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**TEST ON CERN ISOLATION AMPLIFIERS CARD AND NEW DESIGN FOR
THE B0 DIAGNOSTIC VOLTAGE ACQUISITION CARD**

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Abstract

In the frame of the ATLAS collaboration, the LASA Laboratory had to provide the acquisition system for the electrical signals from the B0 model coil. B0 is a full scale model, one third length of ATLAS barrel toroid eight coils. The B0 construction was decided to test the technical construction solutions and reproduce the final coils behaviour. Two types of electrical signal must be handled, the isolated and the non-isolated ones. The isolated signals, for example, come from the inductive pick-up coil, while the non isolated signals are the ones coming directly from the cable.

In order to interrupt the ground loops, reject the common-mode voltage, the electromagnetic noise and to protect the acquisition system from overvoltages during a quench, galvanic insulation must be provided.

In this paper the test performed on two existing insulating CERN cards (POTAIM and DVMM) are reported. Then a new card design, better fitting the acquisition electronic requirements, is discussed.

The design is validated by the utilization of the acquisition cards and system for the B00 tests. Typical signals from the B00 magnet are reported; the noise problem is discussed and the noise reduction solution is presented.

1 INTRODUCTION

The L.A.S.A. (Laboratorio Acceleratori e Superconduttività Applicata) is involved in the ATLAS Collaboration for the design and realization of the Acquisition System (LASA-DAQ) for the electrical signals of the coil model of the main magnet detector.

The superconducting model, called B0, has several purposes, like to verify the design choices, the construction capabilities, and the operational behaviour of the final large superconducting coil, called Barrel Toroid (BT)⁽¹⁾.

The B0 is one-third length but full-scale large model of the BT and all the behaviour test and solicitation can be reproduced in it.

In addition to B0 a smaller magnet, called B00, has been designed, with the aim of checking the superconducting cable.

The electrical signals coming from the coil are of two types, the isolated and non-isolated ones.

The non isolated signals come from voltage taps into the coil cable, and so they are directly linked to the main current flowing in the coil; the others signals come from sensors that are isolated from the main current (i.e. inductive pick-up coils, Hall probes and pressure sensors).

In the B0 model coil there are 31 isolated signals and 32 non-isolated.

For the last signals an electrical isolation circuit must be provided in order to protect the acquisition electronic from overvoltage in quench event (transition from superconductive state to resistive conduction) and interrupt the ground loop.

The detailed list of the electrical signals is reported in ⁽²⁾.

The LASA-DAQ main purpose is the reconstruction and the study of the quench, either spontaneous or intentionally induced.

The LASA acquisition has not operational purposes; the quench detection function is done by the Magnet Safety System (MSS) that provides magnet safety (heaters operating and discharge the magnet energy).

This paper reports the study of the circuit before the acquisition, i.e. the electronic cards providing galvanic isolation between the electronic acquisition and the coil, together with the solutions followed to interrupt the ground loop and reject common-mode voltage and electromagnetic noise^(3,4).

These are typical problems for acquisitions in industrial environment.

At first, two modular general-purpose cards, developed by CERN, have been tested, to check their possible utilization, in order to save money and time.

Following these tests, the best solution both technically and economically was to design a new dedicated card.

2 ACQUISITION CHARACTERISTICS

2.1 General Characteristics of the Acquisition System

- Read about 60 differential voltages.
- Acquisition rate: 1 kS/s.
- Minimum amplitude resolution: some μV .
- To operate in industrial environment, with vacuum pumps and different power apparatus. The acquisition station is about a hundred meters away from the magnet.
- Modularity and expandability of the system, in order to use it for the final Barrel Toroid magnet tests.

2.2 Specific problems solved by the isolation card

- Ground loop between magnet power supply and acquisition system common reference; the grounding of the experimental area where the magnet is tested (CERN Bldg. 180) does not guarantee a homogenous reference among different points of the electrical system.
- Electromagnetic noise of the Danfysik switching power supply (see Table 1).
- Overvoltage, about $1000 \text{ V}^{(1)}$, between the single voltage tap and the power supply ground during a quench event (this is not the case of B0, but it can happen in particular operation conditions of the full toroidal magnet).

TABLE 1 – B0 Power Supply Ripple Characteristics

24 kA – 6 V POWER CONVERTER – DANFYSIK	
Frequency	Output Voltage Ripple (mV r.m.s.)
50 – 300 Hz	15
Switching frequency (> 20 kHz) and its harmonics	3

3 CERN CARD

Two isolating cards have been developed at CERN for the control and diagnostics of the Large Hadron Collider (LHC) superconducting magnets

- Station de tests LHC – Potentials Aimant. Vers.3
- DVMM 100 - DUAL VOLTAGE MEASUREMENT MODULE

Being the latter the evolution of the former.

In order to check the utilisation of these cards a test apparatus has been developed at LASA.

The test apparatus is composed by:

- Multiplexer HP 34970A, 6.5 digit.
- Pt100 with mV/°C conversion card.
- Personal Computer with IEEE 488 interface.
- LabView 5.1 graphic platform.

3.1 POTAIM-3 Card

The main parameters of the POTAIM-3 card are listed in Table 2.

TABLE 2 - Main parameters of the POTAIM-3 card

Isolation Amplifier (IA)	AD210
Input Voltage	±10 V
Output Voltage	±5 V, ±10 V
IA Gain	1.2, 4, 10, 40, 100
Bridge Regulation of the Input Voltage	Yes
IA Offset Regulation	Yes
Input Filter with Settable Cut-off Frequency	Yes

By setting the input gain at 1.2 and $V_{in} = \pm 10$ V the card is not able to acquire signals lower than ± 10 mV, as shown in Fig. 1 and 2. This fact limits the system dynamic range. The problem is increased with higher gain set.

The measured gain for different input voltage is reported in Table 3. During the measurement the temperature was constant, about 21 °C.

TABLE 3 – Measured gain for different input voltages.

$V_{in}(mV)$	Actual Measured Gain (set G = 40)	Actual Measured Gain (set G = 10)
0.5	80	24
1	65	17
2	53	-
5	45	-
10	42	10.7
14	-	10.5

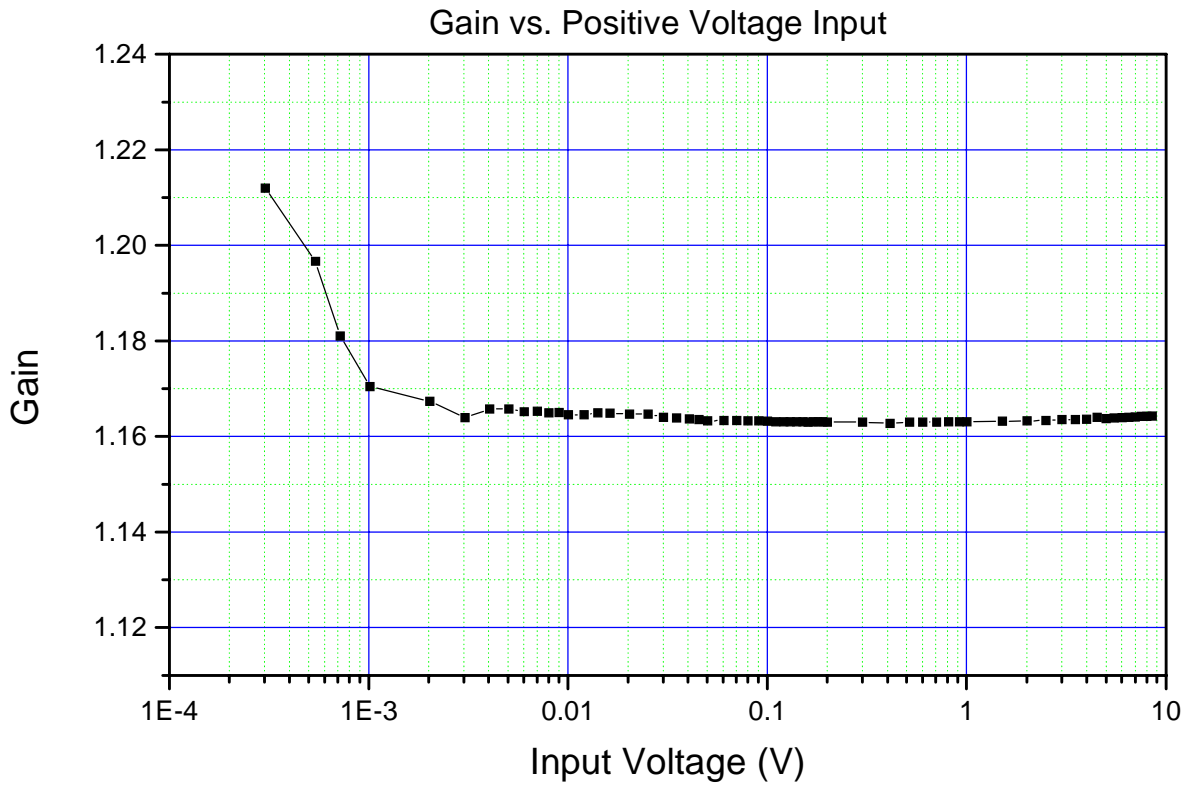


FIG. 1 – POTAIM-3 card test. Gain as a function of a positive input voltage.

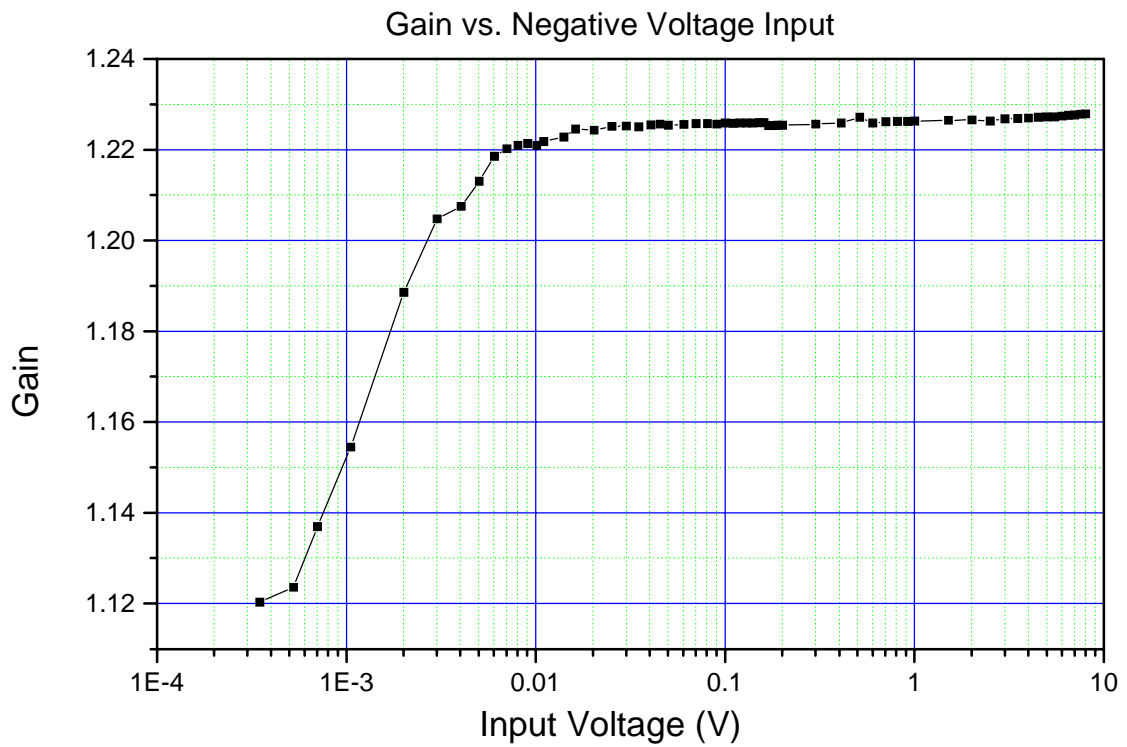


FIG. 2 – POTAIM-3 card test. Gain as a function of a negative input voltage.

Longer measurements times (about 70 hours) have shown a negative temperature effect, i.e. a decrease of the gain respect to an increase of temperature, as shown in Fig.3.

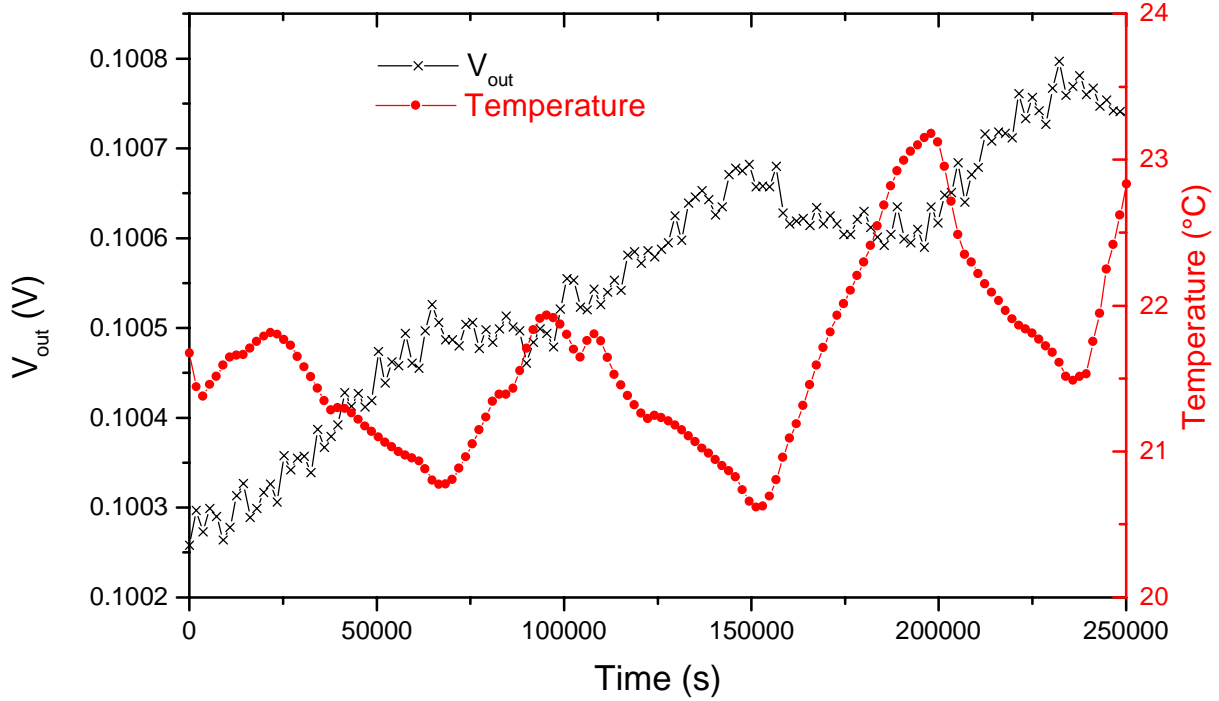


FIG. 3 – Output voltage and temperature vs. time.
The input voltage was 0.86 V with gain set to 1.165.

This thermal drift is due to the passive components, specifically the regulation and gain resistance; the active components have negligible drift characteristics.

The maximum difference is about 500 μ V, with a temperature variation of about 4 degrees. If we consider the gain at 21 $^{\circ}$ C and refers the output voltage to this value the output voltage variation is about 20 μ V representing in this case the thermal drift effect of the electronics with the exclusion of the amplifier (see Fig. 4).

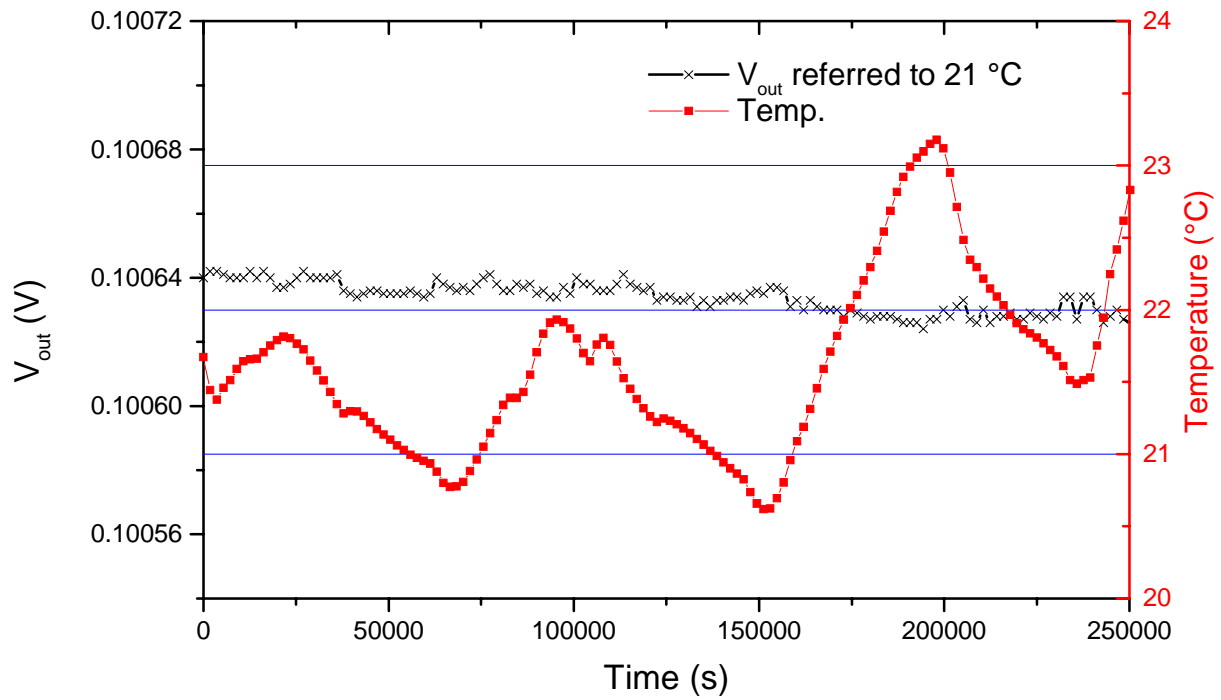


FIG. 4 – V_{out} referred to 21 °C and temperature vs. time.
This normalization shows the thermal effect of the electronics, but the amplifier.

All measurements show temperature dependence, but this problem can be solved via software. As a matter of fact, the temperature effect can be measured during the calibration of the isolation modules; then, during the routinely operation, a monitoring of the temperature will allow to correct for the thermal effect. The temperature effect is almost linear, as shown in Fig.5, where the difference between the output voltage V_{out} and the output voltage V_{outN} referred at 21°C, and the temperature are plotted as a function of the time.

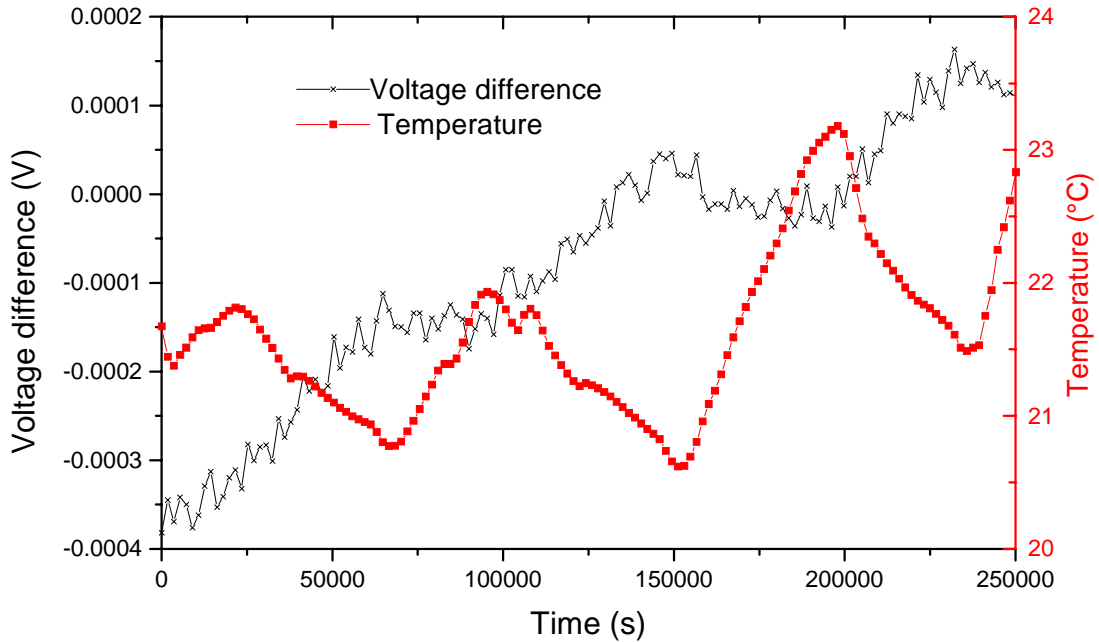


FIG. 5 – $(V_{out} - V_{outN})$ vs. time.

An isolation stage and a digital one with time and amplitude levels compose this CERN circuit. This configuration allows the quench detection in a superconducting cable, so the circuit can be the main component of a Quench Detection System (QDS). For our purpose, i.e. the isolation of the signals, the digital circuit is not useful.

Let's note that the AD210 component (Isolation Amplifier) is an intrinsically noisy component, so the electronic board must be designed in order to have as much as possible a grounded copper layer.

4 DVMM100 CARD

This general-purpose CERN card has been designed for the LHC magnets diagnostic. Like the POTAIM card it is mainly dedicated to the superconducting coils QDS. An instrumentation amplifier (In-Amp), followed by an isolation amplifier (IA) and by an active low-pass filter composes the front-end of this new card. In addition to the improvement of the input circuit, the QDS stage has been developed with the addition of a Dual Voltage Discriminator and a Dual Duration Discriminator. Moreover a 20mA Current Loop Circuit for long distance measurements has been added.

We did not perform any test on this card, being the front-end circuit, the only one useful for the B0 tests, a classical scheme for non-isolated data acquisition.

The DVMM100 circuit analysis suggests these considerations:

- The In-Amp protection diodes have a too high reverse current; this can affect the precision of the component itself.

- The In-Amp has not offset regulation, a fundamental need for low-level signals.
- There is not a large ground plane running under the components on printed circuit board.
- The high capacitance in the 2nd order low-pass filter, after the IA, can affect the circuit settling-time.
- Most of the electronic components are not useful for our purposes.

These facts drove us to decide to develop a new dedicated board, for the quench data acquisition and studies on the B00 and B0 model coils.

5 LASA CIRCUIT

5.1 General Consideration

The designed circuit has three purposes: to isolate galvanically the acquisition from the magnet coil, to interrupt ground loop and leakage paths and to filter the environment noise, particularly from the magnet switching power supply.

The main frequencies from the power supply are:

- 50 Hz and its harmonics due to non-homogenous AC common ground reference between the power supply and the acquisition system.
- 26 kHz switching frequency
- 1400 Hz and ~ 300 Hz, characteristic ripple of the power supply.

The first two parameters have been measured with 10 kA current in the main coil, while the others at 20 kA.

From these data follows that the circuit must be a low-pass filter with cut-off frequency (f_c) lower than 50 Hz, but the quench signal characteristics must be taken into account.

As a matter of fact, because of the parameters of the superconducting cable and of the distance between two voltage taps, the voltage signal goes from 0 to 50 mV with a rising time of about 40 ms. In order to reconstruct the signals, the cut-off frequency of the filter must be higher than 100 Hz.

5.2 Electronic Scheme and circuit analysis

The LASA card scheme is shown in Fig. 6.

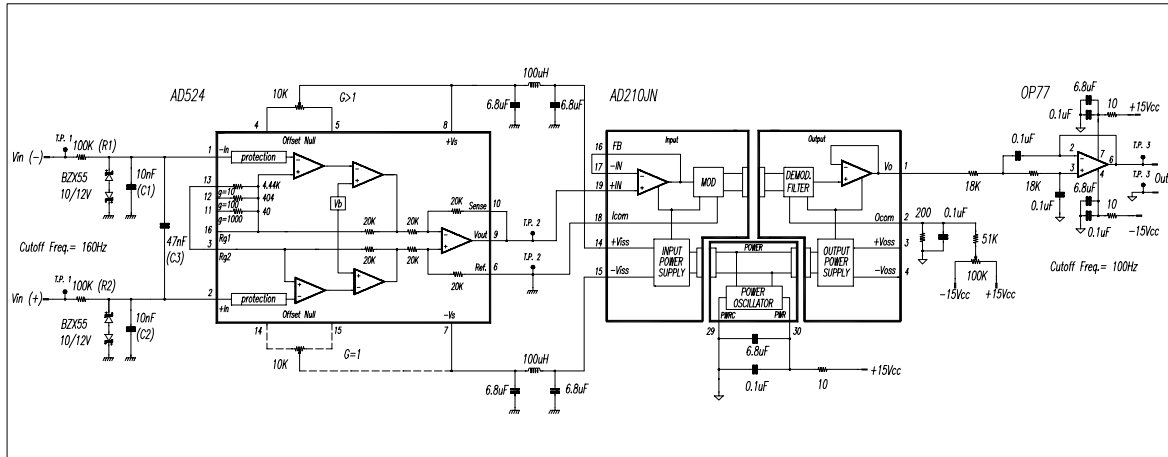


FIG. 6 - LASA Isolation Amplifier Card

The circuit is composed by the following stages:

1. Passive input filter: Radio frequency interference (EMI), by coupling into the operational amplifier through its input, output, or power-supply pins, can affect the DC performance of our high-accuracy circuit. To minimise or prevent errors a proper filtering was improved.

The LASA-circuit input shows a common-mode filtering (R1/C1, R2/C2), and a differential-mode filtering (R1+R2, and C3).

To prevent the conversion of input common-mode in V_{in} differential signal, R1/R2 and C1/C2 must be well matched: R1 and R2 within 1%, C1 and C2 within at least 5%. Capacitor C3 helps to attenuate the differential signal that can result from imperfect matching of the common-mode filters.

For optimum filter performance, the passive components are symmetrically mounted on printed circuit board with a large ground plane under the active components (AD524 and AD210)⁽⁵⁾

TABLE 4 – Passive filter features ($F_{\text{cutoff}} \cong 160 \text{ Hz}$)

$R1/R2 = 100 \text{ k}\Omega$ $C1/C2 = 10 \text{ nF}$ $C3 \gg C1/C2 = 47 \text{ nF}$ Diff. Filter Bandwidth = $\frac{1}{2\pi(R1 + R2) \left[\frac{C1 * C2}{C1 + C2} + C3 \right]}$
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2. **BZX55** low bias current zener, in clamping configuration, to limit the bipolar input voltages and protect the next differential stage.
3. **Instrumentation Amplifier AD524** is a precision monolithic instrumentation amplifier, an outstanding combination of high linearity, high common mode rejection, low offset voltage drift and low noise. The two input terminals impedance are balanced and have high values ($10^9 \Omega$ greater). Input and output offset nulling, pin programmable gain are provided for very high precision applications, as in our case. The main function of the In-Amp is to amplify the difference between two signals. In addition, being this component characterised by a high Common-Mode Rejection (CMRR)^(6,7); it removes the signals common at both the input (external interference). As previously said the acquisition system must operate in an industrial noisy environment where the main noise source is pick-up from 50 Hz power line frequency. Flashing lights, vacuum pumps, motors and every apparatus connected to the main power line are font of noise.

The plot of AD524 CMRR vs. frequency shows the CMRR remains flat up to 100 Hz, it then begins to decrease. His value drops to approximately 90 dB with a gain of 10 at 500 Hz. It means the efficiency of common mode rejection for the AD524 is good from the main interference (50/60 Hz) up to the seventh harmonic (350/420 Hz).

For the switching frequency of the magnet power supply (>20 kHz) more filters must be used both before and after the isolation circuit.

The main characteristics of the AD524 are listed in Table 4. It can be noted the low noise, nonlinearity offset voltage and offset voltage drift and the high CMRR.

TABLE 5 - Main parameter of the AD524 Instrumentation Amplifier

Noise	0.3 μV p-p (0.1 Hz to 10 Hz)
Nonlinearity	0.003% (G=1)
CMRR	120 dB (G=1000)
Offset Voltage	50 μV
Offset Voltage Drift	0.5 $\mu\text{V}/^\circ\text{C}$
Gain Bandwidth Product	25 MHz
Pin Programmable Gain	1, 10, 100, 1000

4. **Isolation Amplifier.** The IA has an input circuit that is galvanically isolated from the power supply and the output circuit. Isolator are intended for application requiring safe, accurate measurement of voltage signals in the presence of high common-mode voltage, to thousands of volts, with high CMR. The AD210 is a three-port isolator. It has the input circuit, output circuit and the power source isolated each other. An auxiliary power is available for the input and output circuitry, so the In-Amp can be powered and contemporarily isolated. The auxiliary power is characterised by a 50 kHz carrier frequency, so a π filter, composed by two 6.8 μF capacitors and a 100 μH inductance, with resonance frequency of 6.1 kHz, is employed. The choice of the LC filter instead of the equivalent RC avoids power dissipation in the resistance, since AD210 Input Power circuit supplies the AD524. The characteristics of the AD210 Isolation Amplifier are listed in Table 5. Note the high CMV isolation and CMR, the low nonlinearity and the wide bandwidth.

TABLE 6 - Main parameter of the AD210 Isolation Amplifier

CMV Isolation	2500 V rms Continuous; ± 3500 V Peak Continuous
Three-port Isolation	Input, Output and Power
Nonlinearity	$\pm 0.012\%$ max
Bandwidth:	20 kHz Full-Power
Gain Drift:	± 25 ppm/ $^\circ\text{C}$ max
CMR	120dB (G=100 V/V)
Isolated Power	± 15 V @ ± 5 mA

5. **Active Filter.** It is a second order low-pass filter. It is devoted to cut the oscillation frequencies of the AD210, without affecting the quench signals. A cut-off frequency lower than 100 Hz would have induced a phase shift and a signal attenuation of the signal, as shown in Figs. 7 and 8. The simulation of the filters is performed with Circuit Maker V6.2.

The Figs.7 and 8 are both in the next page, in order to easies the comparison.

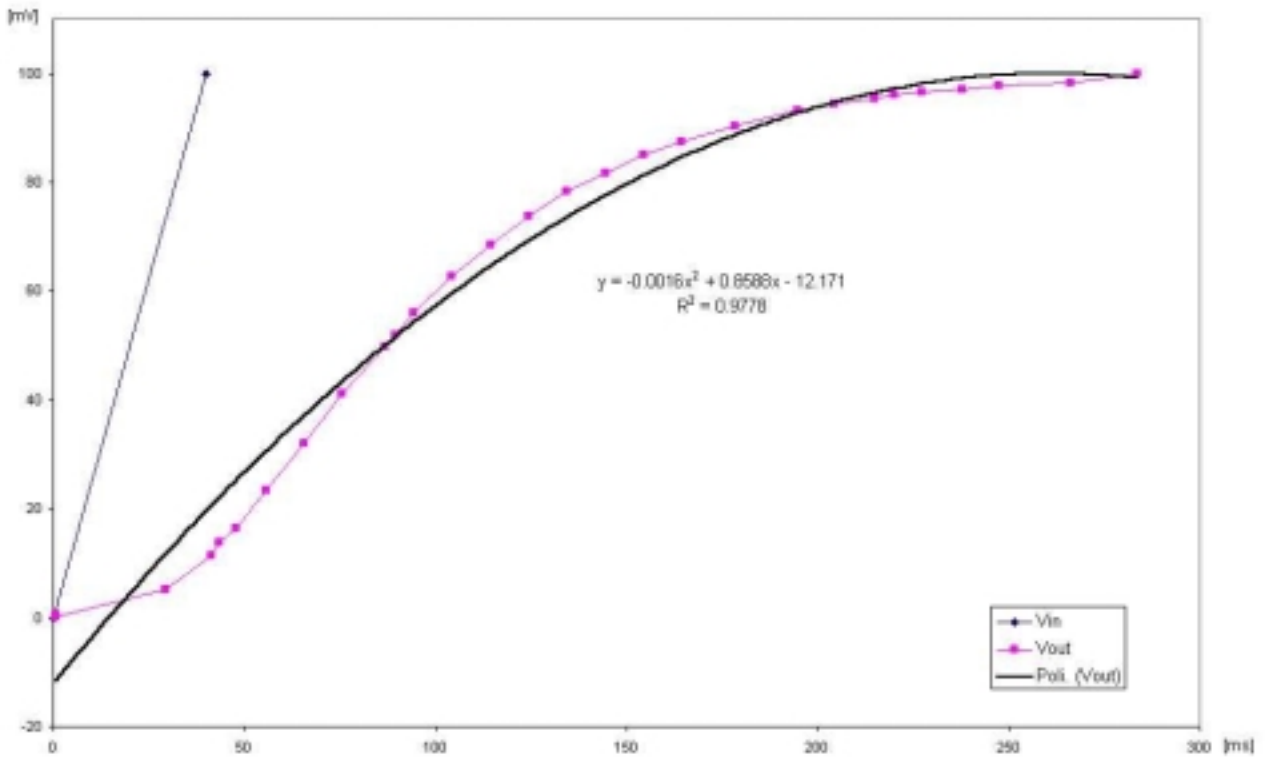


FIG. 7 – Active filter, $f_c = 4$ Hz

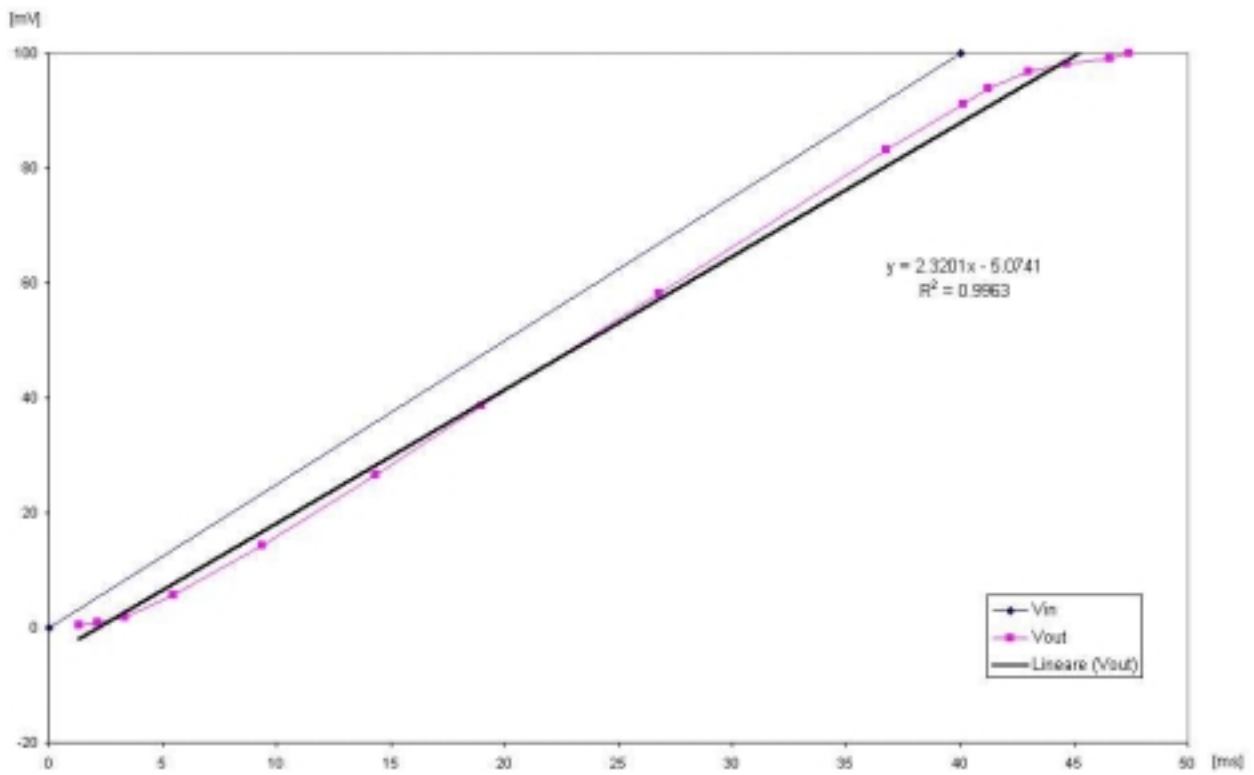


FIG. 8 – Active filter, $f_c = 100$ Hz

6 THE NEW CARD AND THE ACQUISITION SYSTEM

The design of a new circuit by LASA provides a new *ad hoc* card for the quench studies on the B00 and B0 coil. The new card is shown in Fig. 9.

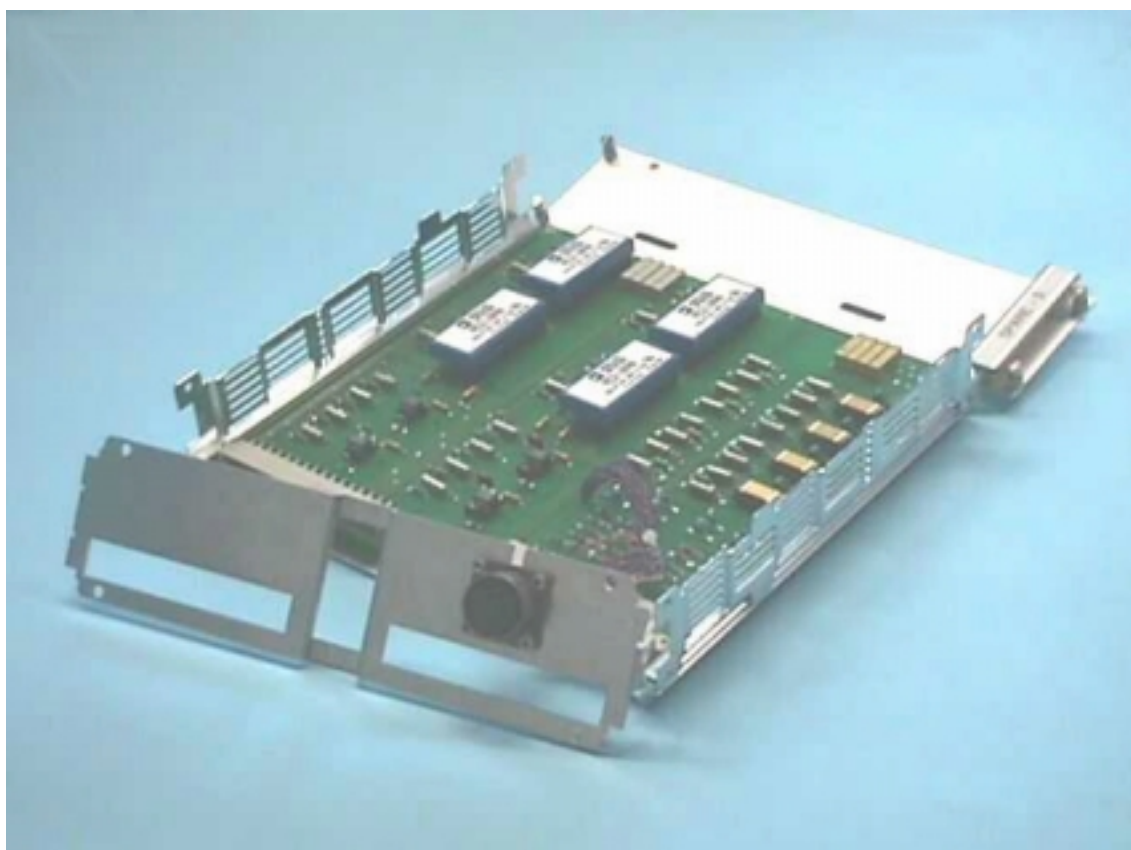


FIG. 9 – The isolation-filter card inside the EMC frame plug-in.

Great care has been given to the circuit engineering in order to have a full harmonization with the LASA-DAQ data acquisition station⁽²⁾, shown in Fig. 10, meanwhile preserving a multi-purpose characteristic.



FIG. 10 – The LASA-DAQ system in the CERN control room (Bldg. 180).

Because of the high signals number (31) the acquisition card has modularity four, i.e. 4 full circuits are on the same board.

Each card is inserted into an Electro Magnetic Compatible frame plug-in, Europe standard that shields the components from the high frequency radiation and avoids direct air flow onto the components⁽⁸⁾.

The operational amplifiers offset regulation can be done from the front panel. In addition a back-mounted connector allow the stage circuit monitoring, both for the calibration and for the diagnostics of each isolated channel.

The cost per channel is relatively low (150 Euro), about the same than for the CERN cards.

7 RESULTS

The B00 test has allowed us to set-up and verifies the LASA acquisition system, particularly the isolation-filter stage of the circuit, dedicated to the acquisition of the voltage tap signals⁽⁹⁾.

During the coil excitation some quenches have been induced; the signals have been acquired with a rate of 500 samples per second either with or without the isolation-filter card.

The data of the voltage signal, called DRP-2, without and with the isolation-filter card are shown in Fig. 11 and 12 respectively.

The good performances of the lowpass isolation-filter circuit are evident; as a matter of fact the inductive signal due to the quench propagation in the different turn of the coil can be seen. The same data acquired without the isolation-filter card and software filtered with a low-pass 6th order Butterworth LabView software filter⁽¹⁰⁾ are shown in Fig. 13. As we can see the signal trend is brought out, but low frequencies (< 50 Hz) are present. This is the aliasing phenomenon: frequency components above the Nyquist frequency are aliased and appear as lower frequency below the Nyquist value. Only analog filters can prevent aliasing. Digital filters cannot aliases because it is impossible to undo aliasing after the signal is sampled.

Figs. 14,15 and 16 are the analogous of Figs. 11,12 and 13 but for the DRP-3 voltage tap signal.

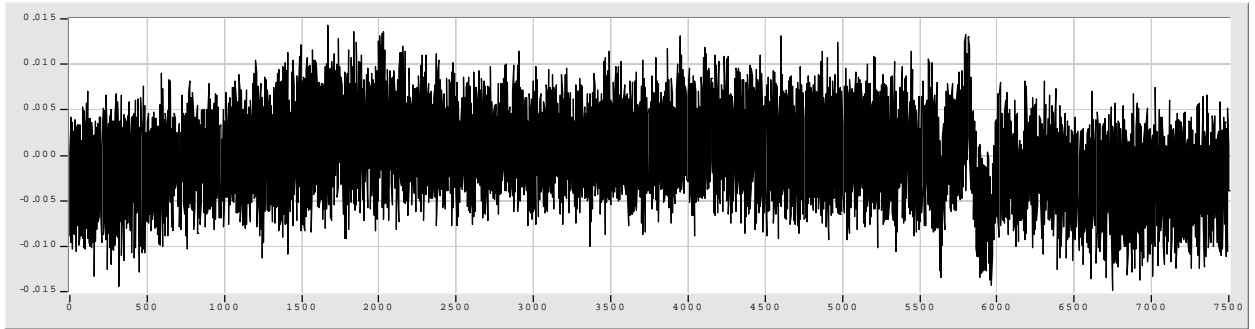


FIG. 11 – DRP-2 signal without the isolation-filter card.

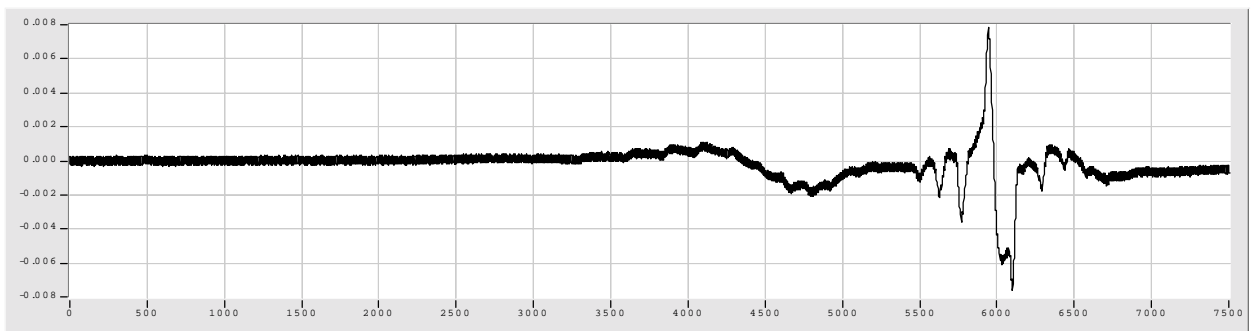


FIG. 12 – DRP-2 signal with the isolation-filter card.

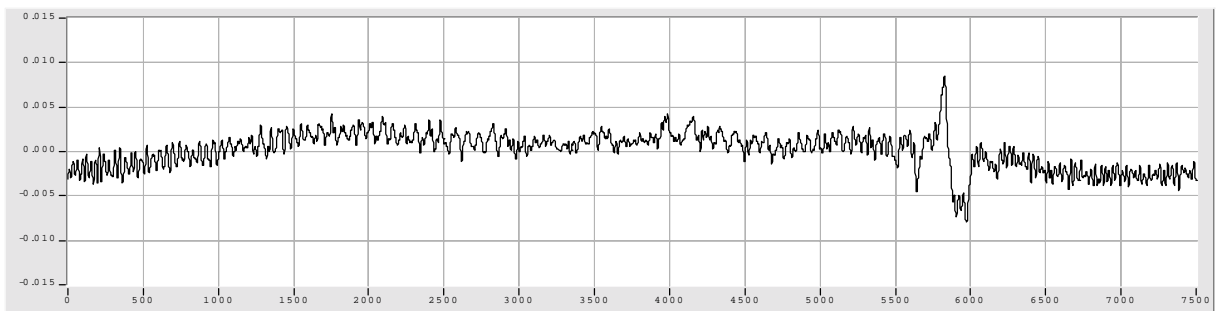


FIG. 13 – DRP-2 signal with the software filter.

In Fig. 14, 15 and 16 the same plots for the signal DRP-3 are shown.

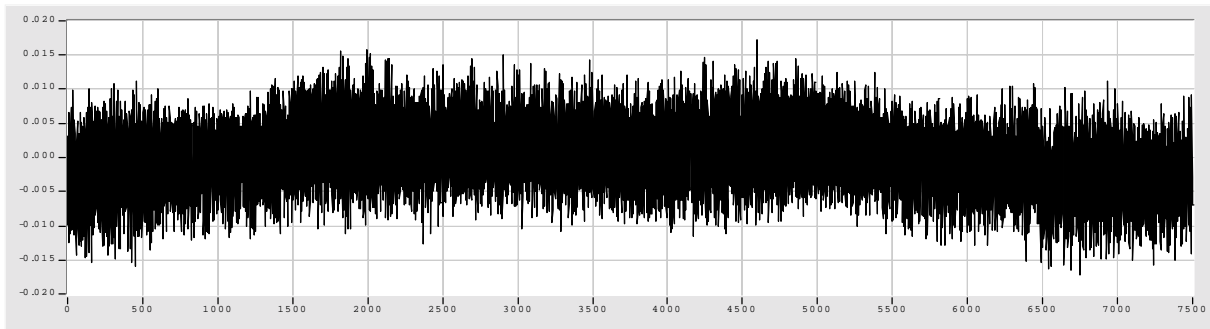


FIG. 14 – DRP-3 signal without the isolation-filter card.

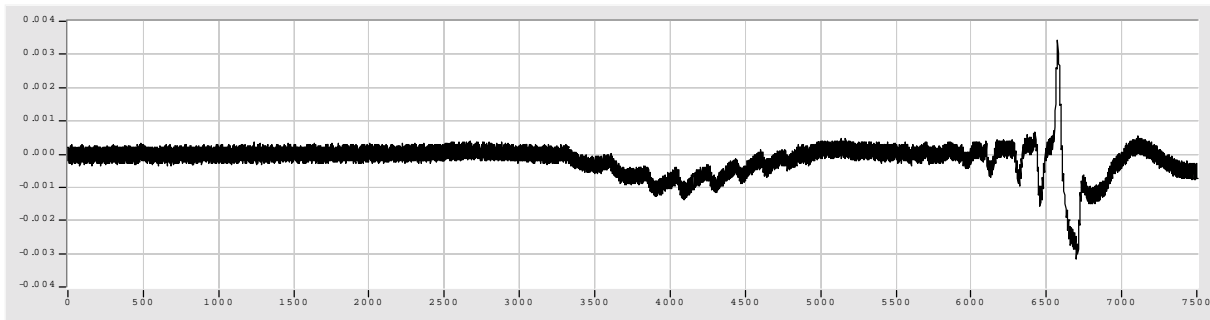


FIG. 15 – DRP-3 signal with the isolation-filter card.

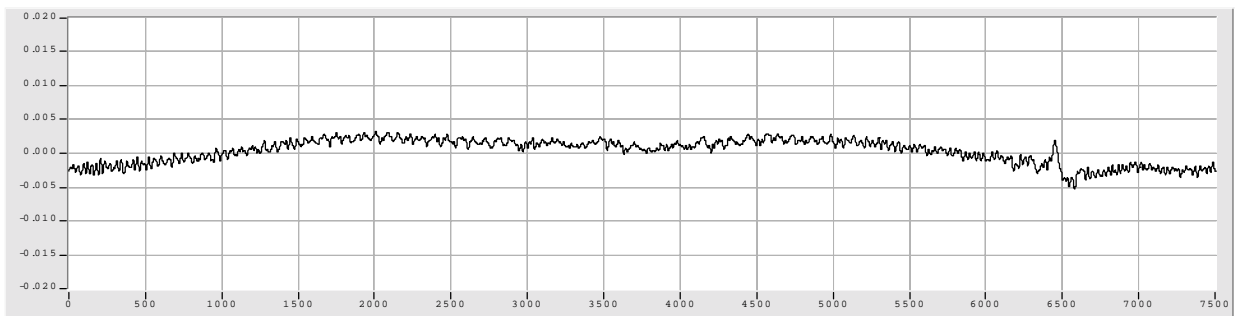


FIG. 16 – DRP-3 signal with the software filter

8 CONCLUSIONS

Starting from the existing CERN cards a new one has been designed. The main purpose of LASA circuit is to acquire the signals that must be isolated by possible overvoltages arising from the quench event. This card does not include the quench detection circuit, not needed for our purpose, but include a filter stadium. Filtering is mandatory because of the environment interferences and the switching frequency of the magnet power supply. The test “on the field” during the B00 excitation, has allowed us to fully harmonise and test the LASA-DAQ for its main purpose, i.e. the B0 tests.

In this way the multipurpose and adaptability of the whole apparatus has already been checked.

The optimum performances of the acquisition system during the B0 test and, particularly, during the B0 excitation, validate the technical choices and design for the acquisition electronics.

9 REFERENCES

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