LBT PROJECT

ADAPTIVE SECONDARY CONTROL SYSTEM

CONTROL ELECTRONICS ASSEMBLY, INTEGRATION and TEST PROCEDURES

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1 INTRODUCTION

This document describes the assembly, integration and test procedures of the LBT adaptive secondary control system electronics.

2 RELATED DOCUMENTS

[RD1] LBT PROJECT - 2 X 8,4 OPTICAL TELESCOPE
ADAPTIVE SECONDARY CONTROL SYSTEM - DESIGN REPORT – Doc. 640a006, Issue B, Dec 12th, 2003

3 ABBREVIATIONS, ACRONYMS AND SYMBOLS

Symbol	Description
ADC	Analog to Digital Converter
DAC	Digital to Analog Converter
DSP	Digital Signal Processor
DUT	Device Under Test
FPGA	Field Programmable Gate Array
LBT	Large Binocular Telescope
MGP	MicroGate udp Protocol
MMT	Multiple Mirror Telescope
MMT336	336 actuators MMT adaptive secondary unit
MTBF	Mean Time Between Failure
OA	Osservatorio di Arcetri
PCB	Printed Circuit Board
TBC	To Be Confirmed
TBD	To Be Defined

4 Electronic system assembly and integration

The following main components can be distinguished within the electronic subsystem of each adaptivce secondary unit:

- 585 internal actuators with capacitive sensor and coils
- 87 internal actuators with capacitive sensor and coils
- Distribution boards (3x 6 different types)
- 84 Cables connecting distribution boards to control crates
- 3 control crates each comprehending
  - 2 backplanes
  - 2 power backplanes
  - 14x2 DSP boards
  - 2 BCU boards
  - 2 signal generation boards

Considering the complexity of the system, it is mandatory to assure the quality of all production processes in order to guarantee the reliability of the final system.

The following main phases can be distinguished in the production and test process:

- PCB production (§4.1)
- Boards assembly (§4.2)
- Screening test (§4.3)
- Main components integration (§4.4)
- Main components test and calibration (§5)
- Crates integration (§6)
- Crates burn-in (§7)
- Integration of electronics on mechanical subsystem (§8.1)
- Burn-in of complete system without shell (§8.3)
- Complete system (without thin shell) functional test at low temperature (§8.4)

4.1 PCB production

All PCBs are manufactured by specialized companies adopting certified quality systems. All boards are subjected to the following checks:

- dimensional check
- visual inspection
- electrical test
- internal layer optical test

The last two tests are particular important, considering that the PCBs are designed with multilayer technology, ranging from 6 to 16 layers. All PCBs production lots are supplied with quality conformity certificate.

Once delivered to Microgate, the PCB boards are stored in sealed packing to avoid moisture absorption.

The same applies also to all electronic components.

4.2 Boards assembly

The electronic boards are all almost completely based on surface mount technology. Printed circuit boards are gold-plated, this guarantees a better quality of soldering, in particular for BGA components, and increases durability.

The assembly of the boards is performed by fully automated machines following a well optimized and traced process by quality certified specialized companies. Reflow soldering is performed under nitrogen atmosphere and following a well tuned temperature profile, to increase soldering quality and reliability.

X-ray inspection is performed after assembly on all BGA components, and the other parts of the board are optically inspected automatically. Final visual inspection completed the production process.

4.3 Screening test

Before completing the integration of the main components, the board are pre-screened to check preliminarily their functionality. The screening test procedures are described in §5.2 and §5.4.

Screening is performed on the following items:

- Capacitive sensor boards (before installing them on the actuator and connecting the coil)
- DSP boards (before mounting the cooling plates)
- BCU boards (before mounting the cooling plates)

4.4 Main components integration

Main system components are integrated with the relevant mechanical parts before performing the final functional and calibration tests.

The integration procedure for the different components, where applicable, is reported hereafter:

4.4.1 Actuators

1. Soldering of flexible contacts (capacitive sensor armature pickup) on capacitive sensor board. This procedure is performed manually using a mounting fixture in order to ensure the same position and bending angle on all devices.
2. Mechanical test of flexible contacts soldering point and PCB gold plating. This test is performed on a sample basis (5% of the actuators) by applying a force of 5 N to the flexible contacts, directed along the main axis of the board for the internal actuators and perpendicular to the board plane for the external actuators.
3. Application of a protective layer of Kapton (100μm thickness) on the bottom side of the capacitive sensor board.

4. Mounting of the pre-assembled (by ADS) coils on the cold finger. Thermal conductive paste (Dow Corning type 340) is used to enhance thermal conductivity
5. Mounting of the capacitive sensor board on the cold finger (actuator body).
6. Soldering of coil terminals on capacitive sensor PCB
7. Final cleaning

4.4.2 DSP boards

1. Mounting of cold plate for heat-removal. 4mm thick, punched thermal conductive rubber pads are inserted between PCB and cold plate. 100µm thick, punched thermal conductive pads are inserted between PCB and cold plate in the middle of the actuator drives.
2. Mounting of front panel.

4.4.3 BCU boards

1. Installation of communication modules: 1 Ethernet module on dedicated slot. 2x FastLink modules on slots 0 and 2.
2. Mounting of cold plate for heat-removal. 4mm thick, punched thermal conductive rubber pads are inserted between PCB and cold plate.
3. Mounting of front panel.

4.4.4 Signal generator boards

1. Installation of analog signal generator board on digital board.
2. Mounting of cold plate for heat-removal. 4mm thick, punched thermal conductive rubber pads are inserted between PCB and cold plate.
3. Mounting of front panel.

5 Main components test and calibration

Once completely integrated, the main components are thoroughly tested and calibrated using the dedicated test-stand developed for this scope. The details of the test stand are described in §9.

In this paragraph new describe the tests performed on the various components.

5.1 Magnet test

Name	Description	Output	Notes
Magnet efficiency test	Performed on 'P1' testbench Measures power (constant current applied to coil) and force	Efficiency N/sqrt(W) Weight	Cell zero calibration at each measurement. Reference magnet used for system calibration. Magnets are labeled at this time.

5.2 Capacitive sensor pre-screening

Purpose: pre-screening of capacitive sensor boards (not yet integrated on actuator)

Name	Description	Output	Notes
Capsens circuit supply current		Current on each rail.	
Capsens Linearity test	Capacitive sensor driven by ref.signal at different amplitudes. Direct measurement of differential output (individual rails and difference)	Sensor gain and offset.	

5.3 Full actuator test and calibration

Purpose: functional test and calibration of actuator and capacitive sensor

Name	Description	Output	Purpose/Notes
Ambient temperature		Ambient temperature	
Capsens circuit supply current		Current on each rail.	
Capsens Linearity test	Capacitive sensor driven by ref.signal at different amplitudes. Direct measurement of differential output (individual rails and difference)	Sensor gain and offset.	The test output is stored in a dedicated database and used for system operation.
Capsens dynamic test	Capacitive sensor driven by ref.signal performing a step in amplitude. Differential output sampled by DSO and compared with reference mask.	Pass/fail	Identify problems on dynamic filters
Coil isolation test	Apply voltage to coil. Measure current flow on actuator body.	Pass/fail	Identify isolation problems on coil.
Coil copper cap grounding	Inject 1A current on copper cap and measure deltaV between cap and actuator body.	Copper cap grounding resistance (mohms)	Important for shielding
Bias magnet force	Measure force exerted by bias magnet on a reference magnet by means of load cell.	Bias magnet force	Actuator shall be accurately aligned and set at correct distance ! The test output is stored in a dedicated database and used for system operation.
Coil force test	Coil driven by positive and negative currents. Force generated on reference magnet.	Coil constant (N/A) Coil resistance	Actuator shall be accurately aligned and set at correct distance ! The coil constant is stored in a dedicated database and used for system operation.
Coil electrical TF	Coil driven by frequency generator. Stimulus generated by IFFT of frequency-limited white noise. Transfer function computed.	Coil electrical TF	Identify winding problems

5.4 DSP boards pre-screening

Purpose: pre-screening of DSP boards, performing board initialization and all 'digital' tests. FPGA configuration, NIOS program and serial number stored on local Flash.

Test performed on boards without cooling plate.

Name	Description	Output	Notes
Supply current	Power-up board and measure supply current on different rails.	Supply current on all rails.	
DSP board initialization	Verify functionality of diagnostic and real-time communication. Verify functionality of local busses. Configure FPGA and load NIOS program.	Configured DSP board. Pass/fail.	
Write serial number	Write serial number on local Flash	Identified board	

5.5 DSP boards test and calibration

Purpose: functional test and calibration of DSP boards

Name	Description	Output	Purpose/Notes
Ambient temperature		Ambient temperature	
Supply current	Power-up board and measure supply current on different rails. Test performed with coils enabled/disabled.	Supply current on all rails.	
Load DSP code	Load DSP code. Verify DSP cluster and diagnostic busses. Prepare board for other tests.	Pass/fail	
Verify backplane physical address lines	Check functionality of dedicated backplane lines used for position-based addressing.	Pass/fail	
Verify analog voltage	Measure voltage for analog circuits (post-regulated on-board). Test performed under load.	VCC_OP and VSS_OP voltages.	The other local voltages (supply of DSPs and FPGA) are measured manually.
Coil enable/disable	Verify functionality of coil	Pass/fail.	

	enable/disable lines. Test performed on both SW commands (acting on each individual drive) and on global line on backplane.		
Coil drive linearity test	Measure linearity of current drive. Check maximum current capability.	Current drive offset and gain.	The test result is stored in the local Flash on the DSP board and used for system operation.
Coil drive dynamic test	Current drive commanded to produce a small (linear) step in current. Coil current and voltage sampled by DSO and compared with reference masks.	Pass/fail	Identify problems on dynamic filters
Coil current diagnostic ADC test	Measure linearity of circuit dedicated to diagnostic measurement of coil current.	Coil current diagnostic ADC offset and gain.	The test result is stored in the local Flash on the DSP board and used for system operation.
Coil drive crosstalk	One current drive commanded to produce a step in current. Crosstalk measured on other coils by sampling on DSO. Test repeated on all coils.	Pass/fail	Identify shorts on PCB and/or connectors.
Coil drive noise	Measure noise of coil output	Coil output noise	
Capsens ADC linearity test	Measure linearity of capsens ADCs. Uses high accuracy reference on test board.	Capsens ADCs offset and gain.	The test result is stored in the local Flash on the DSP board and used for system operation.
Capsens ADC LSB	Capsens ADC driven by slightly changing inputs.	Pass/fail	Verify functionality of ADC Least Significant Bits
Capsens ADC dynamic test	Capsens ADC driven by a stimulus generated by a 'reference' DSP board. Stimulus generated by IFFT of frequency-limited white noise. Transfer function computed.	Capsens electrical TF	Identify problems on dynamic filters

5.6 Signal generator boards test and calibration

Purpose: functional test and calibration of signal generator boards

Name	Description	Output	Purpose/Notes
Ambient temperature		Ambient temperature	
Supply current	Power-up board and measure supply current on different rails. Test performed with coils enabled/disabled.	Supply current on all rails.	
Signal generator board initialization	Verify functionality of diagnostic communication. Verify functionality of local busses. Configure FPGA and load NIOS program.	Configured signal generator board. Pass/fail.	
Write serial number	Write serial number on local Flash	Identified board	
Verify backplane physical address lines	Check functionality of dedicated backplane lines used for position-based addressing.	Pass/fail	
Verify analog voltage	Measure voltage for analog circuits (post-regulated on-board). Test performed under load.	VCC_OP and VSS_OP voltages.	The other local voltages (supply of DSPs and FPGA) are measured manually.
Signal reference output linearity test	Measure linearity of signal reference output by commanding fixed voltages.	Signal reference output offset and gain.	The test result is stored in the local Flash on the signal generator board and used for system operation.
Signal reference output dynamic test	Signal reference output capacitively loaded is sampled by DSO and compared with reference masks.	Pass/fail	Identify problems on dynamic filters

5.7 BCU boards functional test

Purpose: functional test of BCU boards, performing board initialization and all 'digital' tests. FPGA configuration, NIOS program and serial number stored on local Flash.

Name	Description	Output	Notes
Supply current	Power-up board and measure supply current on different rails.	Supply current on all rails.	
BCU board initialization	Verify functionality of diagnostic and real-time communication. Verify functionality of local busses. Configure FPGA and load NIOS program.	Configured BCU board. Pass/fail.	
Write serial number	Write serial number on local Flash.	Identified board	
Set factory BCU IP	Sets standard BCU IP address (can be modified afterwards)		

5.8 Power backplane boards test and calibration

Purpose: functional test and calibration of power backplanes

Name	Description	Output	Purpose/Notes
Ambient temperature		Ambient temperature	
Digital interface (SPI) functional test	Check functionality of SPI line connecting the power backplane to the BCU.	Pass/fail	
Write serial number	Write serial number on local Flash.	Identified board	
Functional test of external digital interfaces	Verify functionality of external digital signals: reset, boot_select, fpga_clear, system_fault, disable_coils, crate identifiers	Pass/fail	
Digital supply (VCC_L) voltage and current test	Measure voltage on VCC_L at 5 different current levels from 0 from 0 to 100% (50A).	Pass/fail	

Analog and coil drives supply enable/disable test	Verify functionality of SW command to enable/disable VCC_A, VSS_A, VCC_P, VSS_P.	Pass/fail	
Analog supply (VCC_A, VSS_A) voltage and current test	Measure voltage on VCC_A and VSS_A at 5 different current levels from 0 from 0 to 100% (12A).	Pass/fail	
Coil drives supply (VCC_P, VSS_P) voltage and current test	Measure voltage on VCC_P and VSS_P at 5 different current levels from 0 from 0 to 100% (25A). Test is performed at nominal operating voltage (10.8V).	Pass/fail	
Coil drives supply (VCC_P, VSS_P) voltage setting calibration	Measure linearity of coil drives supply DAC. Voltages are set by SW and measured. Storage of set value on permanent memory also verified.	VCC_P and VSS_P DAC gain and offset.	The result is stored in a dedicated database and used for system operation
Digital supply (VCC_L) voltage and current diagnostic calibration	Measure linearity of VCC_L voltage and current diagnostic.	VCC_L voltage and current diagnostic gain and offset.	The result is stored in a dedicated database and used for system operation
Analog supply (VCC_A, VSS_A) voltage and current diagnostic calibration	Measure linearity of VCC_A, VSS_A voltage and current diagnostic.	VCC_A, VSS_A voltage and current diagnostic gain and offset.	The result is stored in a dedicated database and used for system operation
Coil drives supply (VCC_P, VSS_P) voltage and current diagnostic calibration	Measure linearity of VCC_P, VSS_P voltage and current diagnostic.	VCC_L voltage and current diagnostic gain and offset.	The result is stored in a dedicated database and used for system operation
Total coil drives current diagnostic test	Measure linearity of total system coil drives current measurement.	Total coil drives current diagnostic gain and offset.	The result is stored in a dedicated database and used for system operation
Total coil drives current threshold (overcurrent protection)	Verify functionality of total system coil drives current threshold. Exceeding the threshold shall assert system_fault flag and disable coil drives. Test performed at all possible levels of threshold setting. Storage of threshold on permanent memory also verified.	Pass/fail Calibration of overcurrent protection threshold.	The result is stored in a dedicated database and used for system operation
Calibration of temperature sensors (PT1000) inputs	Measure linearity of temperature sensing	Temperature sensing inputs gain and offset.	The result is stored in a dedicated database

(4x).	inputs (4x). High accuracy reference resistors used for calibration.		and used for system operation
Calibration of humidity sensor input.	Measure linearity of humidity sensor input. High accuracy reference resistor bridges used for calibration.	Humidity sensor input gain and offset.	The result is stored in a dedicated database and used for system operation
Calibration of pressure gage input.	Measure linearity of pressure gage input. High accuracy reference resistor bridges used for calibration.	Pressure gage input gain and offset.	The result is stored in a dedicated database and used for system operation

5.9 Backplane boards test

Backplane boards are passive and are tested functionally by fully populating the backplane.

5.10 Distribution boards test

Backplane boards are tested functionally by fully populating the board with actuators, connecting it to the DSP boards and checking the correct functionality of all actuators.

5.11 Cables test

All flat cables connecting the DSP boards to the distribution boards are verified against shortcuts and testing the resistance on each individual connection.

6 Crates integration

One the single components have been tested individually, the crates are assembled. The procedure foresees the following steps:

1. Accurate cleaning of all components. After a preliminary cleaning, all components are finely cleaned using filtered compressed air and moved to on ISO 7 (Class 10000) clean room, where the following integration steps will continue
2. Installation of backplane on crates structure
3. Installation of power backplanes on crates structure
4. Installation of boards: BCU, signla generator, DSP

7 Crates burn-in

After functional test and calibration, the integrated crates are subjected to a burn-in test. The purpose of this test is to put to evidence youth problems on assembled boards, in other words to exclude the first, high mortality part of the typical 'bathtub' failure curve.

This approach has proved to be very effective on previous experiences (MMT adaptive secondary electronics).

The burn-in test of the crate components is conducted as follows:

1. Dedicated dummy-load boards are connected to the DSP boards outputs and inputs.
2. Coolant inlet temperature is adjusted in order to reach the maximum operative temperature on the FPGA dies (the FPGAs have an on-chip temperature sensors that can be read through the diagnostic interface). A coolant temperature around 40°C is expected according to current experience, leading to a maximum chip temperature of 70°C
3. The DSP boards are commanded in order to activate sequentially the current drives at maximum rated positive and negative output. 20 drives (out of 112 available on each crate) are activated simultaneously, in this way 90% of the maximum current deliverable by the power backplane DC-DC converters is reached. This load is about 10 times higher than the typical operating one.
4. The analog power regulators are connected to dummy loads and loaded to 90% of the maximum rated current.
5. Continuous communication tests are performed on both diagnostic and real-time links.

The test is planned to last 24 hours, and is performed on each half-crate (one backplane) independently. Considering the accelerated test conditions, this test is expected to simulate ~4000 operating hours, corresponding to ~1 year of system operation. During the test all relevant parameters (supply currents, coil currents, temperatures) are continuously monitored and recorded.

After the burn-in test, the functionality of DSP boards is tested once more, and the calibration tests are performed on ~10% of the boards to verify the stability of the calibration data.

8 Final integration and test of electronics subsytems

8.1 Integration of electronics on mechanical subsystem

The electronics subsystems are now ready to be installed on system mechanics.

This activity is performed in an ISO 7 (Class 10000) clean room according to the following procedure:

Distribution boards installation on coldplate. This activity is performed in advance at ADS premises.

1. Crates installation
2. Connection of power supply
3. Connection of inter-crates flat cable (on power backplanes)
4. Connection of cooling circuit
5. Connection of communication links (diagnostic and real-time)
6. Quick functional test
7. Installation of actuators and mapping of actuator numbers according to physical position. The actuators are installed at constant distance with respect to the backplate surface by means of an appropriate tool
8. Connection of distribution boards (flat cables)
9. System functional test (coils and capacitive sensors individual test)

8.2 ‘Mechanical’ calibration of capacitive sensors

This procedure is aimed to obtain a calibration of each individual capacitive sensor. Instead of using the thin shell as common armature for the capacitive sensors, a reference Zerodur pad with 30mm diameter and a spherical surface, matched with the backplate curvature, is used as calibrated gap. Four different reference pads, with different gaps, are used to derive a calibration curve.

The calibration is performed with the backplate facing up, so that the calibration stays on position by its own weight. All sensors are individually calibrated and the parameters are stored on a database and used for system operation.

On a sample basis, the calibration procedure will be repeated on some actuators to verify its repeatability.

8.3 Burn-in of complete system without shell

After integration, a further burn-in is performed on the complete system. This test is aimed to put to evidence ‘youth’ failures of the of cables, distribution boards and actuators.

The test is conducted as follows:

- Coolant inlet temperature is adjusted to 23°C. This is 5°C higher than the maximum functional inlet temperature (20°C ambient – 2°C = 18°C).
- The DSP boards are commanded in order to drive all actuators at 5 times the typical median seeing conditions power, corresponding to 0.6W per actuator.

On purpose, these conditions are kept quite far from the real maximum operating temperatures and loads for the electronics, because it is neither safe nor reasonable to overstress the fully integrated system.

The test is planned to last 96 hours. During the test all relevant parameters (supply currents, coil currents, temperatures) are continuously monitored and recorded.

8.4 Complete system (without thin shell) functional test at low temperature

The fully integrated unit will be subjected to a further functional test at the lower limit of the system operational temperature.

The system will be placed into a cooled container (or truck trailer), and operated down to -20°C. Cooling fluid will be refrigerated by means of an air/liquid heat exchanger, so that the inlet temperature will be kept very close to the ambient temperature, and re-circulated in closed loop by means of a pump.

The test will be performed according to the following procedure:

1. Cool the system switched off down to –20°C and wait for thermal stabilization
2. Switch on the system and perform immediately a functional test
3. Continue functional test until the internal system temperature is stabilized
4. Repeat steps 1., 2. and 3. at least 5 times
5. Repeat the mechanical calibration procedure (see Sect. 8.2) at –20°C to characterize calibration drift due to temperature

9 Test and calibration setup

In this paragraph we describe the test and calibration setup specifically developed for the LBT control system. This is a fundamental part of system AIT: it allows to perform the test procedures described in this document in an almost automatic way, reducing to a minimum the effort of the operator and the possibilities of mistake.

9.1 Hardware

The test and calibration setup hardware is based on custom design. The following components can be distinguished:

- Microgate AdOpt system backplane (compatible with the AdOpt boards, like DSP and BCU), comprehending
  - BCU board, controlling the operation of all the Microgate-HW based part of the test and calibration setup
  - dedicated test board, specifically developed for this purpose. This boards contains a very accurate and stable voltage reference, precision amplifiers, 8 standard LBT coils acting as load for the DSP board under test plus one additional ‘reference’ coil on which the drives calibration measurements are performed. The reference coil can be selected by means of a set of relais. Electronic switches allow to connect the precision reference to the ADC inputs of the DSP board under test for linearity calibration. The precision, high speed amplifiers allow to drive properly a DSO input with the voltage and current monitoring signals from the coil. The test board is controlled by the BCU board, through the PIO port.
  - Modified and manually calibrated DSP board, used to generate reference patterns, in particular for dynamic tests
  - Standard AdOpt signal generator board, generating the signal for capacitive sensor testing
  - Free slot to host the DSP board under test
- 2x Microgate AdOpt relais boards. A switch matrix with 28 relais is used to route the various signals from the DUT to the instruments
- dedicated mechanical fixture for actuators testing. It comprehends a load cell to measure the force exerted by the coil and a device to inject the capacitive sensor reference signal into the DUT.
- LeCroy WavePro950 DSO
- Agilent 34401A Multimeter
- Agilent 53545A Waveform generator
- Power supply units
- GPIB-Ethernet interface
- Ethernet switch
- P45 distribution board and additional AdOpt backplane used to stabilize thermally the boards before calibration

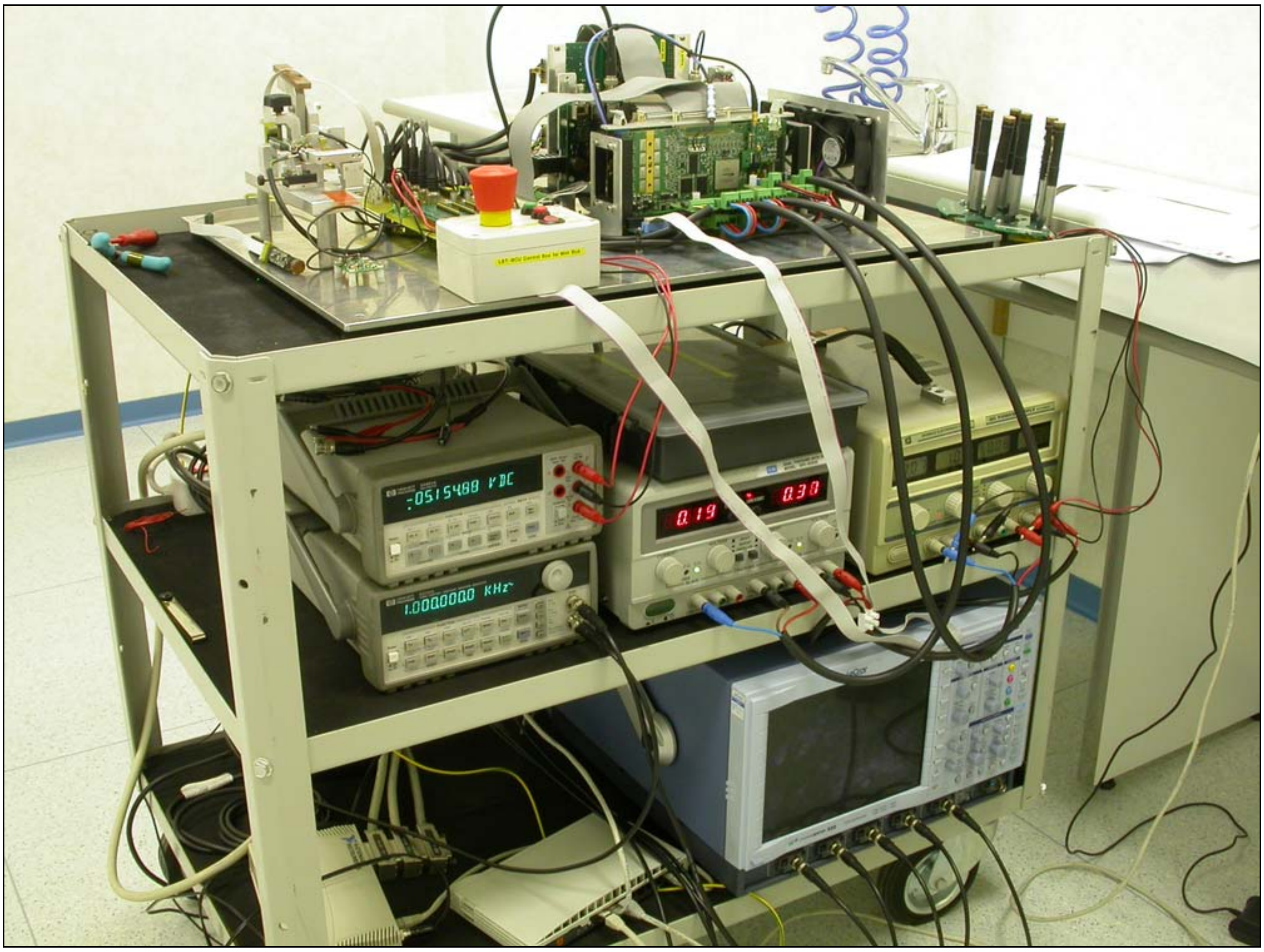

Figure 1 - Test and calibration setup

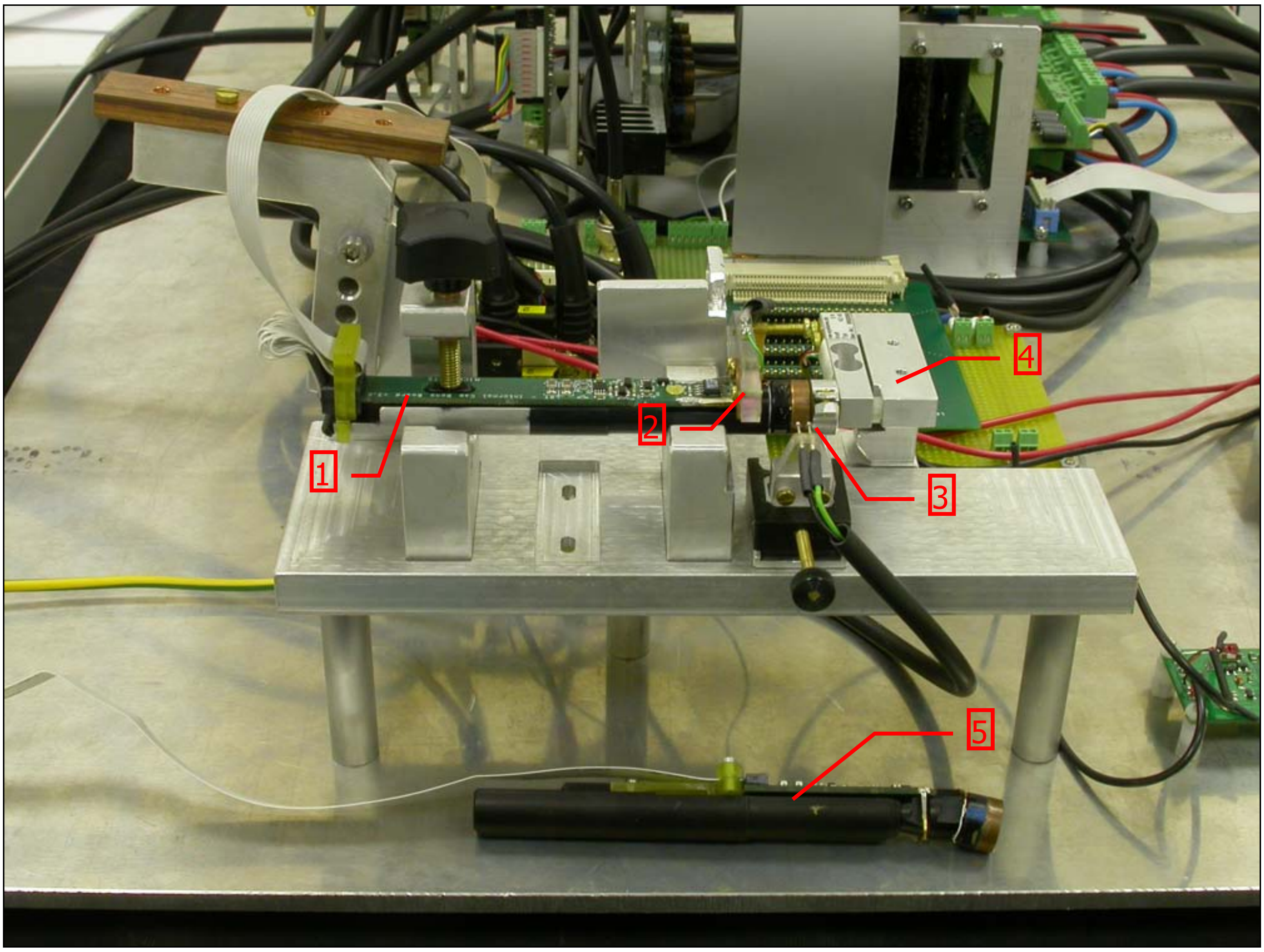

Figure 2 – Detail of mechanical fixture for actuators test and calibration. 1. internal actuator under test; 2. reference signal injector; 3. current injection and voltage pick-up for copper cap test; 4.load cell; 5. adapter for external actuators

9.1.1 Magnets efficiency and weight calibration setup

The magnets efficiency calibration setup has been derived from the test stand originally used for P1 tests. A reference coil without bias magnet is used for all tests.

The coil is driven at constant voltage and coil voltage and current are measured to compute directly the power into the coil. The force exerted on the magnet under test is measured by means of a load cell.

The load cell is calibrated every 20 measurements (offset and gain).

Before starting a testing session, the distance between coil and magnet is adjusted by means of a reference magnet with known efficiency.

A graphic user interface guides the operator through the execution of the test and stores automatically the measured data. The magnets are labeled with a unique number.

Figure 3 – Magnets efficiency and weight calibration setup

9.2 Software

The software used to execute the calibration and setup procedures is Matlab based. Matlab has been interfaces to both MGP and GPIB communication protocol. In this way, both the Microgate electronics (including both the components of the test-calibration setup and the DUT) and the standard instruments are easily controlled inside the Matlab environment. The software makes large use of the standard diagnostic tools available on LBT control electronics real-time SW, and in particular of dynamic buffers.

All raw-data concerning each test are saved on single structure and stored on a file automatically numbered according to number of test_type of test _date of test. The availability of raw data allow to modify the data post-processing at any time.

Test and calibration data are stored on Microgate centralized server and follow our standard backup procedures.