Beam current measurement with logarithmic converter

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BEAM CURRENT MEASUREMENTS WITH LOGARITHMIC CONVERTER

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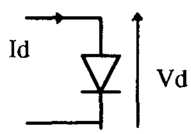
A new electronic device to measure low current has been developped for the new projects THI (Hight Intensity Transport) and SPIRAL at Ganil.
This electronic device gives a voltage proportionnal to the current logarithm. An analog to digital conversion of the voltage is realized. A calculation with the inverse logarithmic equation gives the current value.
The advantage of the logarithmic measurement is its possibility to measure a large scale without range changing.
Developments and tests are now in progress to measure currents between picoamp to milliamp.

1 Principle of the logarithmic conversion

The logarithmic conversion uses the diode caracteristic.
The current-voltage characteristic of a diode is given by:

$$Id = Is(e^{\frac{Vd}{Ut}} - 1)$$



Id : diode current
Is : reverse saturation current

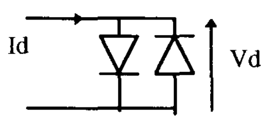
with $Is = BT^3 e^{\frac{-Eg}{KT}}$
Eg : band gap

Vd : diode voltage

$Ut = \frac{kT}{q}$ with k : Boltzmann's constant

T : absolute temperature (K)
q : electronic charge (1,6 10^{-19} C)

The used structure consists in connecting two diodes, with opposite polarities.



We find :

$$Id = Is\left(e^{\frac{Vd}{Ut}} - e^{\frac{-Vd}{Ut}}\right)$$

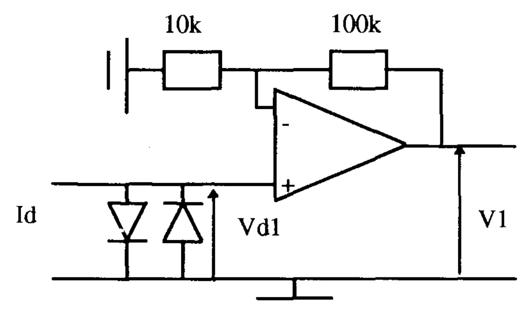
$$Vd = Ut \times \ln\left[\frac{1}{2}\left(\frac{Id}{Is} + \sqrt{\left(\frac{Id}{Is}\right)^2 + 4}\right)\right]$$

If Id/Is >>2

$$\boxed{Vd \cong Ut \times \ln[\frac{Id}{Is}]}$$

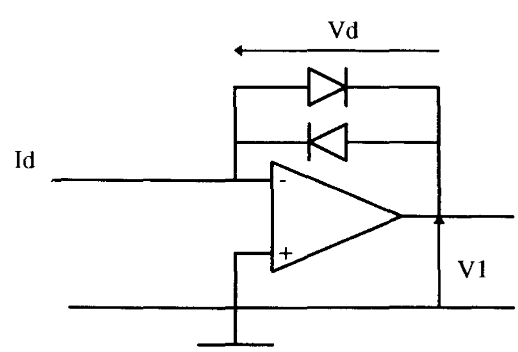
2 Two types of devices are used at GANIL.

2.1 Input stage with diodes upstream



V1 = 11 * Vd1
The advantage of this kind of device is to heavily filter low currents. In parallel the capacitance of the cable and the input equivalent resistance of the electronic realize the filtering.
The disadvantage is that response time for low current becomes very long.

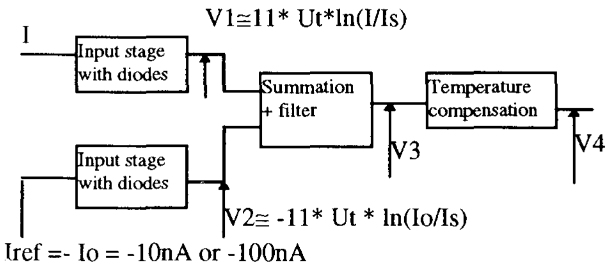
2.2 Input stage with diodes in feedback



V1 = -Vd

The response time is shorter than previous electronic, but it is more sensitive to electronic perturbations.

3 Layout of the electronic converter



4 Equation of converter

$$V3 = k \times (V1 + V2)$$

$$V3 \cong k \times 11 \times Ut \times \left(\ln\left(\frac{I}{Is}\right) - \ln\left(\frac{Io}{Is}\right) \right) \cong K \times Ut \times \ln\left(\frac{I}{Io}\right)$$

An electronic compensation corrects the effect of temperature on Ut and gives the gain 2v/decade.

$$V4 \cong 2 \times \log\left(\frac{I}{Io}\right)$$

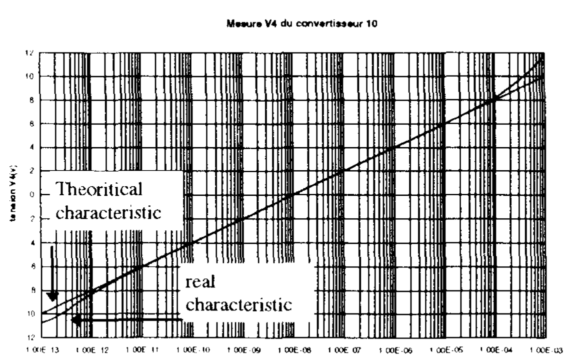
Io : reference current (equal to 10nA or 100nA)

For the device with diodes in feedback we realize the same characteristic V4=f(I).

V4 is include between -10v to 10v, so we can measure 10 decades of current.

5 Converter characteristic V=f(I)

For the logarithmic converter dedicated to SPIRAL, Io = 10nA and the theoritical characteristic is as shown on the figure.



In practice, Ibias (amplifier bias current) and Is (reverse saturation current) make non-linearity in very low current (< 10pA). For the high current (I>100μA) the resistance Rs of diode causes a non-linearity.

For the chosen diode (DPAD5 from TEMIC) we measure for T=25°C:

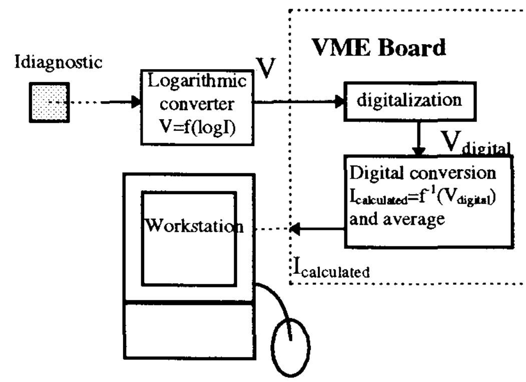
Is ≅ 27fA, Ut ≅ 27 mV, Rs ≅ 55Ω

For the amplifier (OPA 129 from BURR-BROWN) we measure :

Ibias ≅ 117fA

These values depend on the temperature.

6 Current calculation



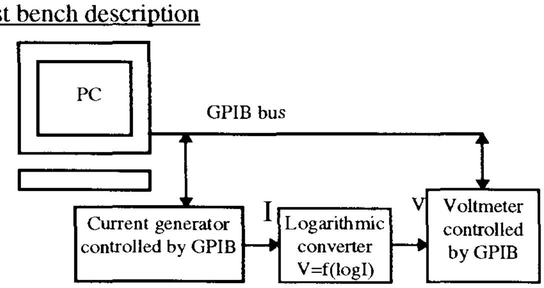
As seen before, the characteristic V=f(I) isn't linear on the whole scale. We have a non-linearity for low current (I< 10pA) and hight current (I>100μA). The theorical equation V=2*log (I/Io) and the inverse equation ($I_{calculated}$=Io*$10^{V4/2}$) can't be used.

The selected solution consists in realizing a conversion table. Values of this table are located in an EPROM on the VME board.

7 Conversion table realization

To realize this table, we must acquire the caracteristic V=f(I) of each electronic converter. A test bench acquires values automatically.

<u>Test bench description</u>



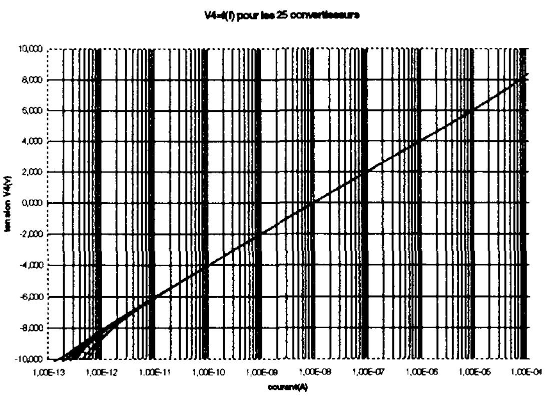
We acquire 1000 measurements of the characteristic V=f(I). We choose an average characteristic and a computer program calculates the characteristic I=f(V) with 4096 points. We use an analog to digital converter with 12 bits precision (2^{12}=4096 values).

We put the values in an EPROM on the VME board.

The microcontroller of the VME board acquires four voltages every 750µs.For all the values, the microcontroller calculates the corresponding currents, averages 400 current values and puts the result in the double access memory.

In practice, with the non-linearity the current can be measured between 0.3pA to 400µA.

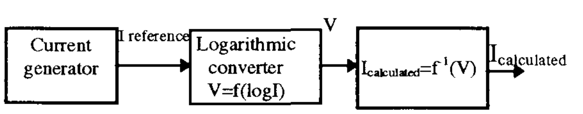
8 Characteristic V=f(I) of 25 converters

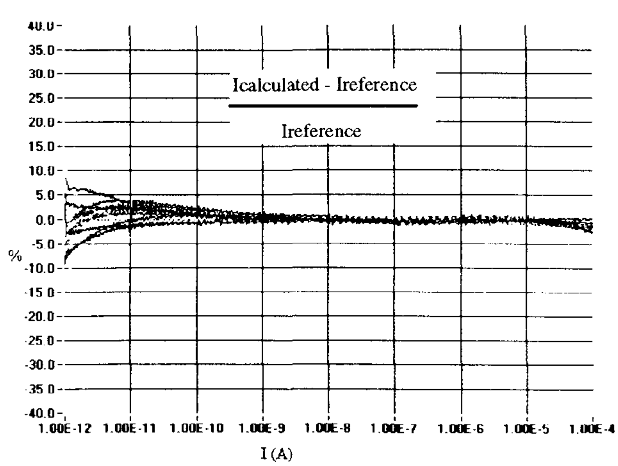


The different converters, for the same room temperature(25°C), have different characteristics for low current. Theses light differences are due to different values of Is.

9 Precision of the current calculation for 25 converters

A comparaison of the reference current and the calculated current gives the precision of calculation with the microcontroller.





The precision for the low current ($i<10^{-10}$A) decreases because diodes have different characteristics.

10 Influence of the offset voltage

The equation of the converter is

$$V \cong 2 \times \log\left(\frac{I}{Io}\right)$$

and the inverse equation is :

$$I_{calculated} \cong I_0 \times 10^{\frac{V}{2}}$$

If we have a offset voltage with V :

$$I_{calculated} \cong I_0 \times 10^{\frac{V+Voffset}{2}}$$

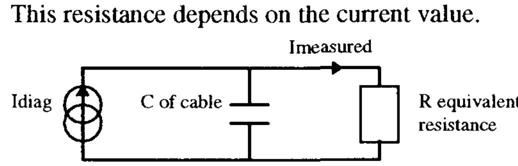
$$I_{calculated} \cong I_0 \times 10^{\frac{V}{2}} \times 10^{\frac{Voffset}{2}}$$

$$I_{calculated} \cong k \times I_0 \times 10^{\frac{V}{2}}$$

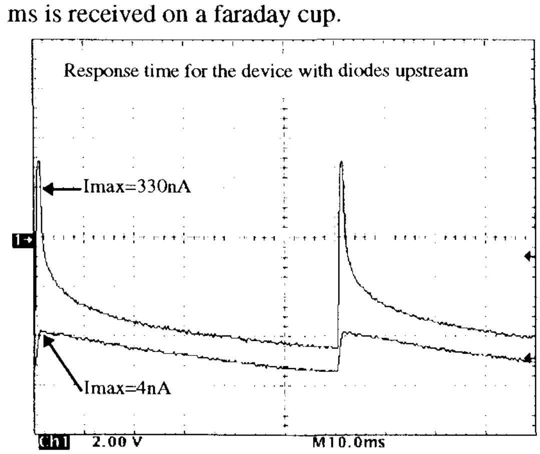
A difference of voltage gives, when we calculate the current, a multiplication factor. So it's very important to tune exactly the offset and the gain of the logarithmic converter.

11 Response time

The response time is due to the capacitance of the cable and the equivalent input resistance of the electronic. This resistance depends on the current value.

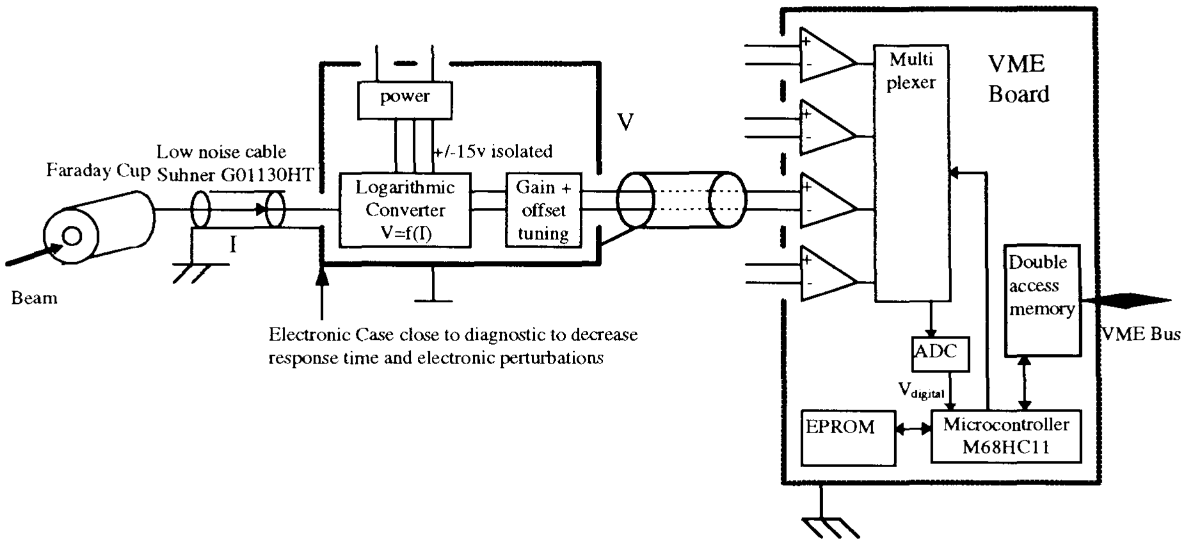


A chopper cuts the beam , a pulse of current during 0.8 ms is received on a faraday cup.



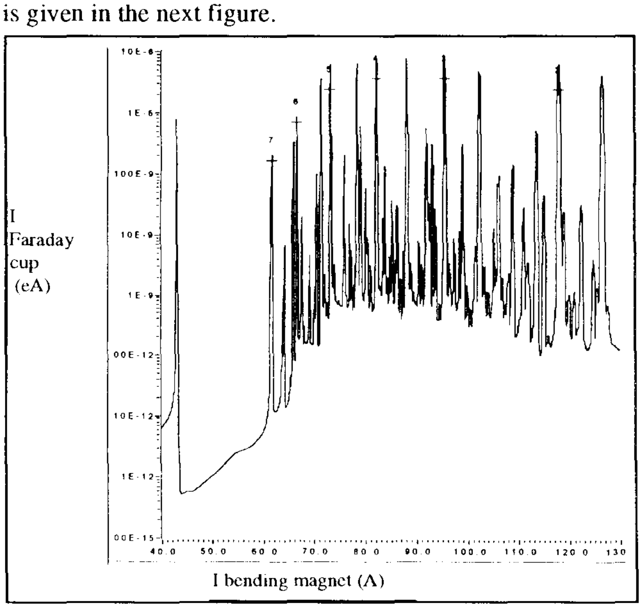
The response time increases when the current value decreases.

12 Layout of SPIRAL low current measurements



13 Charge state distribution of the experimental source

An exemple of measurements with logarithmic converter is given in the next figure.



We can see on the same curve different charge states which have maximum value completely different.

14 Conclusion

Logarithmic converters can measure current on a very large scale (10 decades) without range changing. The precision is about +/- 2% on the scale except for the current < 10pA. A filtering, with the cable capacitance and the equivalent input resistance, increases when the current decreases.