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## THE LASA FAST ACQUISITION SYSTEM FOR THE B00 AND B0 DIAGNOSTICS


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### Abstract

The ATLAS Barrel Toroid (BT) is a superconducting toroid made of 8 superconducting coils of 25 m length and 5 m width, providing the magnetic field for the muon spectrometer of the ATLAS detector, one of the experiments of the Large Hadron Collider, under construction at CERN.

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 behaviour of the final coils.

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.

During the coils excitation there are two physical conditions: the power-on steady state and the quench event.

The LASA-DAQ acquires always at the same sampling rate (500 Sample/sec), while the data storing occours once at second in steady state and at maximum speed during the quench.

In this paper the characteristics and the design; both hardware and software, of the acquisition system of the electrical signals from the B0 model coil are described.



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# 1 INTRODUCTION

The Barrel Toroid Magnet (BT)[1] is part of the Magnet System of the ATLAS Detector that will be installed on the large Hadron Collider (LHC). It consists of eight flat superconducting coils of 25 m length and 5 m width, radially assembled around the beam axis and providing the magnetic field required by the muon spectrometer.

The field will extend over a length of about 26 meters with an inner bore of 9 meters and an outer diameter of about 20 meters. These coils being about 5 times larger than any other superconducting coil ever built, the CEA (Saclay), CERN and INFN (Milan) built a working model, called B0. It is similar to one BT coil, both for the design concept and the construction procedure with the same width and the same cross section (4.5 m x 0.25 m, in order to qualify the design, verify the manufacturing procedure and validate the technical solutions) but with a reduced length (9 m). B0 coil installed in the test station at CERN is shown in Fig. 1.


**FIG. 1:** The B0 magnet in the test station.

In Fig. 1 the “intermediate rack”, or “wiring rack”, where the cables from the magnet are collected and grouped before being sent to the control room (see section 6.1), is shown too.

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.

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 magnet 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 aim 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).

## 2 DATA ACQUISITION (DAQ) FUNDAMENTALS

Today, most data acquisition systems in laboratory research and industrial automation are based on personal computers (PCs) with Pentium processors coupled with the higher performance PCI, PXI and FireWire bus architectures[3)]. Many applications use data acquisition (DAQ) plug-in to acquire data and transfer them directly to computer memory.

A PC-based DAQ system has the following elements:

– Personal Computer
– Transducer
– Signal Conditioning
– DAQ Hardware
– Software

**Transducers:** sense physical phenomena and produce electrical signals that the DAQ system measures. For example, Resistance Temperature Device (RTD), Strain Gages (SG), Hall probes or electrical signals proportional to the physical parameters.

**Signals Conditioning**: the transducer outputs must often be conditioned to provide signals suitable for DAQ board.

The most common type of conditioning is signal amplification. Low level signal should be amplified to increase the resolution and reduce noise. For the highest possible accuracy, the signal should be amplified so that the maximum voltage range of the conditioned signal equals the maximum input ADC range. Isolation conditioning has the purpose to protect the electronic system from high voltages at the sensors. Galvanic isolation is also used to break ground loops where even a small resistance between two system grounds may produce an unacceptably high potential. Filtering is another function; this circuit removes unwanted signals from the signal that it is trying to measure.

**DAQ Hardware:** Basic specifications, available on most DAQ products, are:

– Number of channel inputs
– Sampling rate
– Input range
– Resolution

The number of analog channel inputs is specified for both single-ended and differential inputs on board. Single-ended inputs are all referenced to common point. By differential inputs, every input has its own ground reference; noise errors are reduced because the common-mode noise picked up by the leads is cancelled out.

According to the Nyquist theorem, the data must be sampled at least twice the rate of the maximum frequency component in the signal to prevent aliasing.

The range, resolution and gain available on a DAQ board determine the smallest detectable change in voltage.

**Software:** Software transforms the PC and the DAQ into a complete data acquisition, analysis, and display system. Generally every DAQ boards producer develops his own software. Very useful is LabView, a National Instruments (NI) product. The LabView graphic oriented program allows to control every kind of instrument, also not NI, manages and presents data and supports complex local network.

## 3 B0 SYSTEM REQUIREMENTS

– Signal Number : about 60 analog signals
– Range/resolution : min. ± 100 mV / 100 μV ; max. ± 10 μV / 100 μV
– Sampling rate : 1 ms/Sample = 1 kS/s
– The control room is about a hundred meters away from the magnet and the signal leads

travel through noisy environment.

- Incompatibility between the magnet power supply GND and System Acquisition REF.
- Overvoltage protection during a quench event (~ 1000 V) for some signals in the final BT application
- Output voltage ripple from magnet switching power supply.
- Data transfer by a Local Area Network (LAN) connection.
- Local data visualization every second.

## 4 SIGNALS FOR THE LASA ACQUISITION SYSTEM FOR B0

The signals managed by the LASA acquisition system are the signals of the electrical type, i.e. from sensors[2)] related to the current in the magnet, as voltage taps, pick-up coils and Hall probes; they are listed below and their characteristics are summarized in table 1.

They are divided in 5 groups:

**a) Direct Signals to MCS** (Magnet Control System)

1) Voltage taps for quench studies
2) Pick-up coils signals
3) Junction monitoring
4) Internal Hall probes
5) Heaters

**b) Copy signals from MSS** (Magnet Safety System)

6) Current lead, superconducting line monitor and quench detection

**c) External voltage signals MCS**

7) Power supply circuit, dump resistor.
8) External Hall probes

**d) Digital signals from MSS**

9) Triggers

**e) He pressure monitor during quench**

10) Pressure transducers

The Identification Number, Id, refers to the above listed signal groups (as an example 8c are the signals of group c the item n° 8 i.e. the external Hall probes).

TABLE 1 – Signal list. (* MSS Isol. Amplifier, QDS = Quench Detection System)

| Id | Function | Quantity | Typ. Value | Isol. Amplif. | PreAmp. Gain | DAQ Range | Resolution |
|---|---|---|---|---|---|---|---|
| A1 | Quench V. taps | 19 | ±10 mV | y | 10 | ±100mV | 48.8 μV |
| A2 | Pick-up coils | 15 | ±1 V | n | | ±1 V | 488 μV |
| b6 | DCCT | 1 | 10 V | y * | | 10 V | 2.4 mV |
| | Voltages | 2 | 10 V | y * | | 10 V | 2.4 mV |
| | QDS | 4 | ±10 V | y * | | ± 10 V | 4.8 mV |
| | Voltages | 2 | 5 V | y * | | 5 V | 1.2 mV |
| e10 | LHe pressure | 3 | ± 1V | y | 1 | ± 1V | 488 μV |
| D9 | OR trgs | 1 | 0÷5 V | Optoisol | | | |
| A3 | Junction monitorin g | 5 | ~6 μV | y | 100 | ± 50 mV | 24.4 μV |
| A4 | Int. Hall probes | 2 | 100 mV | n | | 100 mV | 24.4 μV |
| A5 | Heater V. taps | 4 | 60 V | n | 1 : 6 | 10 V | 2.4 mV |
| C7 | Earth bridge | 1 | ± 10 V | y | | 10 V | 2.4 mV |
| | V monitor | 2 | ±20 V | y | | ± 10 V | 4.8 mV |
| | Dump res. Syst. | 1 | ±20 V | y | | ± 10 V | 4.8 mV |
| C8 | Ext. Hall probes | 2 | 100 mV | n | | 100 mV | 24.4 μV |

The pick-up coils are coils facing the magnet cable, whose function is to detect the magnetic field variation due to the current space redistribution during the quench. Detail of the pick-up coil can be found in[4)].

The electrical signals coming from the magnet 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, as previously said.

## 5 LASA-DAQ PRELIMINARY DEFINITIONS

The system is a Peripheral Component Interconnect (PCI) bus based.

We excluded a traditional multiplexer because of its lower acquisition speed, usually a 6.5 digit instrument acquires 60 ch/s, that is 16 ms/S.

Two PCI 32 input with ± 10V max range and 12 bit ADC plug-in boards are required. The 1 kS/s rate is not a problem; because a 12 bit max sampling rate is 1 MS/s.

The signals have not a common reference, for this reason it is indispensable a differential acquisition.

It is necessary to foresee a high accuracy current/voltage generator in order to neglect the acquisition of these powering values but only the physical one.

To avoid ground loop and input overvoltage during a quench event, every signal connected to the coils must be galvanically isolated. The other isolated signals can be directly DAQ acquired.

A filter circuit for every signal is necessary to reduce the electromagnetic noise especially from switching power supply. Other power apparatus, like vacuum pump, are noise generator, in addition we operate in an industrial environment and the acquisition station is about a hundred meters away from the magnet.

The software must control the acquisition boards and LAN connection.

A real time presentation and a simple data management are required. The signals are not homogeneous and have a wide amplitude variation. The user should be able to friendly select one or some signals to be displayed on the monitor and set the best scale to control the physical phenomenon evolution during the tests.

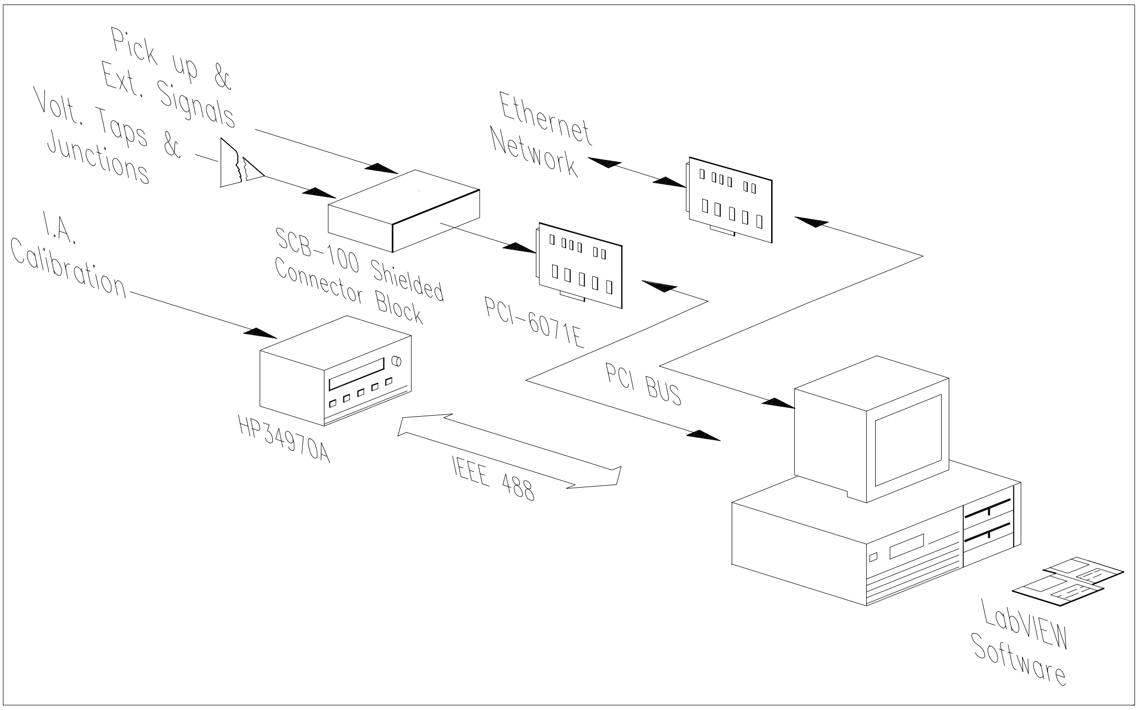



**FIG. 2:** LASA-DAQ Block Diagram.

# 6 LASA-DAQ COMPONENTS DESCRIPTION

## 6.1 Cables

The signals go from the magnet through fifteen 12 pin connectors, according to their location on the magnet, to a "wiring rack" (or intermediate rack), 50 meters away from the coil. Here the signals are grouped, according to their function, in 10 cables (see Fig.1). These cables, whose length is again about 50 m, lead the signals to the LASA acquisition station in the control room. All the cables are shielded, with the shield connected only to cryostat side.

A proper cabling and shielding scheme may be necessary to produce accurate and noise free measurements[5),6),7)]. Two double shielded cables were realized in order to study this phenomenon. Every test cable is composed by six twisted pairs. The outer shield is connected to the connector body on B0 side and to DAQ acquisition rack. The inner shield is isolated to magnet side and connected to the DAQ ground reference.

The external shield purpose is the high frequency suppression, whereas the internal shield, one side connected, avoids low frequency eddy current flowing.

The twisted pairs guarantee a good rejection to magnetic field noise up to 1 MHz, while the shield protects the signal against the electric field interferences.

Because of time constraints, no exhaustive test was made to confirm the technical superiority of this connection. An in-depth study on hardware filtering utilization was preferred. The subject could be tackle during the Barrel Toroid test.

The cable test layout is shown in Fig. 3.

**FIG. 3:** Test cable.

## 6.2 LASA Isolation Amplifier Card

For the non-isolated signals, in number of 31, an electrical isolation circuit must be provided in order to protect the electronic acquisition from overvoltage in quench event (transition from superconductive state to resistive conduction) and interrupt the ground loop[8)].

### *6.2.1 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 coil, see Table 2.

– Overvoltage, about 1000 V, 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).

**TAB. 2:** 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 (> 25 kHz at nominal power ) and its harmonics | 3 |

*6.2.2 Electronic scheme and circuit analysis*

The LASA card scheme is shown in Fig 4.

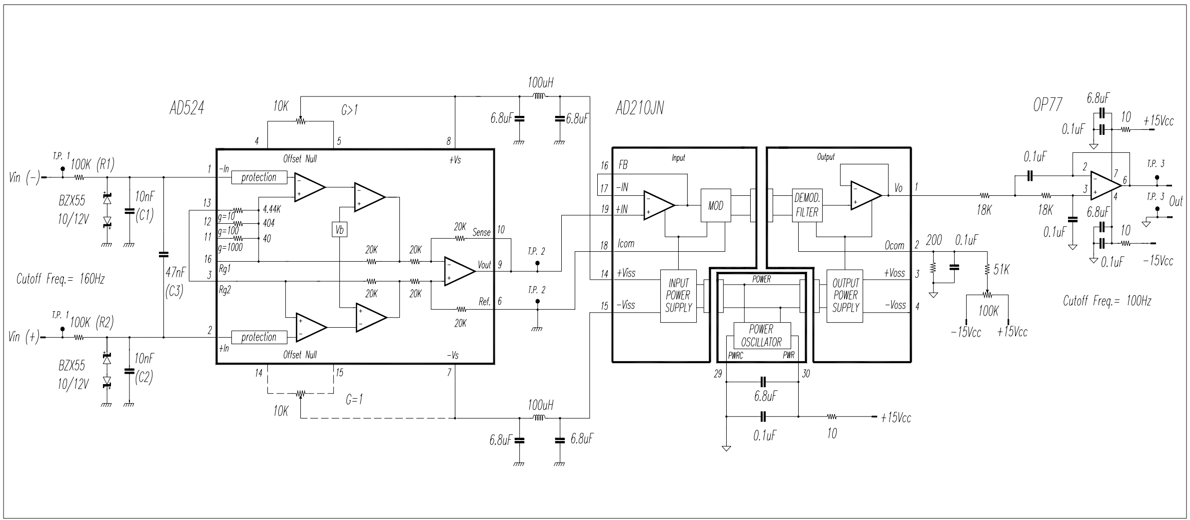



**FIG. 4:** LASA isolation amplifier card scheme.

The circuit is composed by the following stages:

1. **Passive input filter.** Radio frequency interference (EMI) coupled into op-amp through its input, output, or power-supply pins can affect the DC performance of our high-accuracy circuit. To minimize 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 the input differential signal Vin, R1/R2 and C1/C2 must be well matched: R1 and R2 within 1%, C1 and C2 within at least 5%. Capacitor C3 helps 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).

**TAB. 3:** Passive filter features (cutoff frequency = 160 Hz)

R1/R2 = 100 kΩ
C1/C2 = 10 nF
C3»C1/C2 = 47 nF

$$\text{Diff. Filter Bandwidth} = \frac{1}{2\pi(R1+R2)\left[\frac{C1*C2}{C1+C2}+C3\right]}$$

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**[9)] 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, typically $10^9$ ohm or greater. Input and output offset nulling, pins 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 characterized by a high Common-Mode Rejection (CMRR); 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, and then it 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 Hz) up to the seventh harmonic (350 Hz).

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

   Moreover the AD524 provides impedance matching function, the component provides to balance the transducer or line impedance in measurement of a dynamic variable.

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

.

**TAB. 4:** 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 μV/°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 (Common-Mode Rejection). The AD210 is a three-port isolator. It has an input circuit that is galvanically isolated from power supply and the output circuit. An auxiliary power is available to power input and output circuitry, so the In-Amp can be powered and contemporarily isolated. The auxiliary power is characterized 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 the AD210 Input Power circuit supplies the AD524.
In Table 5 the characteristics of the AD210 Isolation Amplifier are listed. The high CMV isolation and CMR, the low nonlinearity and the wide bandwidth can be noted.

**TABLE 5** - Main parameter of the AD210 Isolation Amplifier

| | |
|---|---|
| CMV Isolation | 2500 V rms Continuos; ±3500 V Peak Continuous |
| Three-port Isolation | Input, Output and Power |
| Nonlinearity | ±0.012% max |
| Bandwidth: | 20 kHz Full-Power |
| Gain Drift: | ±25 ppm/°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 AD210 oscillation frequencies, 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[10)].

Great care has been given to the circuit engineering in order to have a full harmonization with the LASA-DAQ data acquisition station[10)], shown in Fig. 6, meanwhile preserving a general-purpose characteristic.

Because of the high signals number the acquisition card has modularity four, 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.

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

The isolation-filter card inside the EMC frame plug-in and a general view of the acquisition system are shown in Figs. 5 and 6 respectively.

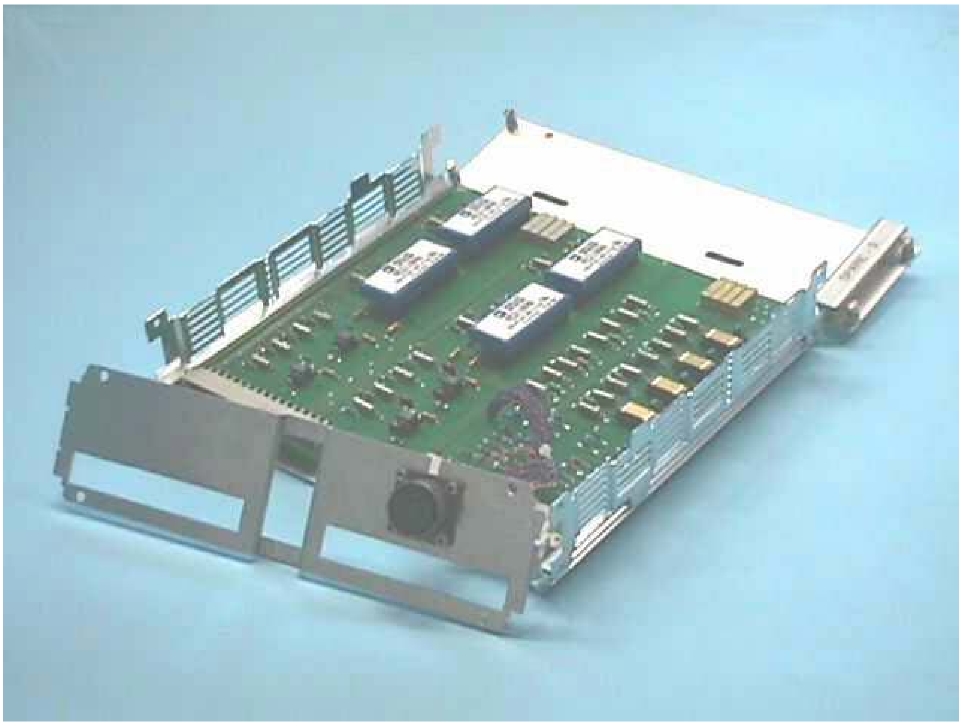


**FIG. 5:** The isolation-filter card inside the EMC frame plug-in.

**FIG. 6:** The LASA-DAQ system (front and rear) in the CERN control room (Bldg.180).

### 6.3 SBC-100 100-Pin Shielded Connector Block

The SBC-100 is a shielded board with 100 screw terminals that connect to the DAQ board using the 0.050 series shielded D type I/O connector.

The non isolated signals, with 2° order low-pass active filter on output, come from the IA circuit, are directly screwed to the SBC board.

Whereas the isolated signals are connected by a RC low pass filter, as in Isolation Amplifier Input configuration.

Differential acquisition on floating signal sources request two 40 kΩ bias resistors connected between each lead and measurement system ground, as the factory (NI) suggests.

### 6.4 Multifunction I/O Boards for PCI Bus Computers

The acquisition system is based on two National PCI-6071E boards. Table 6 shows the board specifications:

**TAB. 6:** PCI-6071E Features

| | |
|---|---|
| Resolution | 12 bit |
| N° of differential channels | 32 |
| Plug & play | Yes |
| Sampling rate | 1.2 MS/s |
| Nominal Range | ± 10 V |
| Bus | PCI |

All signals are plugged into connector block, isolated from magnet, between them and floating i.e. no referenced signals[11)]. They are acquired in Differential Connection Configuration. These connections minimize noise pickup and maximize measurement accuracy because increase common-mode noise rejection.

Each analog input of the board could be software programmed in polarity and range: each channel is configured uniquely.

With the proper gain setting we can use the full resolution of the ADC to measure the input signal.

Table 7 shows the overall input range and precision according to the input range configuration and gain used.

**TAB. 7:** PCI-6071E Input Range and Measurement Precision

| Range Config. | Gain | Actual In Range | Precision |
|---|---|---|---|
| 0 to +10 V | 1.0 | 0 to +10 V | 2.44 mV |
| | 2.0 | 0 to +5 V | 1.22 mV |
| | 5.0 | 0 to +2V | 488.28 μV |
| | 10.0 | 0 to +1 V | 244.14 μV |
| | 20.0 | 0 to +500 mV | 122.07 μV |
| | 50.0 | 0 to +200 mV | 48.83 μV |
| | 100.0 | 0 to +100 mV | 24.41 μV |
| -5 V to +5 V | 0.5 | -10 V to +10 V | 4.88 mV |
| | 1.0 | -5 V to +5 V | 2.44 mV |
| | 2.0 | -2.5 V to +2.5 V | 1.22 mV |
| | 5.0 | -1 V to +1 V | 488.28 μV |
| | 10.0 | -500 mV to +500 mV | 244.14 μV |
| | 20.0 | -250 mV to +250 mV | 122.07 μV |
| | 50.0 | -100 mV to +100 mV | 48.83 μV |
| | 100.0 | -50 mV to +50 mV | 24.41 μV |

### 6.5 Personal Computer

The main features of the personal Computer, controlling the LASA-DAQ are listed in Table 8.

**TAB. 8:** PC Features

| | |
|---|---|
| Case | Mini Tower |
| CPU | Intel Pentium III 550 MHz |
| Chipset | Intel 440BX – FSB @ 100MHZ |
| VGA | embedded VGA |
| Cache memory | 512 KB |
| RAM memory | DIMM x 1 128 Mb SDRAM up to 384 Mb max |
| Graphics | ATI Rage Pro Turbo 2X AGP 8MB SDRAM |
| LAN | On board |
| Slot | 4 PCI + 2 ISA + 1 AGP |
| Ethernet board | Intel 10/100 Wake On |
| On board I/O connectors | 2 PS/2, 1 Parallel, 2 Serial, 1 RJ-45, USB port |
| FDD | 3.5" 1.44MB FDD |
| HDD | 13 GB |
| CD-ROM drive | 40x + embedded audio |
| Operating system | Windows NT |

### 6.6 Software

The LASA-DAQ acquisition software was developed in LabView 5.1. When the application was completed, spring-summer 2001, NI released another version, but the factory was not sure about his reliability for DAQ application.

LabView, National Instruments Trade Mark, is a graphical programming language for building data acquisition and instrumentation systems.

The LASA acquisition system is based on two B0 physical conditions: power on steady state and quench event

Two optoisolated signals, coming from MSS (Magnet Safety System) with an OR function on the Channel 0, points to the LASA-DAQ the quench event. These signals are named: Fast Discharge and Quench Detection.

All the signals are always acquired with 500 Sample/sec. sampling time (the sampling rate is Isolation Amplifier bandwidth depending), and the data are placed in a circular buffer.

During a normal condition, or slow acquisition, all data are shown on screen, stored on Hard Disk and sent through Ethernet connection every second, in order to respect a VI (Virtual Instrument) protocol, each data is the average of 500 sampled data placed in the circular buffer.

In the quench event condition, called fast acquisition, unlike the slow acquisition process, the DMA operation places all data, acquired at 500 S/s, from the DAQ board into the buffer. The data are then transferred on a file which name is the same of slow acquisition plus an extension number that define the quench number in the same run.

While the buffer is being filled by the board, the computer can read the previously acquired values without disrupting the acquisition process. We can continuously use and reuse the data buffer.

Circular buffer allows us to reconstruct the quench phenomenon by the data acquired before and after a trigger event. The user can set the buffer size by the pre-trigger and post-trigger software functions. The pre-trigger limit is 15”, in this case the system must manage about 8 MB data unceasingly.

The post-trigger acquisition duration has not limit because when the buffer is full all data are transferred on file and the DMA operation reinitialized to the beginning of the buffer. In this way, continuous data collection and processing can be sustained indefinitely.

When the fast acquisition is finished, according to the set parameters, only the slow acquisition is still running and the system is ready for another quench event.

During the cool down and the magnet powering the data are visualized on the PC screen every second. The data are collected in order to homogeneity and variation criterion, the scale of the plot can be automatic or user defined.

The data acquired are not network real-time available.

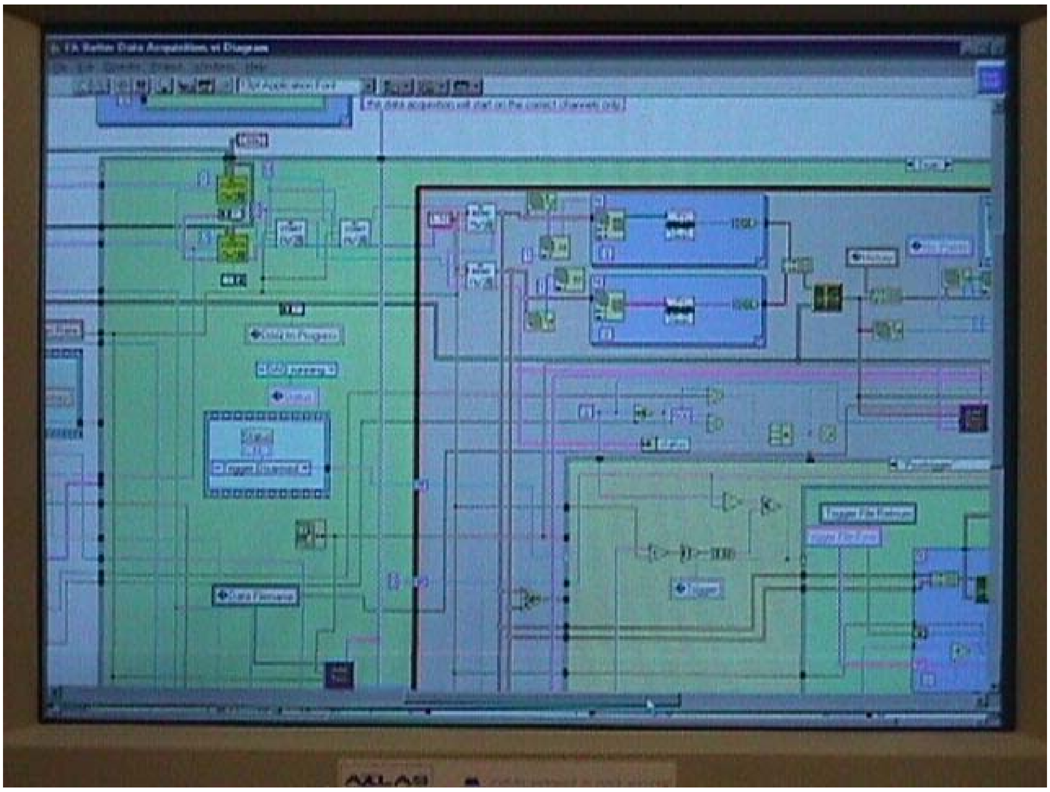
As a matter of fact the network structure and the software do not allow this.

After the closing of the data file (at the end of the acquisition run) the data file are stored in a shared directory; in this way the data file can be accessed and downloaded through the Local network.

For future applications a better integration of the whole data acquisition systems (cryogenic, mechanical, temperature, electrical, safety and control systems) will allow the real-time access to all these signals.

It must be reminded that the acquisition systems are provided by the collaboration institutions, (mechanical from CEA-Saclay, thermal from CERN, electrical from INFN-LASA), thought as independent systems, in this way there was not a standardization on the system themselves.

Of course, in view of next applications, standardization will optimize the performances and the efficiency of the systems. In Fig. 7 (a) and (b) the LASA acquisition program screen is shown. The graphic panels during the test are reported in Fig. 8.



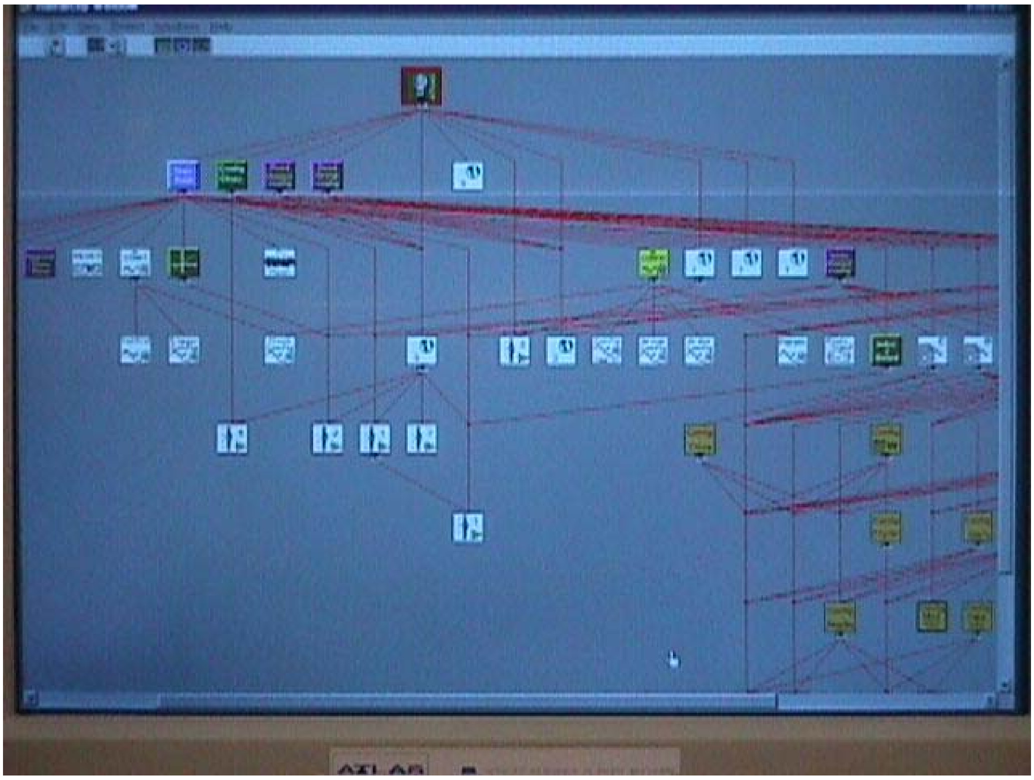


**FIG. 7(a),(b):** LabView software screen.


**FIG. 8 (a),(b):** Measure screen: numerical (a) (top), graphic (b) (bottom).

### 6.7 Multiplexer HP34970A

In the isolation-filter card, the operational amplifiers offset are adjusted by a front panel potentiometer. In addition a back-mounted connects the multiplexer HP34970A and allows the circuit calibration and the stages monitoring of each isolated channel.

The HP34970A is a high performance, low-cost data acquisition and switching mainframe ideal for data logging, data acquisition, and general purpose switching and control applications. It consists of a half-rack main frame with an internal $6^{1/2}$ digit (22bit) digital multimeter. Three module slots are built into the rear of the unit to accept a combination of switch and control modules.

Configured with three 34901A, 20-channel relay multiplexer, the 34970A become an ideal data logger for our test on LASA-DAQ circuits. The test and diagnostic programs run on LabView too.

## 7 HALL PROBES AND PRESSURE TRANSDUCERS

Also four Hall probes are acquired by LASA-DAQ. These sensors are used to monitor the eddy current in the interpancake joint, induced during the ramping up/down of the magnet current[12].

The input/output resistance of the Hall probes is ≈ 3 Ω, the sensitivity is ≈ 100 mV/T when powered with 150 mA current.

In Fig. 9 the 100 mA current generator plan is shown, his reproducibility is ± 50 ppm over 1 o 2 months.

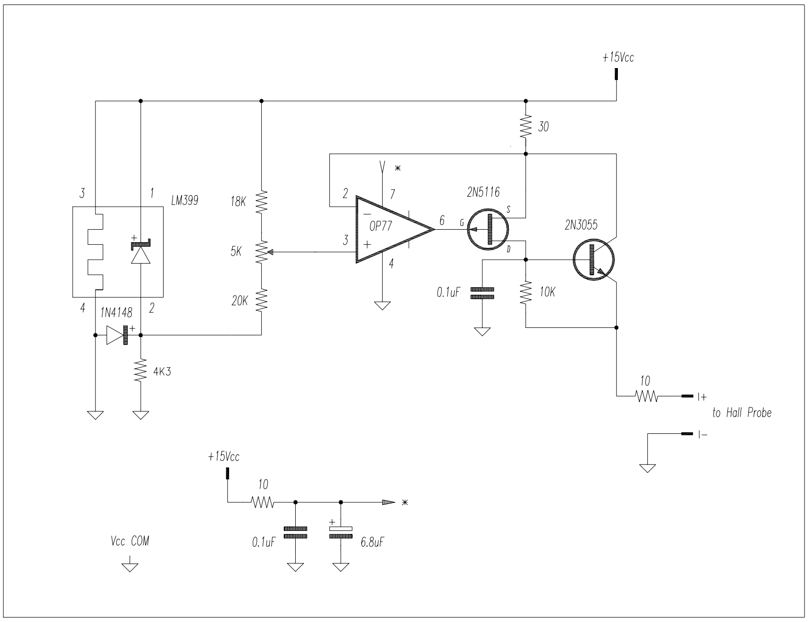



**FIG. 9:** Hall Probe Current Generator.

Four pressure sensors mod. Siemens KPY14 are mounted on B0 He cooling circuit of the cold mass, in order to monitor the cooling He overpressure during the quench.

The component body is braised on He pipeline proper place. The case is not isolated so the sensible zone is ground B0 connected. Since the LASA-DAQ is ground floating a proper voltage power supply board (fig. 10) was foresee in order to have the same magnet reference through the DC/DC converter. To avoid some ground loop the signals acquired were galvanically isolated by the Isolation Amplifier circuit.

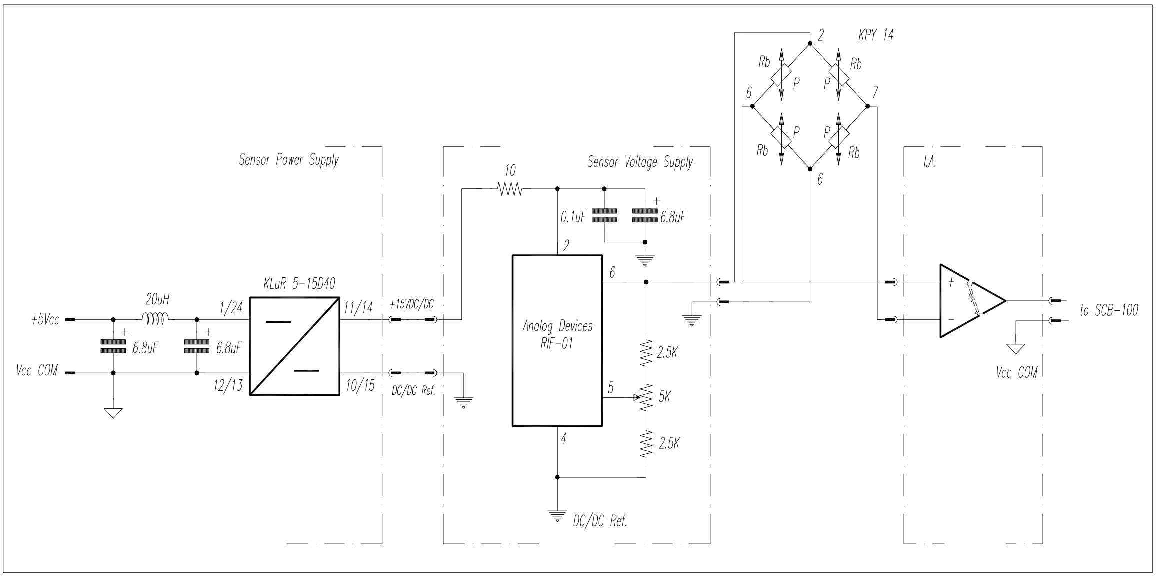



**FIG. 10:** Pressure Sensor Circuit.

## 8 RESULTS

### 8.1 B00 Magnet

The B00 test has allowed us to set-up and verifies the B0 LASA-DAQ, particularly the filter stage of the circuits dedicated to the voltage taps and pick up coil acquisition.

Some ripple measurements of Danfysik power supply were made with an analogical instrument. The AC voltage measured during B00 power up is shown in figure 11(a) to 11(h). The frequency versus the direct current in the magnet is synthesized in Table 8.

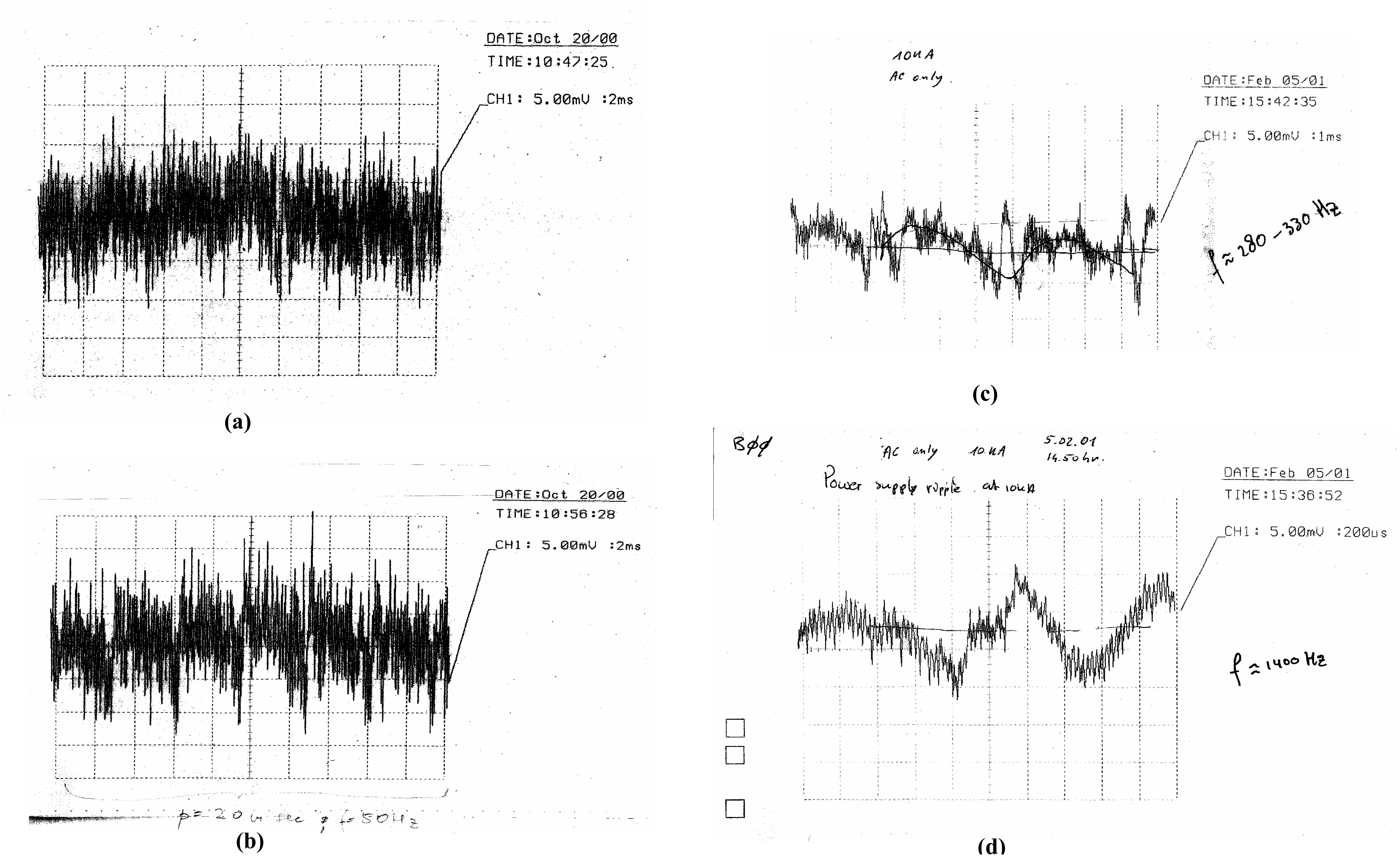



**FIG. 11:** The AC voltage of Danfysik power supply, measured during B0 power up

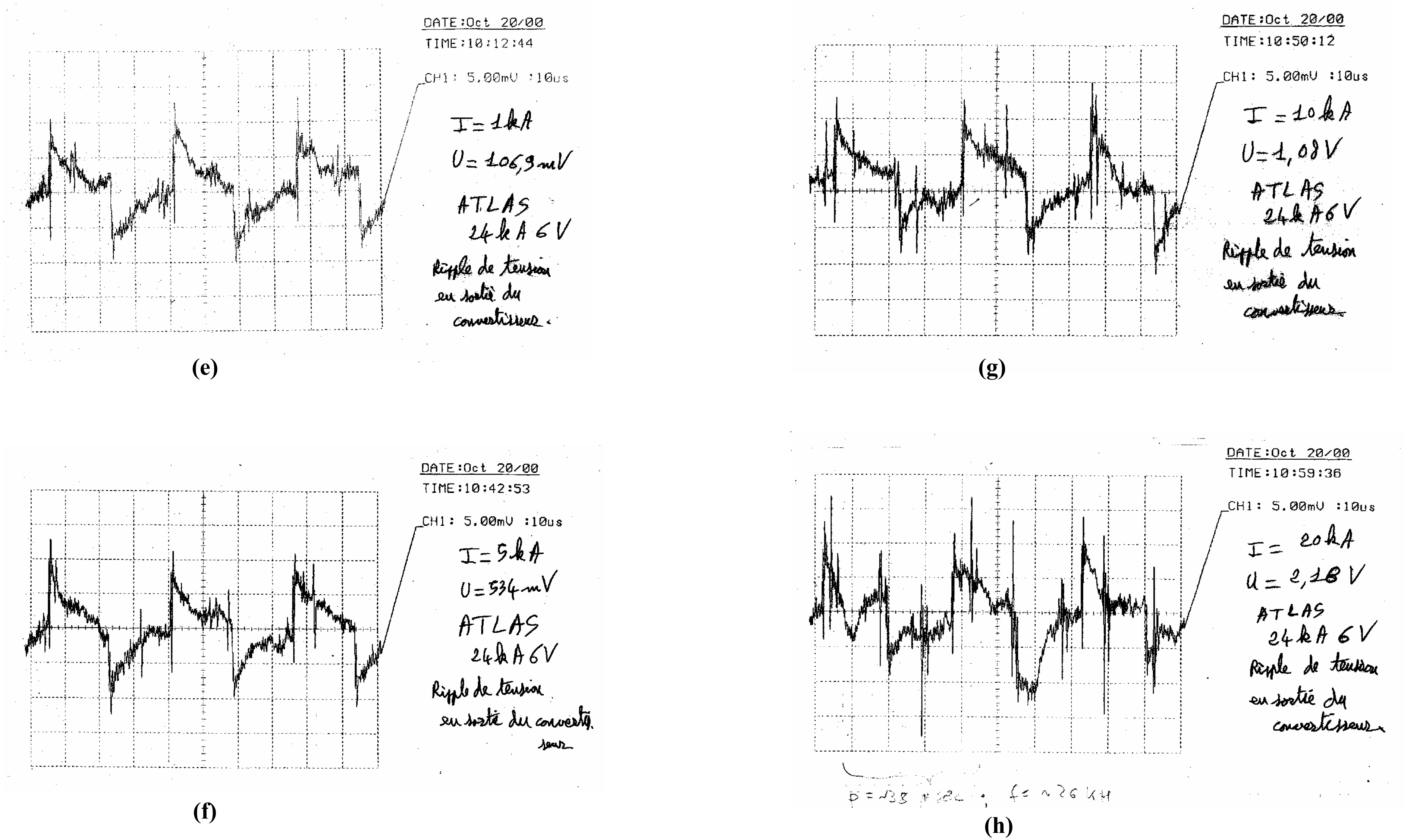



**FIG. 11:** The AC voltage of Danfysik power supply, measured during B0 power up

**TAB. 8:** Vac measured at the power supply output.

| $I_{out}$ (kA) | Frequency (Hz) | Amplitude (peak-peak) (mV) |
|---|---|---|
| 10 | 1400 | 20 |
| 10 | 280 – 330 | 15 |
| 1,5,10,20 | 50 – 250 | 25 |
| 1,5,10,20 | 27777 | 15 |

During the magnet excitation some quenches was induced and the signals acquired with a rate of 500 Samples per second either with or without the filter circuit[13)].

The comparative tests have been made only on pick up coils since the voltage taps are filtered by isolation amplifier card because the galvanic isolation is mandatory for these signals[14)].

The Figs. 12, 13 and 14 show the comparison among different input filter configurations of a signal of a pick-up coil of the B00 magnet[4)]. The slightly difference in the signal (micro)shape is due to the different physical situations during the quench induction (different heater power, main current etc.), of course it is not due to the filtering process. As a matter of fact when the physical conditions are the same the signal is repeatable as shown in Figs. 15 and 16.

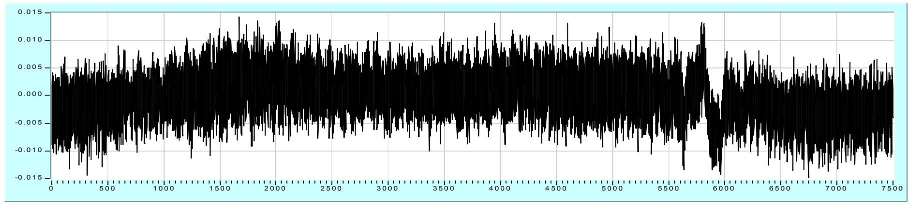



**Fig. 12(a):** DRP-2 Signal without any filter.

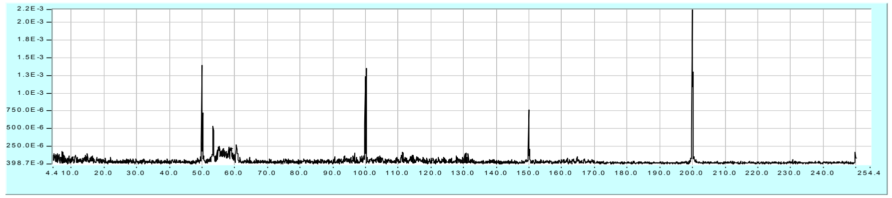



**Fig. 12(a'):** DRP-2 Signal spectrum without any filter.

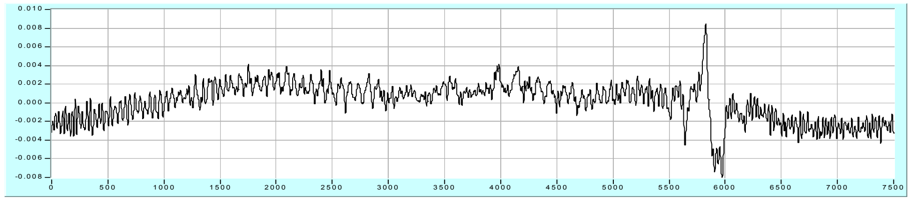



**Fig. 12(b):** DRP-2 Signal with software filter.

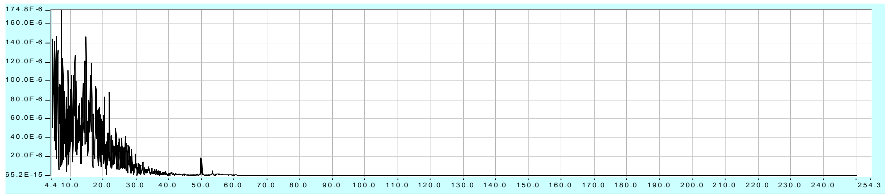



**Fig. 12(b'):** DRP-2 Signal spectrum with software filter.

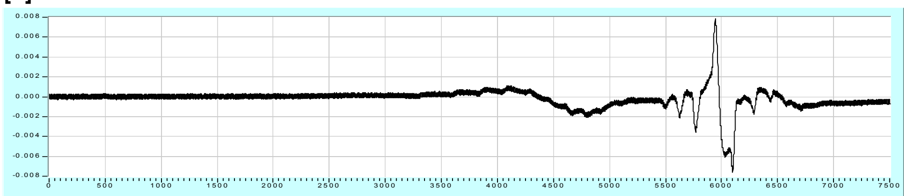



**Fig. 12(c):** DRP-2 Signal with insulating amplifier.

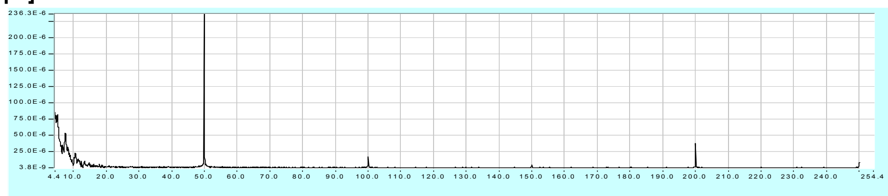



**Fig. 12(c'):** DRP-2 Signal spectrum with insulating amplifier.

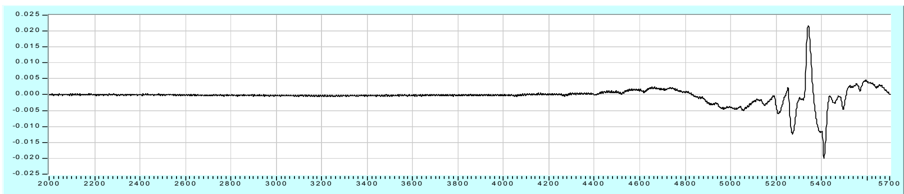



**Fig. 12(d):** DRP-2 Signal with RC filter.

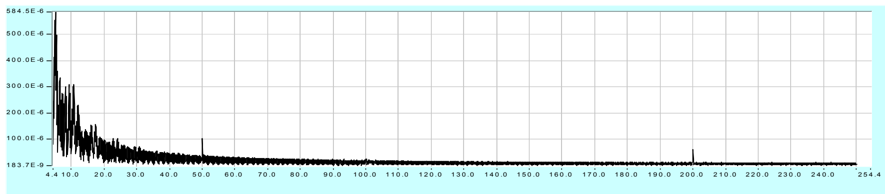



**Fig. 12(d'):** DRP-2 Signal spectrum with RC filter.

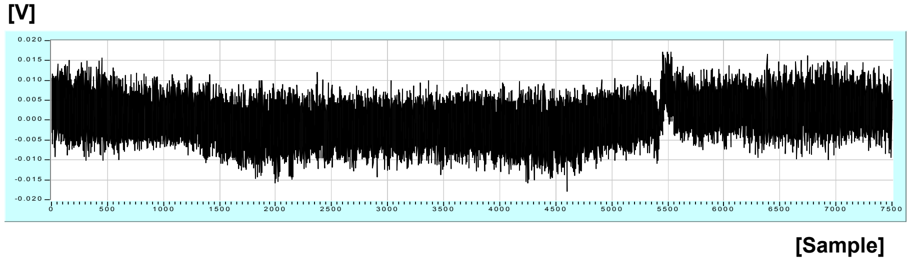



**Fig. 13(a):** DRP-4 Signal without any filter.

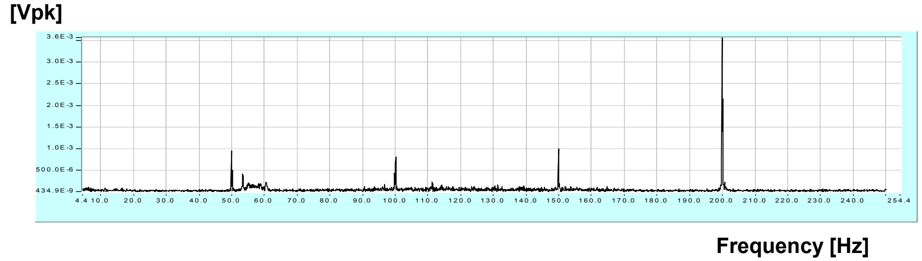



**Fig. 13(a'):** DRP-4 Signal spectrum without any filter.

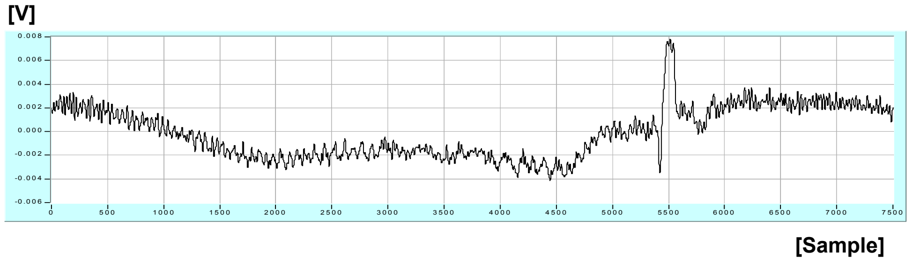



**Fig. 13(b):** DRP-4 Signal with software filter.

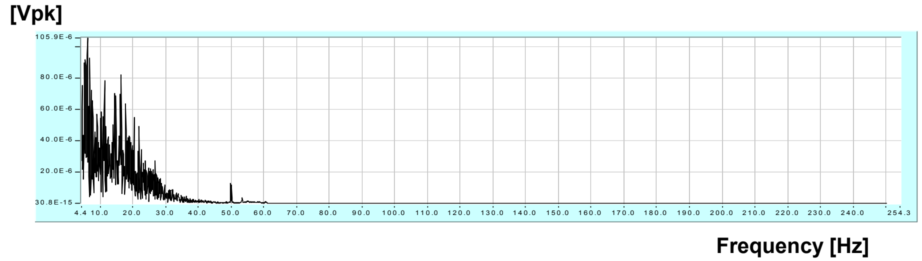



**Fig. 13(b'):** DRP-4 Signal spectrum with software filter.

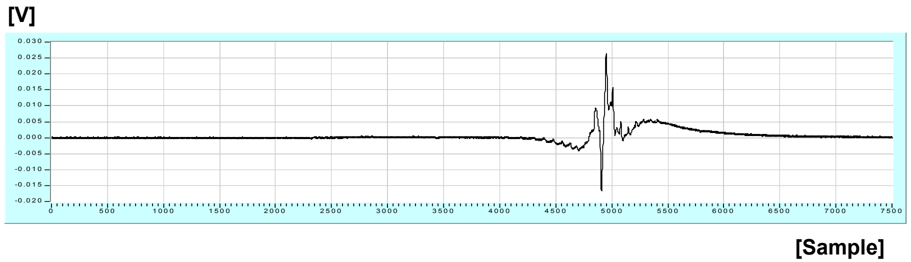



**Fig. 13(c):** DRP-4 Signal with insulating amplifier.

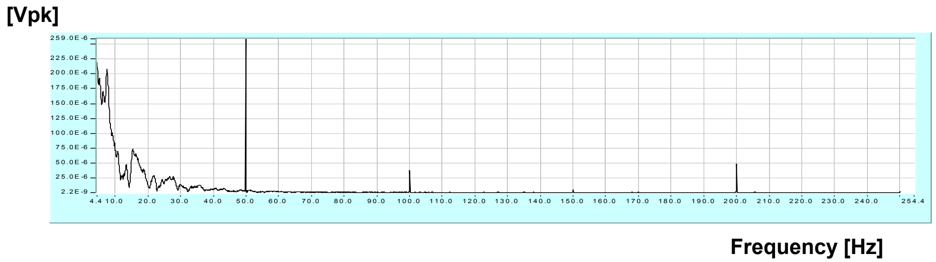



**Fig. 13(c'):** DRP-4 Signal spectrum with insulating amplifier.

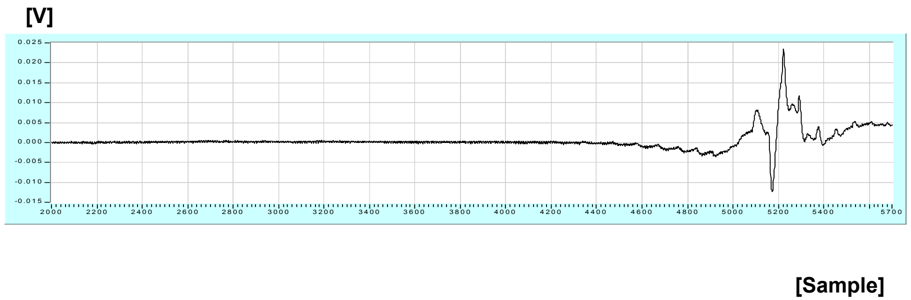



**Fig. 13(d):** DRP-4 Signal with RC filter.

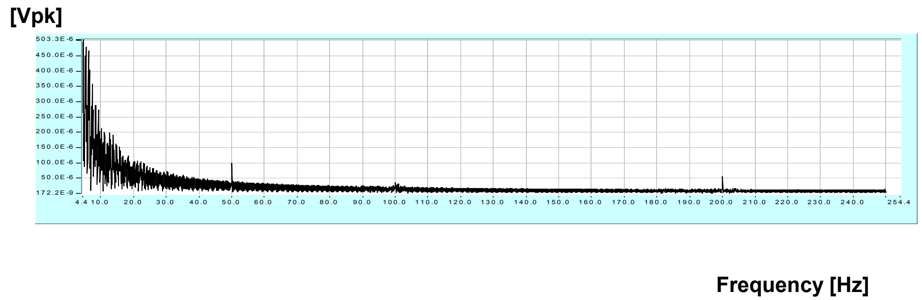
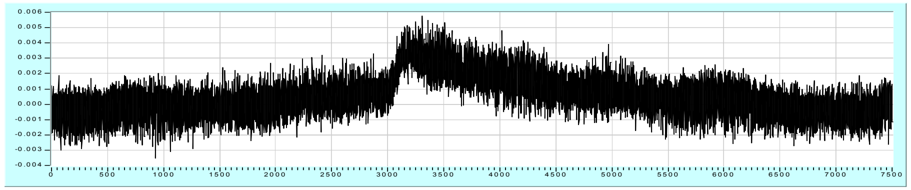



**Fig. 13(d'):** DRP-4 Signal spectrum with RC filter.

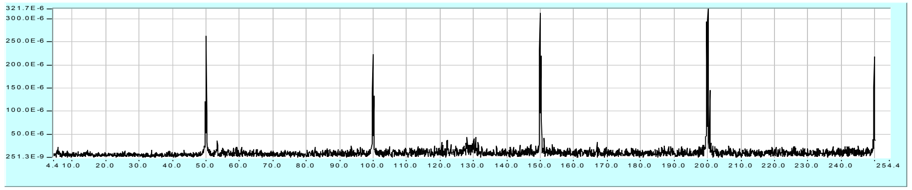
[V]



[Sample]

**Fig. 14(a):** DSP6a Signal without any filter.

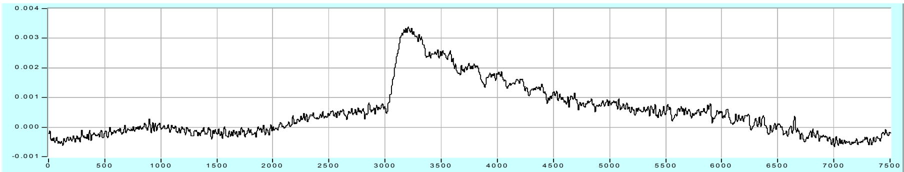
[Vpk]



Frequency [Hz]

**Fig. 14(a'):** DSP-6a Signal spectrum without any filter.

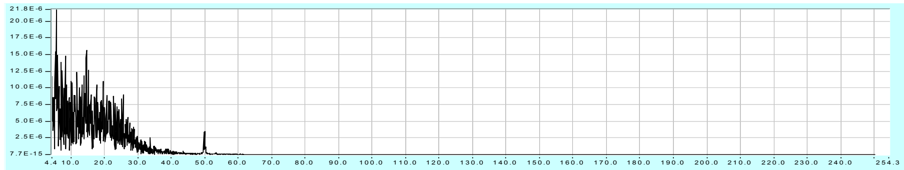
[V]



[Sample]

**Fig. 14(b):** DSP-6a Signal with software filter.

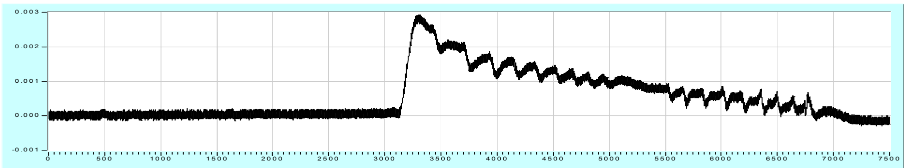
[Vpk]



Frequency [Hz]

**Fig. 14(b'):** DSp-6a Signal spectrum with software filter.

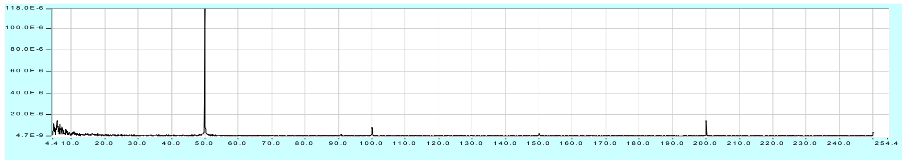
[V]



[Sample]

**Fig. 14(c):** DSP-6a Signal with insulating amplifier.

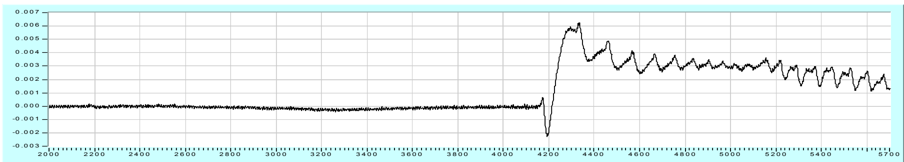
[Vpk]



Frequency [Hz]

**Fig. 14(c'):** DSP-6a Signal spectrum with insulating amplifier.

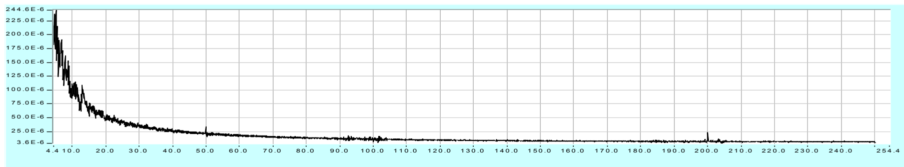
[V]



[Sample]

**Fig. 14(d):** DSP-6a Signal with RC filter

[Vpk]



Frequency [Hz]

**Fig. 14(d'):** DSP-6a Signal spectrum with RC filter.

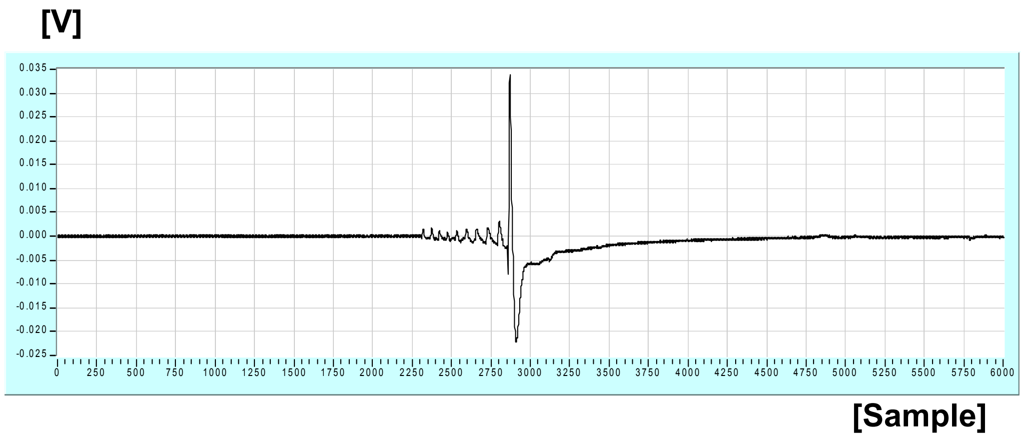



**Fig. 15(a):** DSP-7b Signal with I.A.

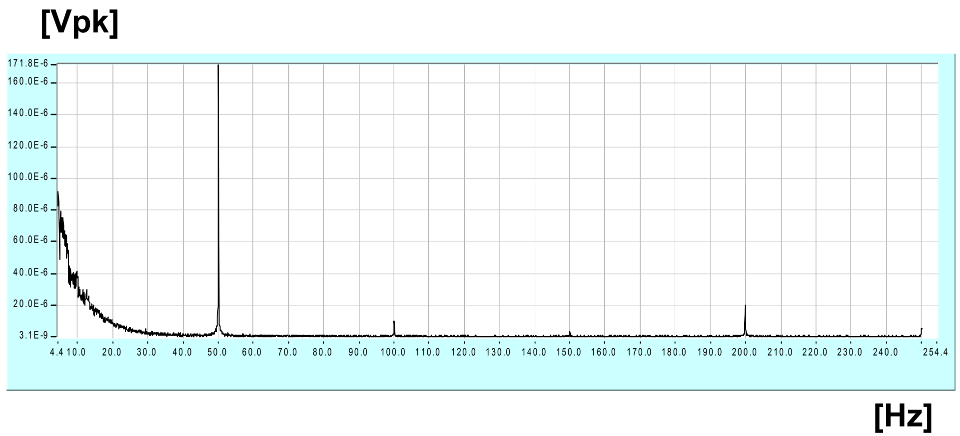



**Fig. 15(a'):** Spectrum of DSP-7b Signal with I.A

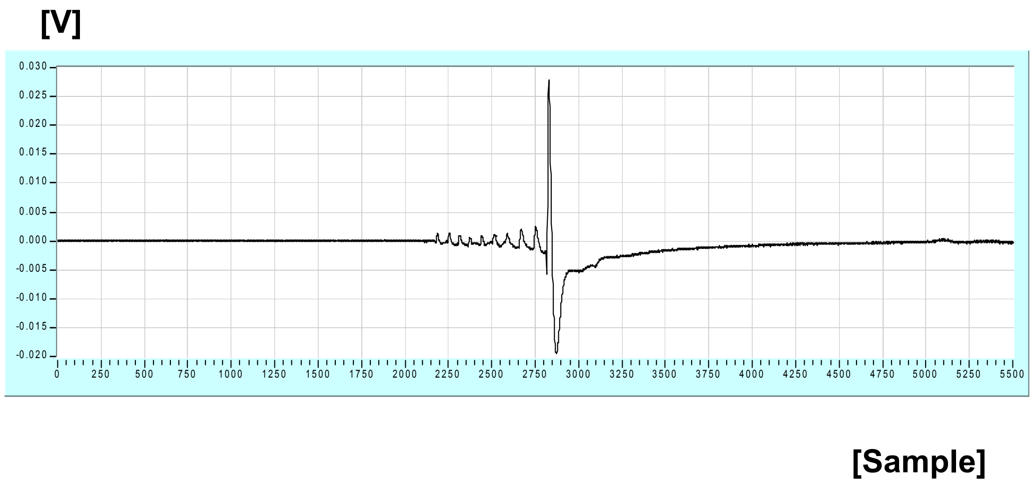



**Fig. 16(a):** DSP-7b Signal with R.C.

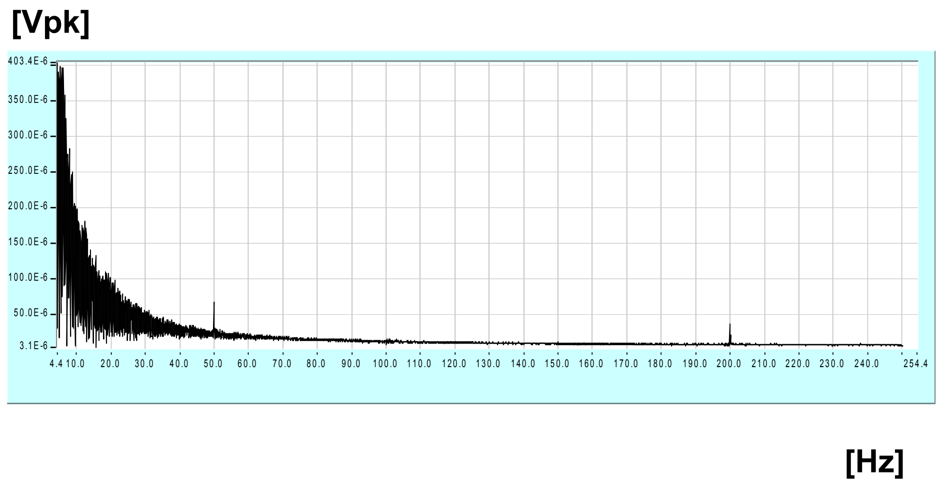



**Fig. 16(a'):** Spectrum of DSP-7b Signal with R.C.

In figure figure 12 the DRP-2 signal is shown. The signal without filter is reported in Fig. 12a.

For a better understanding is necessary to take a look on graphics power supply Vac output of Fig. 11. In fig. 11a, 11b and 11c we can see 50 Hz main interference and its harmonics which are significant up to the sixth harmonic. These frequencies are shown in fig. 12a' too, where the spectrum of the LASA-DAQ data acquired without any filter is presented. Since the acquisition sampling rate is 500 S/s, by the Nyquist theorem, the available frequencies go from 0 to 250 Hz.

The higher frequencies shown in fig. 11d, e, f, g and h are acquired by LASA-DAQ like frequencies lower then 250 Hz (Nyquist frequency), because of phenomenon called aliasing. The Fig. 13b and 13b' clearly demonstrate that a digital filter cannot remove aliases because it is impossible to undo aliasing after the signal sampling.

The effect of passive filter, fc=160 Hz, placed on isolation amplifier input is shown in fig. 12c and 12c'. The board is ground floating in order to galvanically separate the acquisition from the coil, in this way a little width 50 Hz main frequency is inducted. Moreover the intrinsic isolation amplifier noise is present, even if limited by an active filter on his output.

Figs. 12d and 12d' show the better characteristics of the passive filter assembled on DAQ input directly (on SBC-100).

## 8.2 B0 Magnet

After the B00 tests, where the system has been hardly used and tested, (see the noise problem described in the previous section), the B0 application was straightforward.

In the following figures 17,18, 19 and 20 some typical B0 signals are shown.

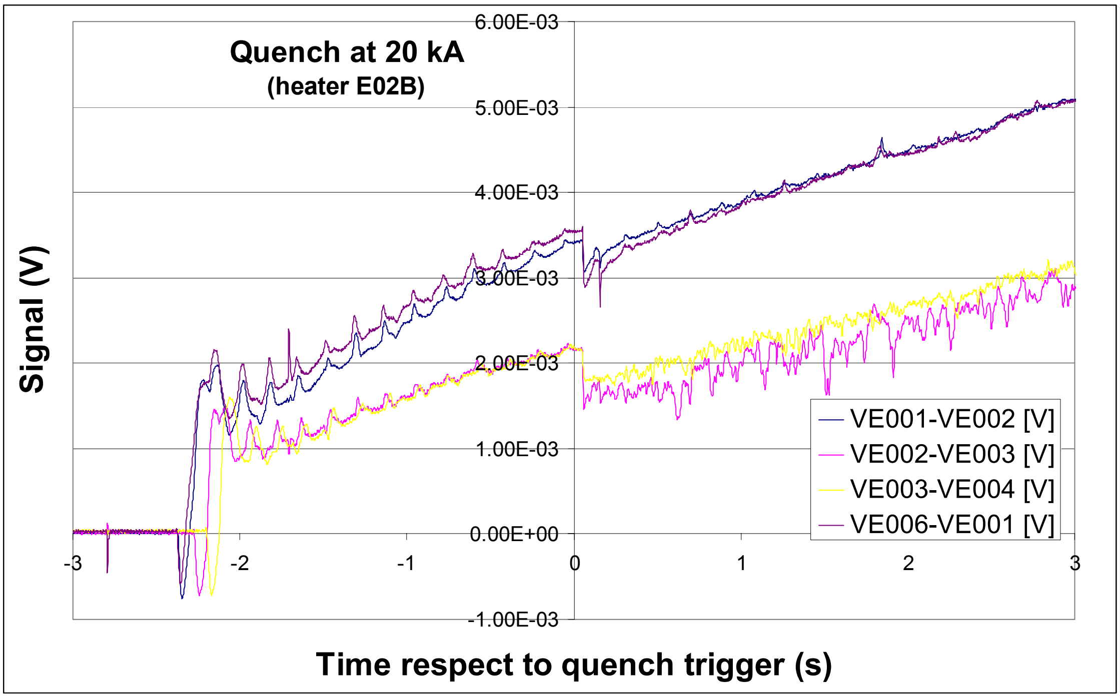



**FIG. 17:** Voltage taps signals during a quench (main current = 20 kA).


**FIG. 18:** Pick-up coil signals during a quench (main current = 20 kA).

During the B0 test two additional internal Hall probes were connected in the channel previously foreseen for the external Hall probes; the four signals are shown in Fig 19.

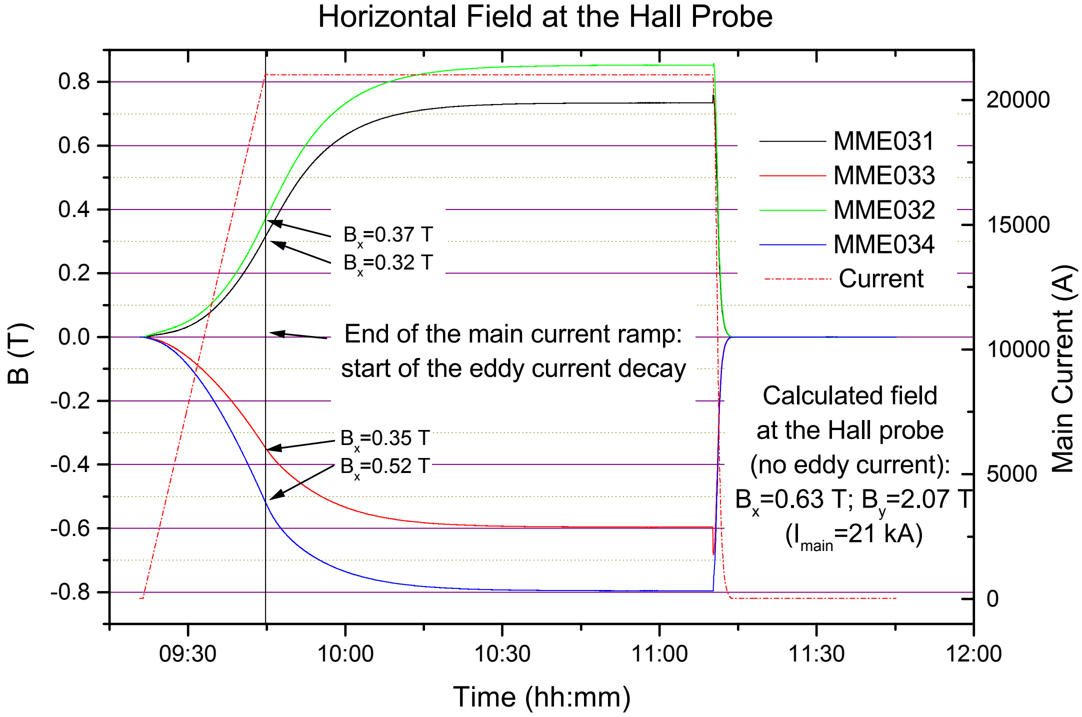



**FIG. 19:** Hall probe signals during a magnet charge up to 21 kA with a 15 A/s ramp rate.

The signals of three (because one was damaged during the magnet integration) pressure transducers are shown in Fig 20. On the top the data of the fast acquisition during a 23 kA quench are plotted, while on the lower part the data of the slow acquisition are shown.

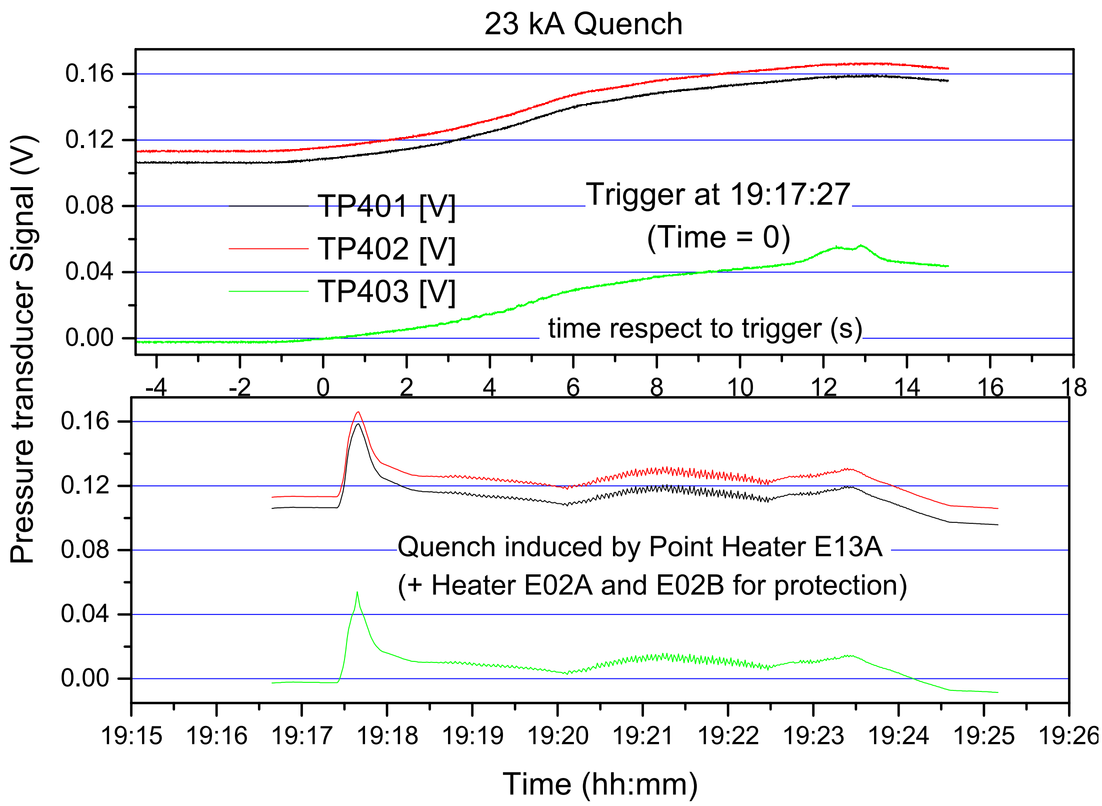



**FIG. 20:** Pressure transducer signals. Top: fast acquisition; bottom: slow acquisition.

## 9 CONCLUSIONS

The full operativity of the LASA-DAQ system has been achieved after the B00 test, because of the noise problems, due to the difficult environmental operation conditions.

After the fixing of the noise problem the system has shown very good performances, allowing detailed studies of the quench, eddy currents, current sharing limits[12,15,16,17)] and other works.

Improvements can be done on the network links in order to allow an easier sharing of the data.

Depending on the test program and technical choices, the system can easily be configured to operate for the tests of the full-length BT magnets.

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(16) F.Broggi, "Pick-up Coil Quench Signal Analysis", to be published as INFN/TC Report.
(17) N.Dolgetta, "B0 Critical Current and Margins (temperature and henthalpy)", private communication.