

1st step

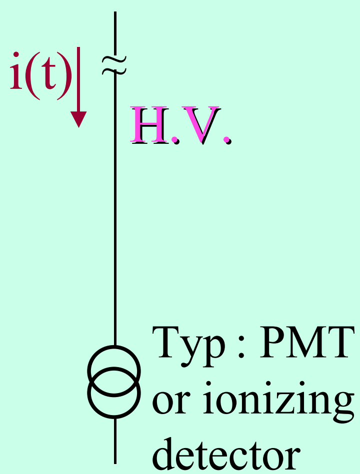
(1) Detector biased



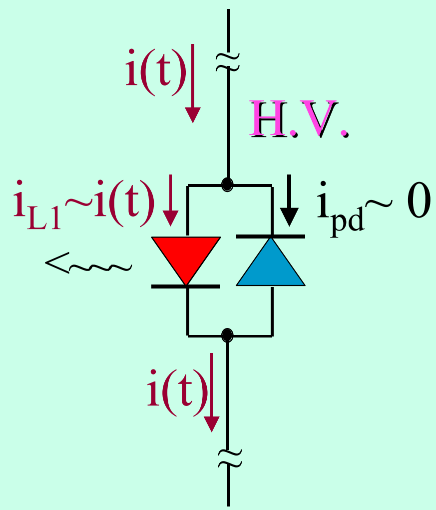
OCCM

2nd step

(1) Detector biased



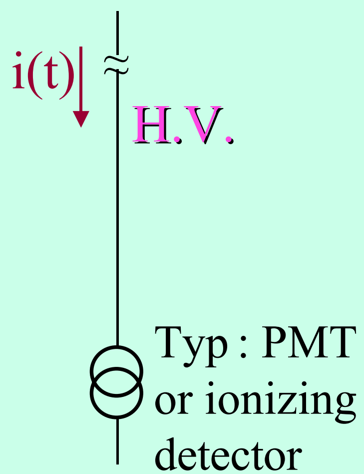
(2) Diodes interposed



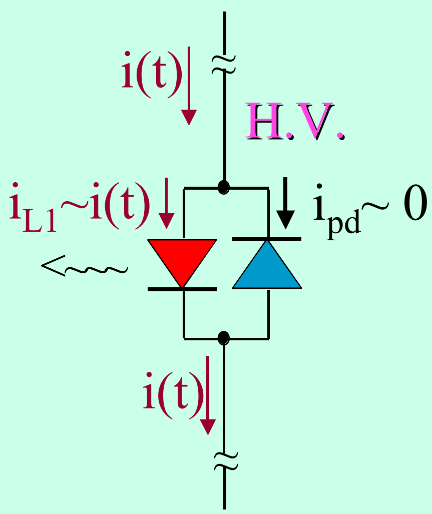
OCCM

3rd step

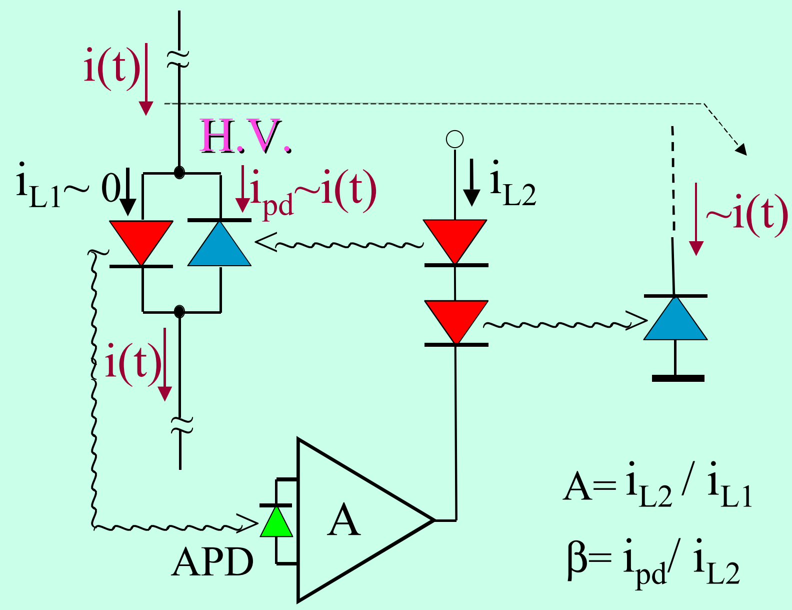
(1) Detector biased



(2) Diodes interposed

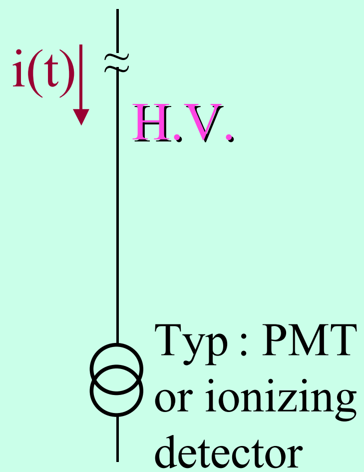


(3) Feedback action *flips* the currents and i(t) is *mirrored*

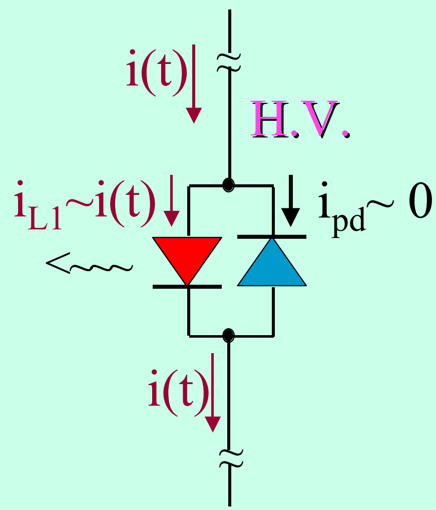


OCCM

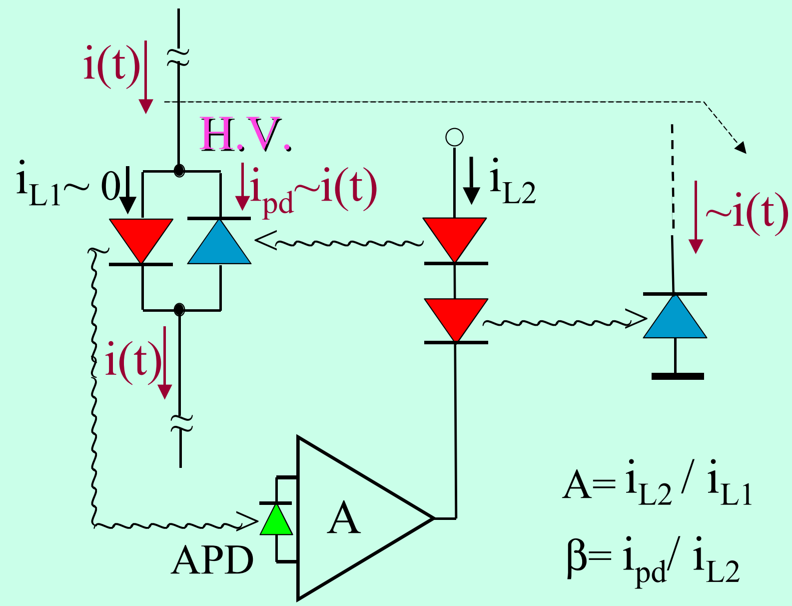
(1) Detector biased



(2) Diodes interposed

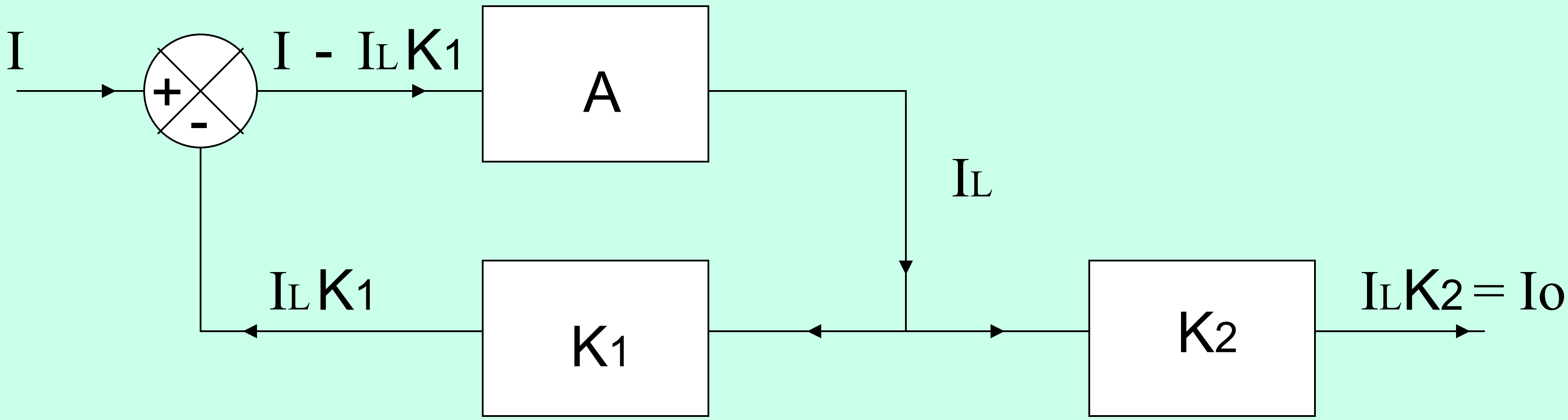


(3) Feedback action *flips* the currents and i(t) is *mirrored*



- DC or pulsed current-signals are linearly mirrored to ground potential via F.O.
- The input circuit is ***passive and low impedance***: ideal for current-signals.
- The only components under risk of radiation damage:LED,photodiode,and fiber.
- ***No LV power supply*** is required at the conductor's potential.

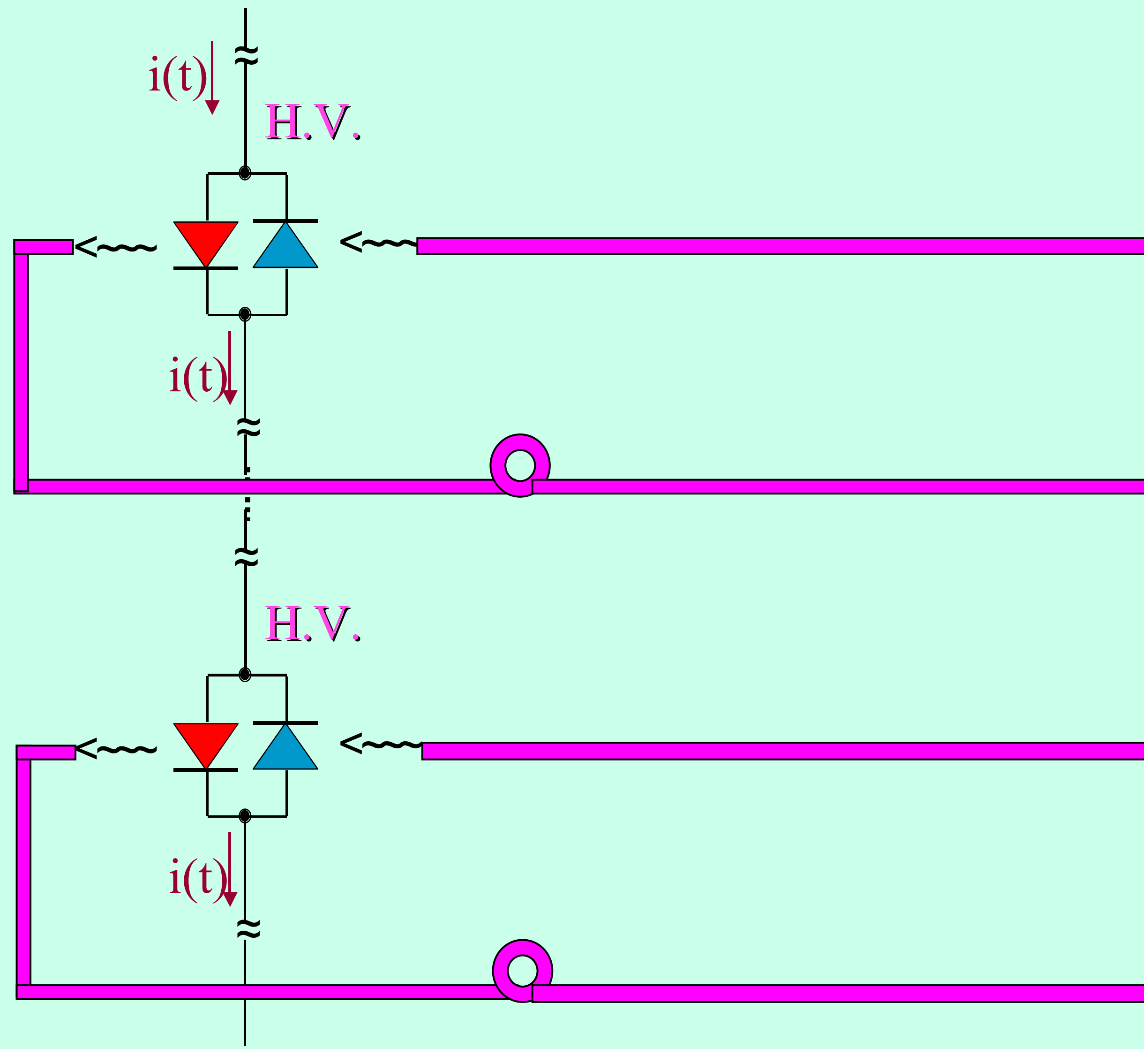
The OCCM: a current feedback loop



$$I_O = I \cdot \frac{K_2}{K_1} \cdot \frac{1}{1 + \frac{1}{AK_1}} = I \cdot K'_3$$

Increasing dynamic range

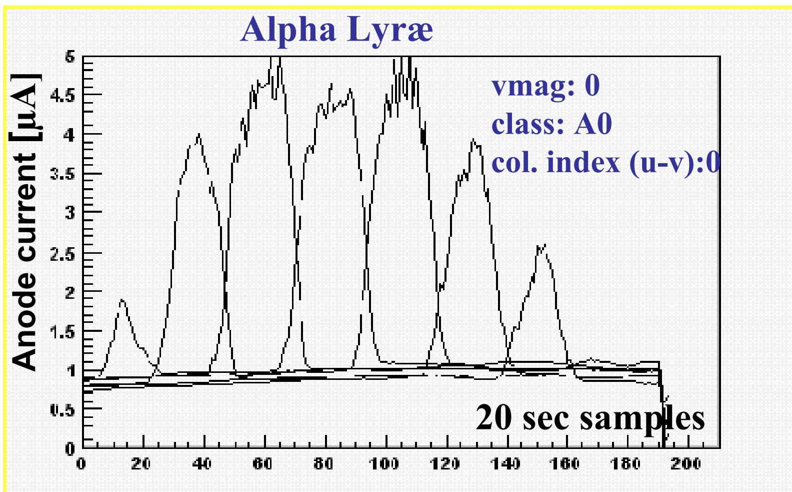
Stage with gain 1



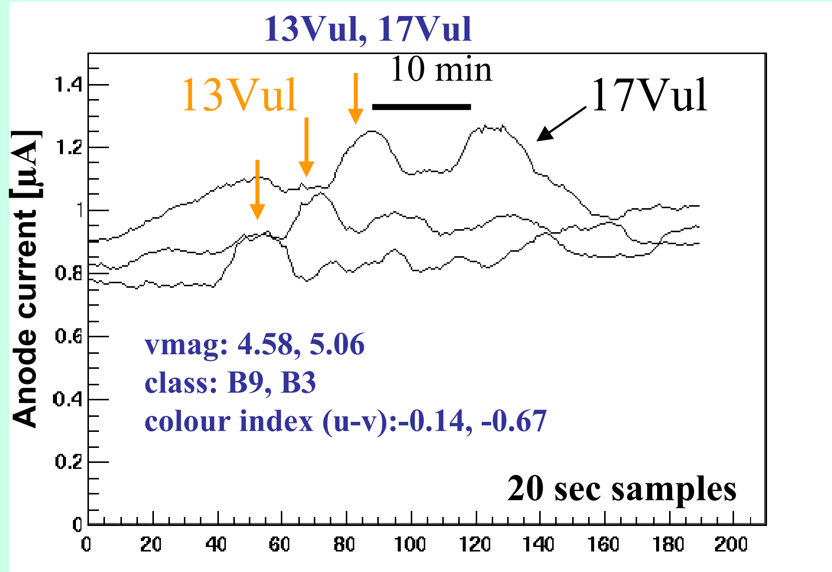
Stage with gain N

Relevant results obtained with the OCCM:

a) The first star tracks recorded by the Auger Fluorescence Detector prototype



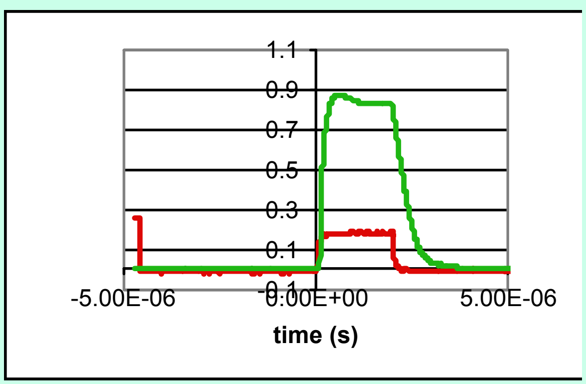
Stefano Argiro, Viviana Scherini, Daniel Camin. Malargue 25-06-2001



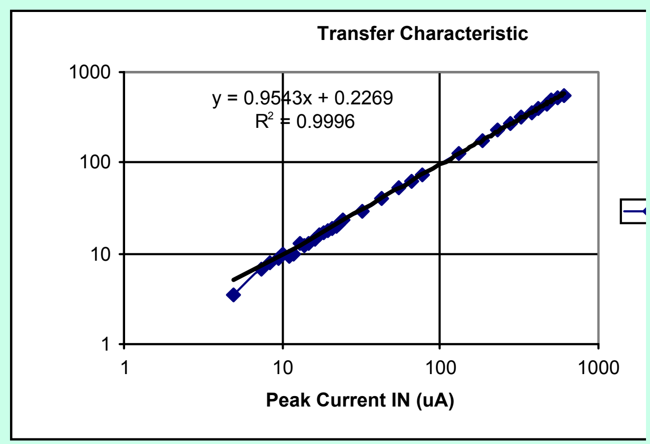
Resolution referred to photocathode: less than 1 pA .

PMT gain ~ 4.1 x 10 ⁴

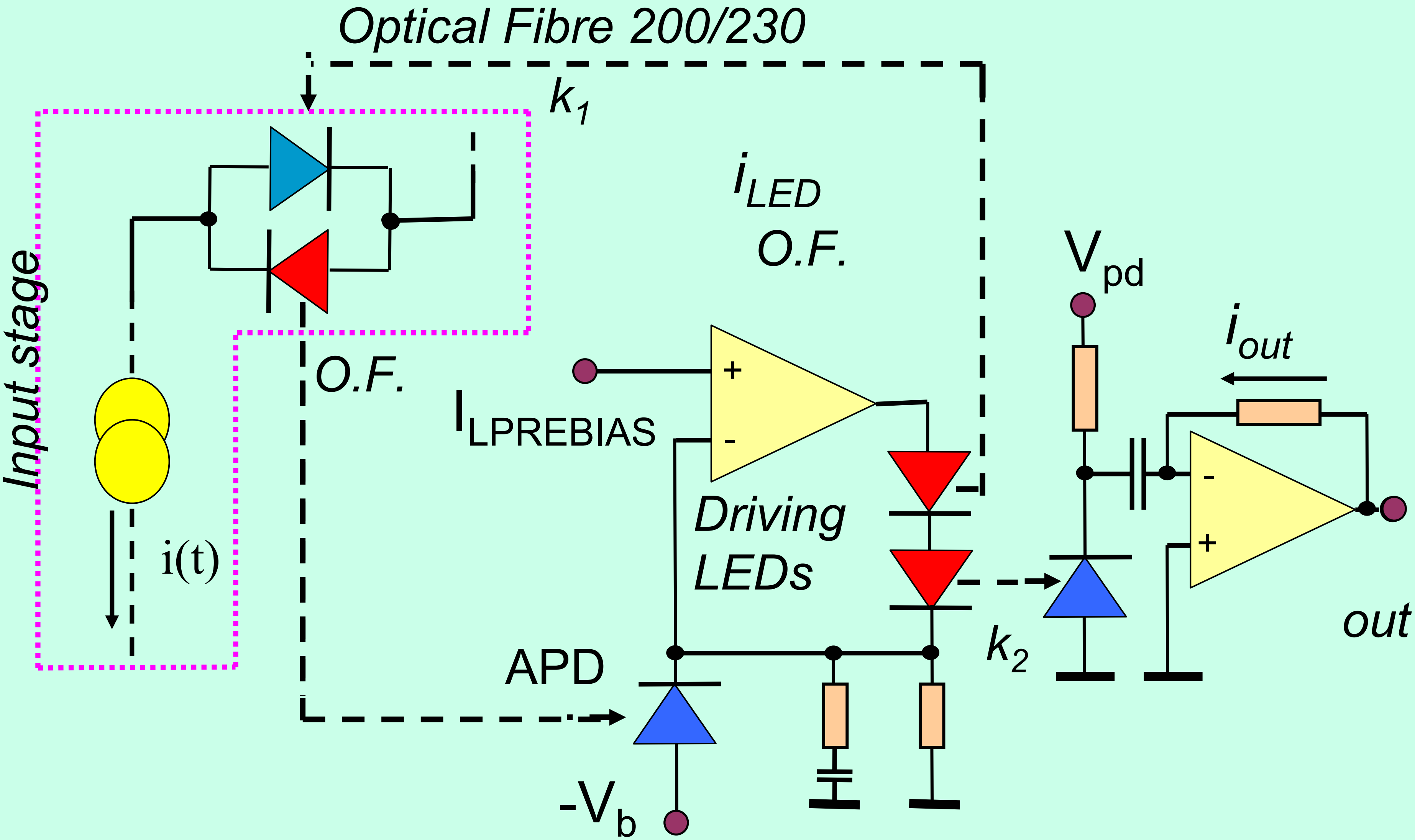
b) The *very first* pulses sent linearly via fiber-optics:



Pulse width:2µs
T_{rise} ~ 180 ns;
BW ~ 1.5-1.9 MHz



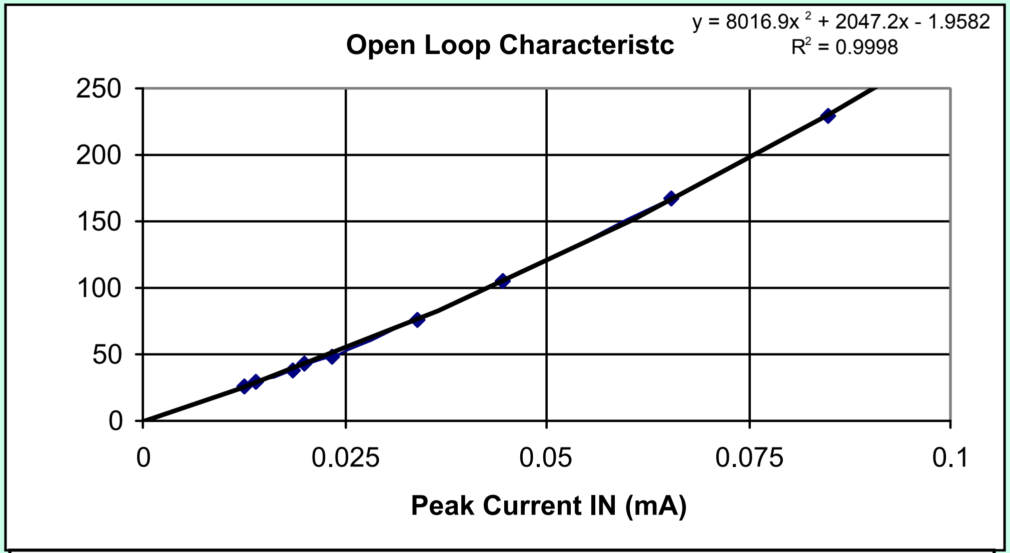
The OCCM used for the transmission of fast current signals, also from cryogenic detectors



Pulsed operation: experimental results

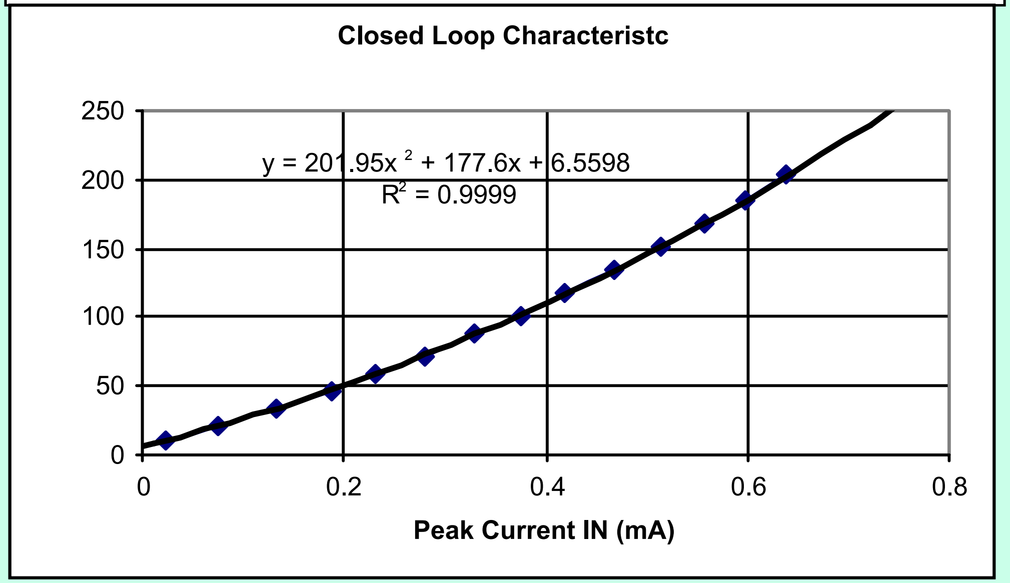
LED- driving current vs. input current

<u>Open Loop</u>:
saturation at
$i_{in} \sim 85\ \mu A$



Small signal
open-loop gain:
A = 2047

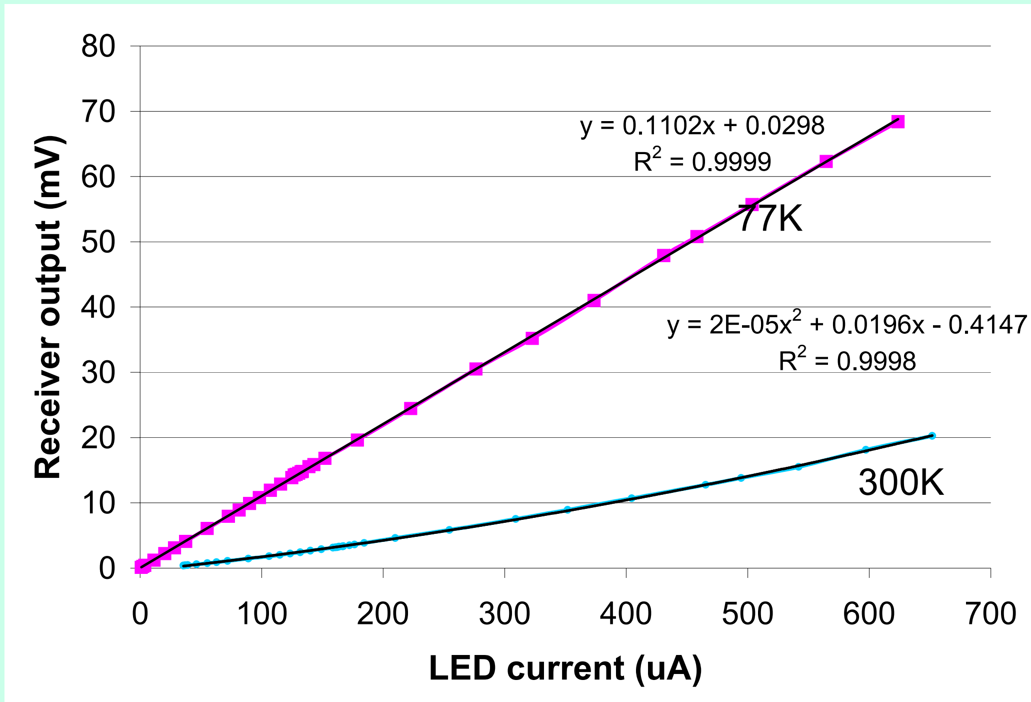
<u>Closed Loop</u>:
saturation at
$i_{in} \sim 750\ \mu A$



Feedback return ratio:
$\beta = (178)^{-1} = 5.6\ 10^{-3}$
Loop gain : 11.5

Behavior of an LED at 300K and 77 K

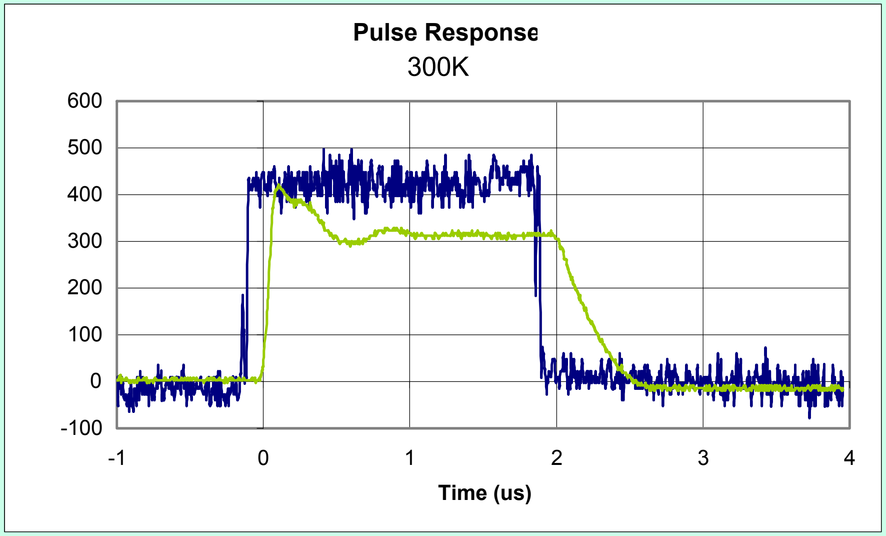
At 77K the linear term improves by a factor x 5.6

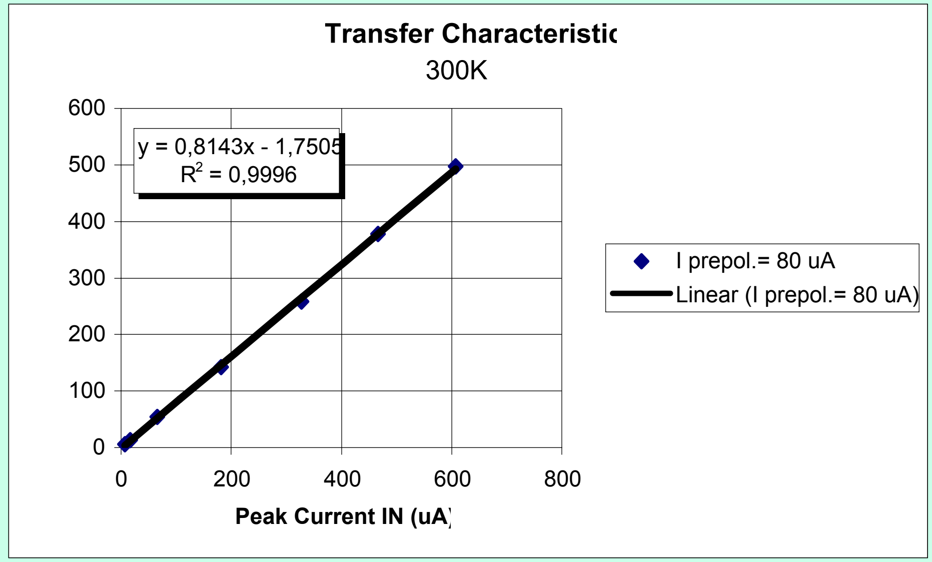


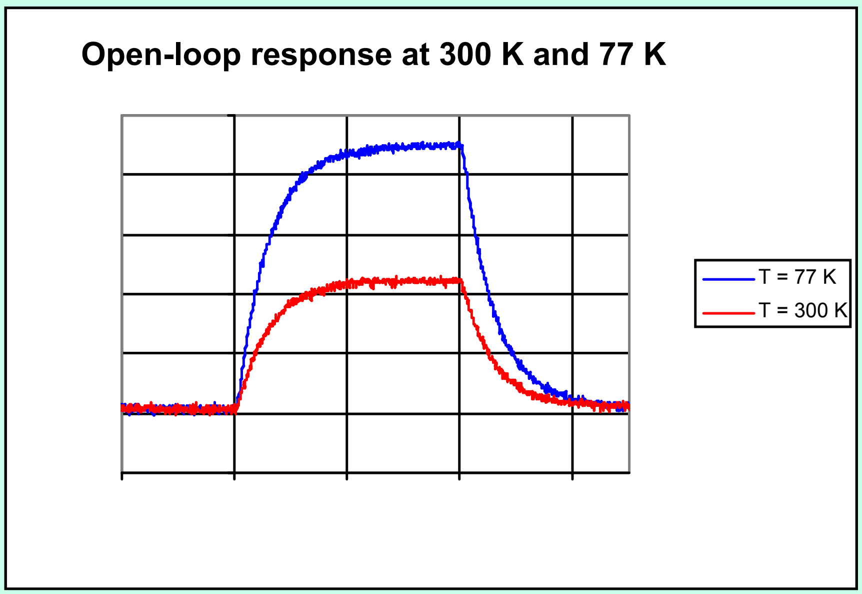
At 77 K the LED efficiency is a factor 5.5 higher
even at very small LED current, as required by the OCCM

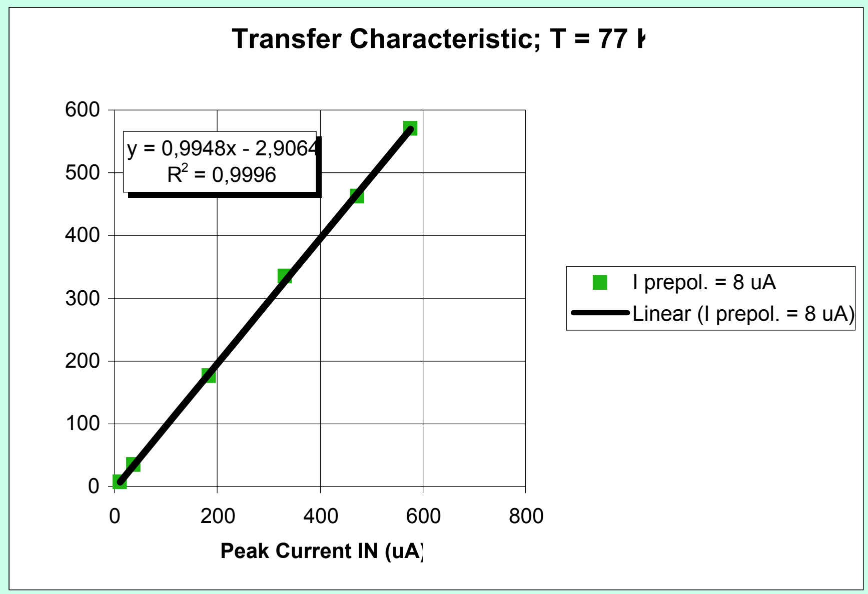
Light receiver: Agilent 2406 (pin photodiode followed by an amplifier)

Pulsed operation: Input-Output characteristics









US006316930B1

(12) **United States Patent**
Camin

(10) **Patent No.: US 6,316,930 B1**
(45) **Date of Patent: Nov. 13, 2001**

(54) **DIRECT CURRENT METER WITH PASSIVE INPUT AND GALVANIC INSULATION, PARTICULARLY FOR HIGH VOLTAGE**

(75) Inventor: **Daniel V. Camin**, Milan (IT)

(73) Assignee: **Istito Nazionale di Fisica Nucleare**, Frascati (IT)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **09/467,895**

(22) Filed: **Dec. 21, 1999**

(30) **Foreign Application Priority Data**

Dec. 21, 1998 (IT) MI98A2754

(51) **Int. Cl.**[7] **G01R 31/00**
(52) **U.S. Cl.** **324/97**; 324/96
(58) **Field of Search** 324/97, 96, 126, 324/127

(56) **References Cited**

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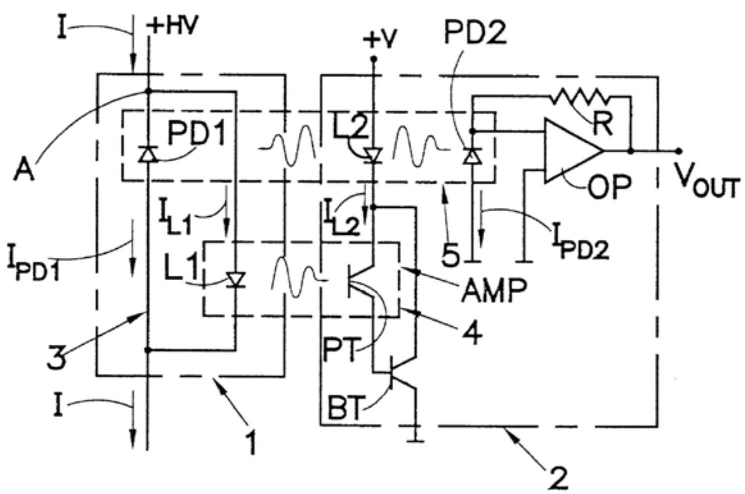
Primary Examiner—Safet Metjahic
Assistant Examiner—T. R. Sundaram
(74) *Attorney, Agent, or Firm*—Nixon & Vanderhye, P.C.

(57) **ABSTRACT**

There is described a direct current meter with passive input and galvanic insulation, particularly for high voltage. The direct current meter is made up of a passive input part and of an active output part that is optically coupled to the passive part and electrically insulated from it. In this way the high voltage present at the input only affects the passive part of the meter, whereas the active part can be supplied with a low voltage and can be made capable to provide an output signal proportional to the current to be measured and substantially independent from the working temperature.

6 Claims, 1 Drawing Sheet



(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) **EP 1 014 098 B1**

(12) **EUROPEAN PATENT SPECIFICATION**

(45) Date of publication and mention of the grant of the patent: **23.04.2003 Bulletin 2003/17**

(51) Int Cl.[7]: **G01R 15/22**

(21) Application number: **99204319.0**

(22) Date of filing: **15.12.1999**

(54) **Direct current meter with passive input and galvanic insulation, particularly for high voltage**

Gleichstrommessgerät mit passivem Eingang und mit galvanischer Isolierung, insbesondere für Hochspannung

Appareil de mesure de courant continu avec entrée passive et isolation galvanique, en particulier pour haute tension

(84) Designated Contracting States
AT BE CH CY DE DK ES FI FR GB GR IE IT LI LU MC NL PT SE

(30) Priority: **21.12.1998 IT MI982754**

(43) Date of publication of application: **28.06.2000 Bulletin 2000/26**

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EP 1 014 098 B1

Note: Within nine months from the publication of the mention of the grant of the European patent, any person may give notice to the European Patent Office of opposition to the European patent granted. Notice of opposition shall be filed in a written reasoned statement. It shall not be deemed to have been filed until the opposition fee has been paid. (Art. 99(1) European Patent Convention).

Summary and conclusions

- The OCCM architecture allows linear mirroring, via optical means, of a DC or pulsed current-signals flowing trough a *passive input* stage.
- No *LV PS* is required at the potential of the isolated conductor.
- When the *input stage is cooled down to 77 K*, performance improves strongly: *the loop-gain increases a factor two* and *signal threshold reduces*. This opens new opportunities for the signal readout of cryogenic detectors.
- The OCCM has been successfully *installed and operated in the 880 PMTs* of two prototype telescopes of the Auger FD.
- Linear transmission of fast pulses via fiber optics has recently been performed with the OCCM over a *5 MHz bandwidth* and at least a *100:1 dynamic range:* a reasonable starting point with large room for improvement.
- *Dynamic range* can *increase* by connecting several stages in series.
- The *only components under risk of radiation damage*: the LED, the photodiode and the fiber.