# MASCOT

## MAG EID-B

MASCOT-MAG-EID-B-0014

| | |
|---|---|
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| Agreed | |
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# DOCUMENT CHANGE LOG

| *Description of changes* | *Paragraph* | *Issue* | *Revision* | *Date* |
|---|---|---|---|---|
| Initial issue | All | 1 | 0 | 26.04.2012 |
| Test levels for sensor added,<br>Mag General Design added<br>Electrical Design Description added<br>Power demands updated<br>Mechanical Configuration added<br>Harness updated<br>Software Description see RIDS | 4.5.<br>2.2.1.<br>2.4.1.<br>2.4.2.3<br>2.2.2.<br>2.4.2.4<br>2.7. | 1 | 1 | 22.05.2012 |
| Update of Power consumption<br>Signals M/NR & M/NR-Return deleted<br>Main/Red Interface concept clarified<br>Main/Red Interface concept clarified<br>Size of Error code corrected | 2.4.2.3<br>2.4.2.4<br>2.5.1<br>2.5.2<br>2.7.4.2 | 1 | 2 | 19.06.2012 |
| Document reformated | all | 1 | 3 | 15.10.2012 |
| Update of TC/TM definitions<br><br>Updated Analog HK Values (Sensor Temperat-ure & Baord Temprature instead of Board Temperature 1 & Board Temperature)<br>Mass update<br>E-board dimensions update<br>Physical envelope requirements changes to outer dimmensions<br>Performance requirements updated<br>Operation modes update<br>Correction of PRAM Mirror size<br>Temperature range update<br>The name of pins A9/A10 signals corrected from -5V to -5V_RETURN | 2.9.4.1<br>2.9.4.2<br>2.9.4.2<br>2.9.5.3<br>2.2.3<br>2.2.2<br>2.2.3.4<br>2.8.3<br>2.9.5.4<br>2.9.4.4<br>2.3.1<br>2.6.2.4 | 1 | 4 | 31.10.2012 |
| EGSE desctiption<br>Reviews and deliverables update<br>Autonomy operations requirements<br>Organisation and responsibility update<br>Operational requirements update<br>failure recovery<br>startup/shutdown procedures<br>Plan update | 3<br>7.3 and 7.4<br>2.9.5.2<br>7.1<br>5<br>2.9.10<br>2.9.9<br>7.2 | 1 | 5 | 3.12.2012 |
| * section '2.2.2.4 - mechanical interface draw-ings' removed, part of MICD<br>* 2.8 and 2.9 Environmental and operational req. sections ware blank - removed<br>* Reviews updated<br>* Inflight testing description update<br>* redefinition of sensor switch-on temperature ranges<br>* Grounding concept and scheme added<br>* AIV plan implemented into AIV section<br>* Product assurance plan implemented into PA section<br>* Voltage limits updated<br>* Power consumption updated<br>* Switch-off thresholds updated<br>* Operational plan implemented<br>* Mass update | 2.2.2<br>2<br>7.3<br>2.9.8<br>2.3.1<br>2.8.1<br>4<br>6<br>2.6.2.2<br>2.6.2.3<br>2.9.4.2<br>5.3<br>2.2.3.1 | 1 | 6 | 5.03.2013 |
| TC0x33 update<br>TM0x90 update LSByte changed to MSByte | 2.9.4.1<br>2.9.4.2 | 1 | 7 | |

| | | | | |
|---|---|---|---|---|
| according to request from OBC | | | | |
| Correction of Byte numbers in Table 15<br>Mass update<br>switch-on temperatures update | 2.9.4.2<br>2.2.3.1<br>2.3.1 | 1 | 8 | 15.5.2013<br>22.8.2013<br>1.10.2013 |
| Format implementation (INT/UINT) of science data and HK values from telemetry described. | 2.9.4.2 | 1 | 9 | 13.12.2013 |
| GENERAL UPDATE for FM unit<br>- power dissipation changed<br>- power consumption updated<br>-thresholds for HK (current consumption) updated<br>- operational plan updated | <br>2.3.1<br>2.6.2.3<br>2.9.4.2<br><br>5.3 | 2 | 0 | |
| Health check sequence update<br>Temperature range for electronics update | 5.3<br>2.3.1 | 2 | 1 | 19.2.2014 |
| Operational plan updated | 5.3 | 2 | 2 | 22.7.2014 |
| Instrument data rate updated | 2.9.7 | 2 | 3 | 27.8.2015 |

# Table of Contents

# 1 INTRODUCTION

## 1.1 SCOPE

The Experiment Interface Document Part B (MAG EID-B) is the response to the requirements defined in the Experiment Interface Document Part A (EID-A). The EID-A has been issued to define the managerial, programmatic and technical requirements applicable to the scientific instrument interfaces within the MASCOT spacecraft. The MAG experiment has to comply with the EID-A (GEN-0010).

The content of the EID-A issue reflects the current design status of the MASCOT spacecraft and is to be considered as a baseline for the design of the individual payload instruments and their respective Experiment Interface Document Part B (EID-B).

The MAG EID-B specifies the applicable interface information between the MAG instrument and the MASCOT systems team (GEN-0020).

In addition to the EID-B there are other managerial and programmatic documents, which complement the basic documentation tree of the interface agreement.

## 1.2 PURPOSE

The EID-B specifies in particular the following aspects:

- The resources required by the MAG instrument as response to the resources allocated to the Instruments
- The detailed mechanical, thermal, electrical, and data interfaces between the MASCOT spacecraft and the MAG instrument
- The results/outcome of the design verification program which has been implemented to demonstrate the Instrument compliance, and the Instrument/Lander interface compliance with the defined mission environmental requirements and with the mission operational requirements
- Compatibility/response to the management and programmatic requirements to each Instrument TC to comply with the instrument development activities and their relation with the MASCOT spacecraft development program
- Compatibility/response to the operational interfaces applicable during MASCOT spacecraft ground testing, launch campaign, operations in flight and science operations on the asteroid surface.

The document is structured in the following chapters:

- Chapter 1 - Introduction
  ... This Chapter
- Chapter 2 - Engineering
  ... describes the mechanical, thermal, and electrical design of the MAG instrument as well as further design and interfaces requirements
- Chapter 3 - Ground Support Equipment Design and interfaces
  ...describes the ground support equipment and interfaces
- Chapter 4 – Instrument Assembly, Verification and Test Requirements
  …describes the lander assembly and verification concept, design verification requirements as well as further test procedures
- Chapter 5 - Operational Requirements
  ...defines the ground and flight operations requirements

- Chapter 6 – Product Assurance and Safety
  ... addresses aspects concerning safety, materials (parts and components), processes and assurance
- Chapter 7 - Instrument Management Requirements
  ... contains the management, scheduling and reporting requirements applicable to the MAG instrument.
- Chapter 8 - Acronyms and Abbreviations
- Chapter 9 – Reference
- Appendix

## 1.3 Applicable Documents

| *AD#* | *Document reference* | *Author* |
|---|---|---|
| [AD01] | MASCOT-IRD-VEGA-0001 MASCOT to Lander EIRD | DLR |
| [AD02] | MSC-RYES-PCB-SPEC_Draft-1 | DLR |
| [AD03] | EID-A | DLR |
| [AD04] | MASCOT-MAG-DML-0001 | TU-BS, Magson |
| [AD05] | MASCOT-MAG-DPL-0001 | TU-BS, Magson |
| [AD06] | MASCOT-MAG-DCL-0000 | TU-BS, Magson |
| [AD07] | ~~MASCOT-MAG-AIV-plan-0000~~ - deprecated | TU-BS, Magson |
| [AD08] | ~~MASCOT-MAG-OP-plan-0000~~ - deprecated | TU-BS, Magson |
| [AD09] | ~~MASCOT-MAG-PA-plan-0000~~ - deprecated | TU-BS, Magson |
| [AD10] | MASCOT-MAG-HealthCheck-006 | TU-BS, Magson |
| [AD11] | MASCOT-MAG-RTM-003 | TU-BS |
| [AD12] | MASCOT-MAG-FunctionalCheck-005 | TU-BS,Magson |

# 2 ENGINEERING

## 2.1 General Design Rules

### 2.1.1 Standard Metric System

Drawings, specifications and engineering data use the International System (SI) Metric Standard as specified in ECSS-E-ST-10-09C. The key and derived units are specified in:

- Dimensions in Millimeters [mm]
- Angles in degrees
- Temperatures in degrees Celsius
- Power / Heat in Watts [W]
- Energy in Joules [J]
- Mass in Kilogramm [kg]
- Magnetic Field in Tesla [T]
- Time in seconds [s]
- Electric Current in Ampere [A]
- Amount of substances in moles
- Luminous Intensity in candelas
- Force in Newtons [N]
- Torque in Newton-meter [Nm]

**(ENG-GEN-0010)**

### 2.1.2 Workmanship

All design and manufacturing comply with the space industry standard and comply with the Product Assurance requirements as laid down in chapter 7 of the EID-A document. **(ENG-GEN-0020)**

### 2.1.3 Life Time Requirements

All mechanisms and instruments are designed for a lifetime including in orbit and ground operations necessary for functional tests, system tests as specified in **ENG-GEN-0030.**

### 2.1.4 Maintainability

The instrument does not require any periodic maintenance for the entire duration of the ground activities from delivery to the prime up to Launch including potential storage period. **(ENG-GEN-0040)**

### 2.1.5 Mathematical Simulation And Tools

The MAG team uses the mathematical simulation tools as specified in **ENG-GEN-0050**.

### 2.1.6 Design Margin Requirements Policy

#### *2.1.6.1 Mass Margins*

Every piece of equipment is given a margin on mass based on its maturity. The MAG team applies one of the three levels based on the following definition:

- 5% for fully developed items.
- 10% for items to be modified.
- 20% for items to be developed

**(ENG-GEN-0060)**

#### *2.1.6.2 Power Margins*

At equipment level the following design maturity margin is applied:

- 5% for OTS equipment
- 10% for OTS parts to be modified
- 20% for items to be developed

**(ENG-GEN-0070)**

#### *2.1.6.3 Memory Margins*

N/A

#### *2.1.6.4 Processor Margins*

N/A

#### *2.1.6.5 Dimensions Tolerance*

The dimension, d, of each unit is specified in this document to a tolerance smaller than

- +0.5/-0.0 mm for d<300 mm
- +1.0/-0.0 mm for d>300mm

**(ENG-GEN-0100)**

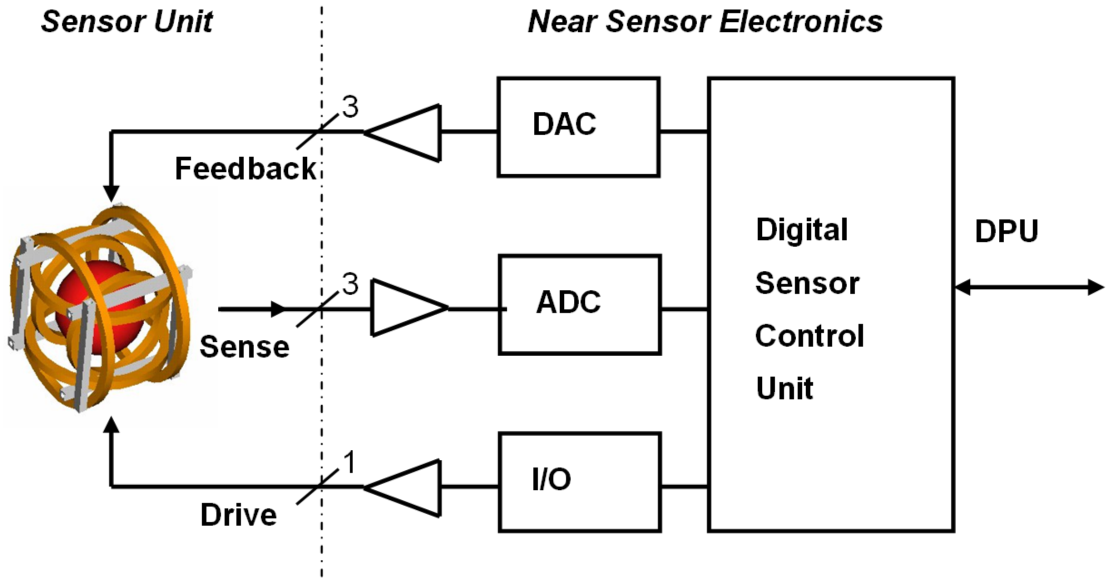
## 2.2 Mechanical Design and Interfaces

### 2.2.1 MAG General Design

The MAG instrument consists of a fluxgate sensor in the cold compartment, covered by MLI and connected with a short pigtail to the fluxgate electronics accommodated inside the common e-box.

The fluxgate sensor consists of two single ring-core elements measuring the magnetic field in X- and Y-direction. The magnetic field in Z-direction is measured by a coil surrounding both single sensors. The side length of the cubic shaped sensor triad is approx. 4cm. The sensor core: (ring-cores, pick-up and feedback coils) is identical to the ones used for Rosetta Lander, Venus Express, Themis and BepiColombo. The ring-cores have been tested under extreme environmental conditions aboard numerous space missions as well as in applied geophysics. The sensor has been operated in a wide temperature range between -120°C (Rosetta) and +180°C (BepiColombo), therefore the sensors can be mounted outside of the temperature controlled compartment.

The sensor electronics generates an excitation AC current (fundamental frequency of approx. 9.6kHz), which drives the soft magnetic core material in the sensor deep into positive and negative saturation. According to the fluxgate principle, the external magnetic field distorts the symmetry of the magnetic flux and generates field proportional to even harmonics of the excitation frequency in the sense coils. The induced voltage in the sense coil is digitised immediately after the preamplifier at four times the excitation frequency. The 'front end' signal processing (synchronous detection and integration as well as feedback value and field calculation) is done by logic blocks within an FPGA. A feedback field increases the overall linearity and stability of the magnetometer. It is supplied to all sensor elements via 16-bit DACs (feedback DACs) and a separate pair of feedback coils (Helmholtz coils) per sensor axis. Sense (from ADC) and feedback values (setting of feedback DACs) are continuously used for calculating the magnetic field values (24 bits) by scaling and adding: k1*ADC+k2*DAC. An artificial magnetic field can independently be applied to each sensor via additional 16-bit DACs for compensation of any disturbing bias field (due to magnetic spacecraft parts). The digital magnetometer concept requires analog-to-digital conversion at a higher data rate but it shows a number of advantages over the more traditional analog fluxgate magnetometer. Early digitisation makes the sensed signal robust to changes of the environmental temperature and the supply voltages as well as insensitive to EMC. Furthermore, no range switching is needed for getting the required resolution, which reduces design complexity and facilitates data analysis.




### 2.2.2 MAG Configuration

#### 2.2.2.1 Module / Unit Identification

| *Full Name* | *Abbreviation* |
|---|---|
| Magnetometer PCB | MAG-E |
| Sensor | MAG-S |
| Thermal hardware | MAG-T |
| Sensor pigtail | MAG-H |

#### 2.2.2.2 Connector Identification

| *Full Name* | *Abbreviation* |
|---|---|
| Interface Connector | MAG-J01 |
| Sensor Connector | MAG-J02 |

#### 2.2.2.3 Dimensions

| *Module / Unit* | *X [mm]* | *Y [mm]* | *Z [mm]* |
|---|---|---|---|
| Sensor without thermal hardware and pigtail | Diameter 68mm | | 36mm+10 standoffs |
| PCB incl. Connector | 109 | 94 | 20 |

### 2.2.3 Configuration

#### 2.2.3.1 Mass And Mass Tolerance Requirements

| *Module / Unit* | *Mass [kg]* | *Margin [kg]* | *Sum [kg]* |
|---|---|---|---|
| Sensor | 0,086 | 0,004 | 0,090 |
| PCB [2)] | 0,181 | 0,009 | 0,190 |
| 1) including pigtail, without thermal hardware<br>2) including mass of connectors, wedgelocks and 5% margin | | | |

#### 2.2.3.2 Centre Of Mass

| Module / Unit | COM Location (in mm) with respect to reference hole | | |
|---|---|---|---|
| | X-Coord. | Y-Coord. | Z-Coord. |
| Sensor w/o pigtail and thermal hardware | tbd | tbd | tbd |
| PCB incl. Connector | tbd | tbd | tbd |

#### 2.2.3.3 Moments Of Inertia

| *Module / Unit* | *Moment of Inertia (± TBD kgm^2)* | | | | | |
|---|---|---|---|---|---|---|
| | *Ixx* | *Iyy* | *Izz* | *Ixy* | *Ixz* | *Iyz* |
| Sensor w/o. pigtail and thermal hardware | tbd | tbd | tbd | tbd | tbd | tbd |
| PCB incl. Connector | tbd | tbd | tbd | tbd | tbd | tbd |

#### 2.2.3.4 Physical Envelope Requirements

| *Module / Unit* | *X [mm]* | *Y [mm]* | *Z [mm]* |
|---|---|---|---|
| Sensor with thermal hardware and w/o pigtail | 79 | 79 | 54 |
| PCB incl. Connector | 109 | 94 | 20 |

#### 2.2.3.5 Alignment And Field Of View Requirements

The alignment/orientation of the lander can be arbitrary; there are no special requirements for the MAG instrument.

#### 2.2.3.6 Accessibility Requirements

No late access needed

#### 2.2.3.7 Mechanical Environment

N/A

### 2.2.4 Structural Design

No analysis of the structure (verification by vibration tests) will be delivered.

### 2.2.5 Mechanisms

N/A

### 2.2.6 Mounting Attachment And Handling

Mounting attachment shall be done by an authorizes personnel only. No special handling required.

### 2.2.7 Aperture Covers

N/A

### 2.2.8 Electrical Connectors Mechanical Accommodation

The position of the Backplane Connector is given by the Drawings in [AD02]. The position of the sensor connector is selected in agreement with the MASCOT system team.

### 2.2.9 Purging Interfaces

N/A

#### 2.2.10 Payload Generated Disturbancess

Excitation frequency of the magnetometer is 9.6 kHz. Clock frequency of the crystal controlled oscillator is 19.6608 MHz.

## 2.3 Thermal Design and Interfaces

### 2.3.1 Thermal Design Description

The sensor resides in a thermal uncontrolled department of the lander. Therefore the Sensor will be mounted via isolating washers and be covered in MLI to achieve the maximal thermal stability possible. The thermal control of the sensor is completely passive, through good insulation from exterior influences.

The temperature of the sensor will be monitored by the magnetometer electronics.

The sensor and the harness will be covered in MLI to reduce heat loss through radiation. The alpha/epsilon ratios of the outer and inner layers will be selected so to archive the optimal temperature stability for the sensor. The goal for the design is thermal stability of 1°C/min. The MLI used is 8-layered MLI with a black kapton on the outer side.

The Temperature Reference Point (TRP), representing the thermal behaviour of the instrument is the sensor itself.

## 2.4 Temperature Ranges

| *Unit* | *Operating Temperature (°C)* | | *Non-operating Temperature (°C)* | | *Switch-on Temperature (°C)* | |
|---|---|---|---|---|---|---|
| | *Min* | *Max* | *Min* | *Max* | *Min* | *Max* |
| Sensors | -80 | +60 | -80 | +60 | any | any |
| Electronics | -50 | +75 | -55 | +75 | -50 | +75 |

*Table 1: Operational / Non-operational Temperatures*

## 2.5 Heat Dissipation

| *Unit* | *Non-Operating Mode* | *Operating Mode* |
|---|---|---|
| Sensor | 0 | 0.05 W |
| Electronics | 0.235 | 0.53 W |

*Table 2: Heat dissipation (without margin)*

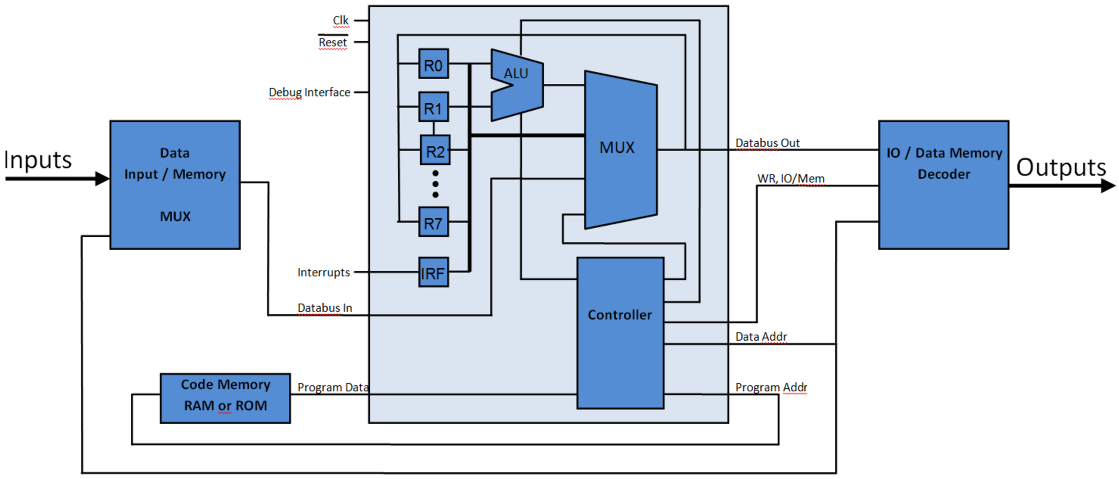
### 2.5.1 Thermal Mathematical Analysis

A MAG Reduced Thermal Model will be delivered in a ESATAN file exported from ThermXL to the lander team. The model is provided in document [AD11].

## 2.6 Electrical Power Design and Interfaces

### 2.6.1 Electrical Design Description

A processor system which is an in-house development by Magson shall be used for processing the magnetometer data and managing the interface. It contains a RISC like processor structure according to the Harvard architecture which allows for a parallel access to code and data memory. The processor is highly configurable in its parameters like data and instruction width and can be easily adapted to the processing requirements of certain project. In most applications it is used with a data width of 32 bits and an instruction width of 16 bits. It is programmed using a machine-oriented assembly language with 19 instructions. The following figure shows the structure of the processor system.




The processor was originally developed for the NASA Themis mission and it has since then continuously been improved and expanded in its functionality. It is used successfully for the Themis mission as well as in reaction wheels, attitude control magnetometers, magnetotorquers and other terrestrial applications and will also be used for the MPO and MMO magnetometers of the ESA/JAXA BepiColombo mission

### 2.6.2 Electrical Design

#### *2.6.2.1 General*

The MAG electronic board dimensions are 20mm x 109mm x 94mm as defined in [AD02].

#### *2.6.2.2 Power Generation And Distribution*

The MAG instrument is supplied by the PCDU with the regulated voltages of 3.3V, +5V and -5V. Each voltage rail has its own separate return.

The voltage levels are given in Table 11.

| *Voltage level ranges* | | |
|---|---|---|
| *Voltage level* | *Min* | *Max* |
| +5V | 4.75V | 5.25V |
| -5V | -5.5V | -4.5V |
| 3.3V | 3.0V | 3.6V |

*Table 3: Voltage levels range.*

#### *2.6.2.3 Budgets*

The MAG power consumption is given in following table.

| *Mode* | *Allocated Margin* | *5V* | | *-5V* | | *3.3V* | | *Ptotal/[mW]* |
|---|---|---|---|---|---|---|---|---|
| | | *I/ [mA]* | *P/ [mW]* | *I/ [mA]* | *P/ [mW]* | *I/ [mA]* | *P/ [mW]* | |
| MAG normal operation | 0% | 64 | 320 | 12 | 60 | 45 | 148.5 | 528.5 |

| All units on | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | +20% margin | 76.8 | 384.0 | 14.4 | 72.0 | 54.0 | 178.2 | 634.2 |

*Table 4: Instrument Power Budget*

No change of current or power consumption is expected for the time from BOL to EOL.

| *Sequence* | *Description* | *Energy [Wh]* | *Duration* |
|---|---|---|---|
| Sequence 1 | MAG switched off | 0 | N/A |
| Sequence 2 | MAG operating | ~4.3Wh | ~8h |

*Table 5: Instrument Energy Budget*

The energy consumptions for BOL and EOL are equal

#### 2.6.2.4 Harness

Power and data are routed via the following connector, which is connected to the backplane

Pinout of the Backplane-Connector, type Hypertac MHD 052 13 41 110

| *Pin* | *Signal* | *Destination* | *Comment* |
|---|---|---|---|
| A18 | Shield MRX | OBC | Shield connected to MAG Ground |
| A16 | MRX+ | OBC | Instruments Main RX+, connects to OBC TX+ |
| A15 | MRX- | OBC | Instruments Main RX-, connects to OBC TX- |
| F7 | Shield MTX | OBC | Shield connected to MAG Ground |
| F9 | MTX+ | OBC | Instruments Main TX+, connects to OBC RX+ |
| F10 | MTX- | OBC | Instruments Main TX-, connects to OBC RX- |
| A14 | RRX+ | OBC | Instruments Redundant RX+, connects to OBC TX+ |
| A13 | RRX- | OBC | Instruments Redundant RX-, connects to OBC TX- |
| A12 | Shield RRX | OBC | Shield connected to MAG Ground |
| F11 | RTX+ | OBC | Instruments Redundant TX+, connects to OBC RX+ |
| F12 | RTX- | OBC | Instruments Redundant TX-, connects to OBC RX- |
| F13 | Shield RTX | OBC | Shield connected to MAG Ground |
| F5<br>F6 | +3.3V | PCDU | 3.3V |
| A21<br>A22 | +3.3V_RETURN | PCDU | 3.3V Return |
| A23<br>A24 | +5VA | PCDU | +5.0V Analog |
| F3<br>F4 | +5VA_RETURN | PCDU | +5.0V Analog Return |
| A9<br>A10 | -5VA | PCDU | -5.0V Analog |
| A7<br>A8 | -5VA_RETURN | PCDU | -5.0V Analog Return |

The Instrument electronics board is connected with its sensor heads via the sensor cable and connector. The cable is passed through a hole in the backplane. The Pinout of the the Sensor Connector, type Micro-D 25 (PCB Socket, Pigtail Pin) is provided in following Table 13.

| *Pin* | *Signal name* | *Remarks* |
|---|---|---|
| 1 | EXCITATION | Twisted with 14 |
| 2 | EXCITATION-SCREEN | |
| 3 | NC | |
| 4 | TEMP-S1 | Twisted with 16 |
| 5 | NC | |
| 6 | SENSE-SCREEN | |
| 7 | SENSE-X-(+) | Twisted with 19 |
| 8 | SENSE-Y-(+) | Twisted with 20 |
| 9 | SENSE-Z-(+) | Twisted with 21 |
| 10 | FEEDBACK-SCREEN | |
| 11 | FEEDBACK-X-(+) | Twisted with 23 |
| 12 | FEEDBACK-Y-(+) | Twisted with 24 |
| 13 | FEEDBACK-Z-(+) | Twisted with 25 |
| 14 | EXCITATION-RTN | |
| 15 | NC | |
| 16 | TEMP-S1-RTN | |
| 17 | NC | |
| 18 | NC | |
| 19 | SENSE-X-(-) | |
| 20 | SENSE-Y-(-) | |
| 21 | SENSE-Z-(-) | |
| 22 | NC | |
| 23 | FEEDBACK-X-(-) | |
| 24 | FEEDBACK-Y-(-) | |
| 25 | FEEDBACK-Z-(-) | |

*Table 6: Pinout of the the sensor connector.*

## 2.7 Data Handling Design and Interfaces Requirements

### 2.7.1 MASCOT Data Handling Architecture

Any data exchange between OBC and the instrument is to be initiated by the OBC.

### 2.7.2 MASCOT Interface Characteristics

The MAG Instrument uses an EIA422 compatible serial interface. The interface consists of a quad receiver and quad transmitter on the MAG PCB providing two equivalent interfaces, while two receivers and transmitters remain unused. The MAG instrument listen to both equivalent interfaces and replies to that where valid TC were received. OBC is connected to both interfaces but only one is enabled at a time.

The data interface will be low speed UARTs with a data transmission rate of 19.2 kbps.

## 2.8 ELECTROMAGNETIC DESIGN AND PERFORMANCE

### 2.8.1 General Concept

The general grounding concept is given shown in Figure 1. The MASCOT main electric ground goes to the MAG-E PCB via MHM connector. At the PCB a star point is created to form 5 different grounds for MAG instrument. The grounds are used separately for feedback, excitation, pick-up, HK, and digital circuitry. The MLI, harness aluminium shield, sensor aluminium cover, and baseplate are connected at one point to the harness clamp forming a mechanical ground. There are two options to connect this mechanical ground. One option is to connect to the pick-up ground going through the harness. This option shall be selected, when there is no electrical contact of the MLI or mechanical frame of MAG with MASCOT structure. In case such electrical contact exists, it might be preferable to connect the mechanical ground to the chassis MASCOT ground.

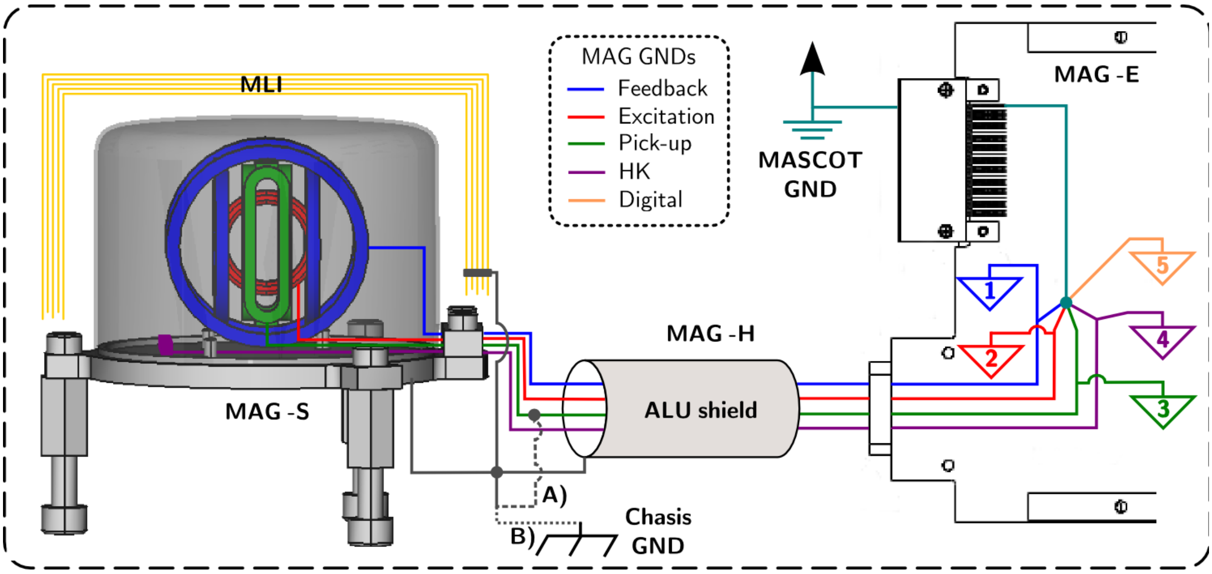



*Figure 1: MASCOT MAG grounding scheme.*

### 2.8.2 Design Requirements

#### *2.8.2.1 GROUNDING AND ISOLATION*

Grounding of structure including boxes, housings, shielding and MLI shall be strictly separated from power grounds leading currents. For avoiding current loops all return power lines shall be routed to a star point as close as possible to the “hot” power lines.

#### *2.8.2.2 ELECTRICAL BONDING AND SHIELDING*

Sensor harness is shielded by aluminium tape.

#### *2.8.2.3 MAGNETIC CLEANLINESS*

Magnetic (DC) disturbances of the lander up to 500 nT at the sensor position can be accepted. Magnetic (AC) disturbances should be as low as possible. Current loops should be avoided. All magnetic cleanliness efforts concerning the lander will be supported by the MAG team. The following photos show exemplarily testing procedures.

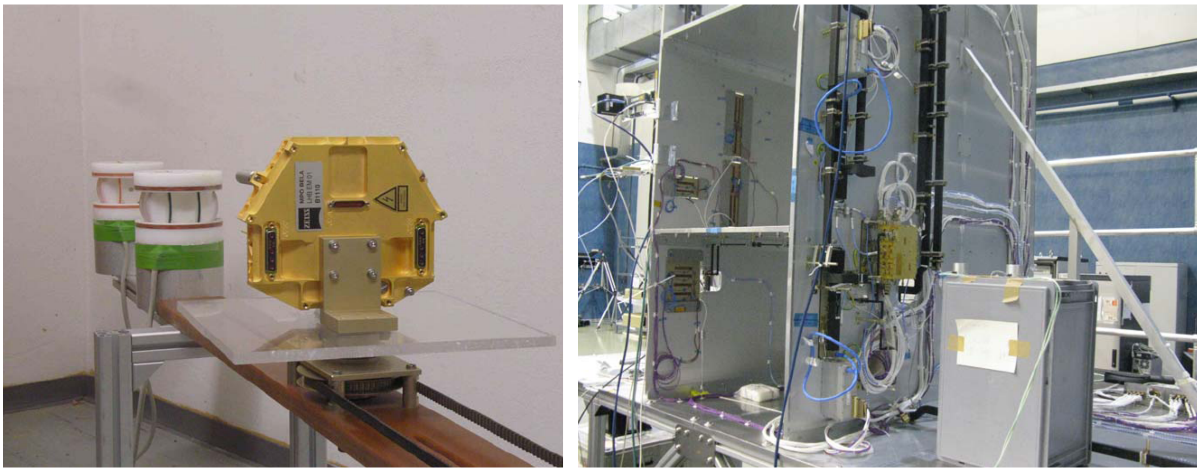


*Figure 2: AC and DC tests with portable facility (left) and testing on an integrated system (right)*

### 2.8.3 Performance Requirements

Science requirements are to measure the magnetic field with the accuracy better than 10 nT. Therefore the bias field generated by the MASCOT itself shall not exceed 500 nT at the position of the MAG sensor.

### 2.8.4 Fault Tolerances

The application of the nominal signals or a faulty signal to an unpowered interface, as required by **[ENG-EC-0350]** (EID-A) do not cause damage to that interface. An undetermined status at the interfaces of a powered unit do not cause damage to an unpowered interface (**[ENG-EC-0360]**). The signal interfaces withstand without damage positive or negative nominal voltages that are accessible on the same connector (from the unit itself, from the interfaced units or from EGSE) **[ENG-EC-0370]**.

## 2.9 SOFTWARE DESIGN AND INTERFACE DESCRIPTION

### 2.9.1 Responsibility

MAG instrument software to be executed by the MAG FPGA will be developed by the MAG team

### 2.9.2 Software Design Requirements

MAG does not require any software to run on the OBC. MAG will be commandable through a set of simple telecommands as specified in 2.9.4.1. The OBC can obtain a status check by checking MAG housekeepings from the telemetry as specified in 2.9.4.2. Erroneous operation of MAG will not cause any safety hazards.

The possibility of an update for the MAG FPGA software is implemented. It is commandable by simple telecommands, making use of the FPGA RAM. The relevant telecommands are "Dump PRAM", "Boot Operation" and "Write PRAM".

### 2.9.3 TM/TC Packet Structure

The telecommand packets have variable cargo size and a maximal cargo size of 23 bytes.

MAG is compliant with the definitions of the generic packet format, its usage, and timing as defined in the section "3 Communication Protocol for Asynchronous Serial Interfaces" of

[AD01]. It is also compliant with the physical and framing layer requirements as specified in section "2.1 Asynchronous Serial Link Interface" of [AD01].

### 2.9.4 Instruments Control

#### 2.9.4.1 TELECOMMANDS

| *TC Addr (hex)* | *Cargo length [B]* | *Function* |
|---|---|---|
| **0x01** | 0 | Link Test |

| *TC Addr (hex)* | *Cargo length [B]* | *Function* |
|---|---|---|
| **0x02** | 1 | HK Request |
| Byte 0: HKStructure-ID | | |

| *TC Addr (hex)* | *Cargo length [B]* | *Function* |
|---|---|---|
| **0x10** | 0 | Mag Data Request |

| *TC Addr (hex)* | *Cargo length [B]* | *Function* |
|---|---|---|
| **0x11** | 3 | Mag Dump PRAM Mirror |
| Byte 0: Dump byte length | | |
| Byte 1-2: PRAM Mirror Start Addr | | |

| *TC Addr (hex)* | *Cargo length [B]* | *Function* |
|---|---|---|
| **0x30** | 4 | Mag Timestamp |
| Byte 0-3: Timestamp | | |
| *Bit #* | *Value* | *Description* |
| 0 to 4: (1/32) seconds | | |
| 5 to 31: seconds | | |

| *TC Addr (hex)* | *Cargo length [B]* | *Function* |
|---|---|---|
| **0x31** | 1 | Mag Boot Operation |
| Byte 0: Boot Operation | | |
| *Bit #* | *Value* | *Description* |
| 0-1: Boot-Operation | 00: Boot from PROM<br>01: Copy PRAM Mirror ->PRAM, Boot PRAM<br>10: Boot from PRAM<br>11: Boot from PRAM | |
| 2-6:spare | | |
| 7: Reset | | Reset to default values |

| *TC Addr (hex)* | *Cargo length [B]* | *Function* |
|---|---|---|
| **0x32** | 2 | Mag LUP |
| Byte 0: LUP_OffOn-Delay | | |

| |
|---|
| in 1/100 s per LSB -> example: LUP_OffOn-Delay=128 (default) -> t_OffOn = 128*1/100 = 1.28s |
| Byte 1: LUP_Blank-Delay |
| in 1/9600 s per LSB -> example: LUP_Blank-Delay=10 (default) -> t_Blank = 10*1/9600 = 1.04ms |

| *TC Addr (hex)* | *Cargo length [B]* | *Function* |
|---|---|---|
| **0x33** | 2 | Mag Mode |
| Byte 0-1: Mode settings | | |
| *Bit #* | *Value* | *Description* |
| 0-2: Mag-Mode 1 | 000: Closed Loop with Compensation<br>001: Closed Loop Fullrange<br>010: Open Loop<br>011: Step-Function | |
| 3-4: Mag-Mode 2 | 00: Standard<br>01: ADC/DAC-Mode X<br>10: ADC/DAC-Mode Y<br>11: ADC/DAC-Mode Z | |
| 5: PEO | 0: Even<br>1: Odd | |
| 6: Excitation | 0: Excitation on<br>1: Excitation off | |
| 7: Measuring | 0: Measuring on<br>1: Measuring off | |
| 8: Analogue | 0: Analog off<br>1: Analog on | |
| 9: Reload Default Config | 0: do nothing<br>1: reload default config | |
| 10: RISC Debug | 0: Debug off<br>1: Debug on | |
| 11-15: spare | | |

| *TC Addr (hex)* | *Cargo length [B]* | *Function* |
|---|---|---|
| **0x34** | 6 | Mag Config 1 |
| 0-1: K1X | | |
| 2-3: K1Y | | |
| 4-5: K1Z | | |

| *TC Addr (hex)* | *Cargo length [B]* | *Function* |
|---|---|---|
| **0x35** | 6 | Mag Config 2 |
| 0-1: K2X | | |
| 2-3: K2Y | | |
| 4-5: K2Z | | |

| *TC Addr (hex)* | *Cargo length [B]* | *Function* |
|---|---|---|
| **0x36** | 6 | Mag Config 3 |
| 0-1: K3X | | |
| 2-3: K3Y | | |

| |
|---|
| 4-5: K3Z |

| *TC Addr (hex)* | *Cargo length [B]* | *Function* |
|---|---|---|
| **0x37** | 5 | Mag Config 4 |
| 0: PhaseX | | |
| 1: PhaseY | | |
| 2: PhaseZ | | |
| 3: KF XYZ | | |
| 4: NOSP | | |

| *TC Addr (hex)* | *Cargo length [B]* | *Function* |
|---|---|---|
| **0x38** | 6 | Mag Config 5 |
| 0-1: DACX Coarse | | |
| 2-3: DACY Coarse | | |
| 4-5: DACZ Coarse | | |

| *TC Addr (hex)* | *Cargo length [B]* | *Function* |
|---|---|---|
| **0x39** | 6 | Mag Config 6 |
| 0-1: DACX Fine | | |
| 2-3: DACY Fine | | |
| 4-5: DACZ Fine | | |

| *TC Addr (hex)* | *Cargo length [B]* | *Function* |
|---|---|---|
| **0x3A** | 6 | Mag Config 7 |
| 0-1: DACX Fact | | |
| 2-3: DACY Fact | | |
| 4-5: DACZ Fact | | |

| *TC Addr (hex)* | *Cargo length [B]* | *Function* |
|---|---|---|
| **0x60** | 2+N (max: N=20) | Mag write PRAM Mirror |
| 0-1: PRAM Mirror-Start Addr | | |
| 2 to (N+1): N PRAM Mirror Data Bytes | | |

#### *2.9.4.2 Telemetry (TM)*

| *TM Addr (hex)* | *Cargo length [B]* | *Function* |
|---|---|---|
| **0x80** | 4 | TC Ack |
| Byte 0: TC Counter | | |
| Byte 1: TC Type | | |
| Byte 2-3: Error Code | | |

| *Bit #* | *Description* |
|---|---|
| 0: LE_LESS3 | Length error: message length must be greater or equal to 3 |
| 1: LE_GREATER255 | Length error: message is too long and will not fit into the message buffer |
| 2: LE_EOMMSB | Length error: no EndOfMessage MSB at the expected position |
| 3: LE_EOMLSB | Length error: no EndOfMessage LSB at the expected position |
| 4: UC_ERROR | Unknown command address error |
| 5: CC_TOLONG | Cargo consistence error: cargo block too long for the current command type |
| 6: CC_TOSHORT | Cargo consistence error: cargo block too short for the current command type |
| 7: TO_PROCREPLY | Timeout: RISC Processor didn’t deliver science data packet after request |
| 8: TO_RECEIVE | Timeout: message wasn’t received completely after StartOfMessage |
| 9: MAXRAMADDRREACHED | PRAM write to an address outside the PRAM address range (0x000…0x7FF) |
| 10: BUFFER_OVERRUN | TC buffer overrun; all commands in the buffer will be discarded |
| 11: WRONG_UID | Command includes a wrong Unit ID |
| 12: UNKNOWN_SID | HK request with an unsupported HK structure ID |

| *TM Addr (hex)* | *Cargo length [B]* | *Function* |
|---|---|---|
| **0x81** | 41(HK_ID=0x00)/49(HK_ID=0x01) | Mag HK |
| Byte 0: HK-structure-ID | | |
| HK-structure-ID=0x00 | | |
| Byte 1-5: Status | | |
| *Bit #* | *Value* | *Description* |
| 0-15: LUP Counter | | |
| 16-19: Board ID | | |
| 20-21: RISC Status | 00: Bootloader running<br>01: PROM Firm running<br>10: PRAM Firm running | |
| 22: Firm CRC Test | RISC Status = PRAM running<br>0: Checksum wrong<br>1: Checksum valid<br>else<br>don’t care | |
| 23-25: Mag-Mode 1 | 000: Closed Loop with Compensation<br>001: Closed Loop Fullrange<br>010: Open Loop<br>011: Step-Function | |
| 26-27: Mag-Mode 2 | 00: Standard<br>01: ADC/DAC-Mode X<br>10: ADC/DAC-Mode Y<br>11: ADC/DAC-Mode Z | |
| 28: PEO | 0: Even<br>1: Odd | |
| 29: Excitation | 0: Excitation on<br>1: Excitation off | |
| 30: Measuring | 0: Measuring on<br>1: Measuring off | |

| | | |
|---|---|---|
| 31: Analogue | 0: Analog off<br>1: Analog on | |
| 32: RISC Debug | 0: Debug off<br>1: Debug on | |
| 33-39: tbd | | |
| Byte 6-9: Instrument Timestamp | | |
| *Bit #* | *Value* | *Description* |
| 0-4: (1/32) seconds | | |
| 5-31: seconds | | |
| Byte 10-25: 8 analogue HK values per 2 Bytes | | |
| Byte 26-28: B field X | | |
| Byte 29-31: B field Y | | |
| Byte 32-34: B field Z | | |
| Byte 35: ASLFraming Error Counter | | |
| Byte 36: ASLParity Error Counter | | |
| Byte 37: ASLOverrun Error Counter | | |
| Byte 38: ASL Break Error Counter | | |
| Byte 39-40: Checksum | | |
| HK-structure-ID=0x01 | | |
| Byte 1: Boot Operation | | |
| *Bit #* | *Value* | *Description* |
| 0-1: Boot-Operation | 00: Boot from PROM<br>01: Copy PRAM Mirror ->PRAM, Boot PRAM<br>10: Boot from PRAM<br>11: Boot from PRAM | |
| Byte 2: LUP_OffOn-Delay | | |
| Byte 3: LUP_Blank-Delay | | |
| Byte 4-5: Mode settings | | |
| *Bit #* | *Value* | *Description* |
| 0-2: Mag-Mode 1 | 000: Closed Loop with Compensation<br>001: Closed Loop Fullrange<br>010: Open Loop<br>011: Step-Function | |
| 3-4: Mag-Mode 2 | 00: Standard<br>01: ADC/DAC-Mode X<br>10: ADC/DAC-Mode Y<br>11: ADC/DAC-Mode Z | |
| 5: PEO | 0: Even<br>1: Odd | |
| 6: Excitation | 0: Excitation on<br>1: Excitation off | |
| 7: Measuring | 0: Measuring on<br>1: Measuring off | |
| 8: Analogue | 0: Analog off<br>1: Analog on | |
| 9: not used | 0 | |
| 10: RISC Debug | 0: Debug off<br>1: Debug on | |
| 11-15: spare | | |

| |
|---|
| Byte 6-7: K1X |
| Byte 8-9: K1Y |
| Byte 10-11: K1Z |
| Byte 12-13: K2X |
| Byte 14-15: K2Y |
| Byte 16-17: K2Z |
| Byte 18-19: K3X |
| Byte 20-21: K3Y |
| Byte 22-23: K3Z |
| Byte 24: PhaseX |
| Byte 25: PhaseY |
| Byte 26: PhaseZ |
| Byte 27: KF XYZ |
| Byte 28: NOSP |
| Byte 29-30: DACX Coarse |
| Byte 31-32: DACY Coarse |
| Byte 33-34: DACZ Coarse |
| Byte 35-36: DACX Fine |
| Byte 37-38: DACY Fine |
| Byte 39-40: DACZ Fine |
| Byte 41-42: DACX Fact |
| Byte 43-44: DACY Fact |
| Byte 45-46: DACZ Fact |
| Byte 47-48: Checksum |

| *TM Addr (hex)* | *Cargo length [B]* | *Function* |
|---|---|---|
| **0x90** | 8 - 116 | Mag Data Packet |
| Byte 0: Status | | |
| *Bit #* | *Value* | *Description* |
| 0: Clipping X | | |
| 1: Clipping Y | | |
| 2: Clipping Z | | |
| 3-7: tbd | | |
| Byte 1-4: Instrument Timestamp<br>• (of last Vector in the Packet)<br>• MSByte first | | |
| Byte 5: Number of Vectors in the Packet (NV)<br>• 0 - 12 | | |
| Byte 6 to (9* NV+5): NV 3-Comp. Data Vectors per 3 byte<br>• MSByte first<br>• Signed int in 2 complement implementation | | |
| Byte (9* NV+6) to (9* NV+7): Checksum | | |

| *TM Addr (hex)* | *Cargo length [B]* | *Function* |
|---|---|---|
| **0x91** | N+4 | Mag Dump PRAM Mirror Data |

| |
|---|
| Byte 0-1: PRAM Mirror Start Addr<br>• N: as requested via Mag PRAM Mirror TC |
| Byte 2 to N+1: PRAM Mirror Data Bytes |
| Byte N+2 to N+3: Checksum |

Mag Housekeeping and Data Packets comprise a 2 byte checksum. Checksum calculation includes the whole cargo and uses the CRC16 CCITT method with start value 0x0000.

Housekeeping Data Packet **0x81** is transferred after reception of a Housekeeping request telemetry command **0x02**. Mag Dump Packet **0x91** is transferred after reception of a Mag Dump RAM telecommand **0x11**. Mag Science Data Packet **0x90** is transferred after reception of a Mag Data request telemetry command **0x10**.

The Housekeeping Data Packet comprises the following housekeeping values. Thresholds are stored in the OBC and are given in Table 15. The threshold values stored in the OBC shall be changeable during cruise.

| *HK-Structure ID=0* | | | | |
|---|---|---|---|---|
| *Byte* | *HK- Value* | *Threshold Min* | *Threshold Max* | *FORMAT* |
| 10-11 | Voltage at +5VA-Line | 4.75 V | 5.25V | Unsigned INT |
| 12-13 | Current at +5VA-Line | 30 mA | 90 mA | Signed INT |
| 14-15 | Voltage at -5VA-Line | -5.5 V | -4.5 V | Unsigned INT |
| 16-17 | Current at -5VA- Line | 3 mA | 20 mA | Signed INT |
| 18-19 | Voltage at 3.3V-Line | 3.0 V | 3.6 V | Unsigned INT |
| 20-21 | Current at 3.3V-Line | 20 mA | 70 mA | Signed INT |
| 22-23 | Sensor Temperature | N/A | N/A | Unsigned INT |
| 24-25 | Board Temperature | -50°C | +75°C | Unsigned INT |
| 26-28 | Bx field component | N/A | N/A | Signed INT |
| 29-31 | By field component | N/A | N/A | Signed INT |
| 32-34 | Bz field component | N/A | N/A | Signed INT |

*Table 7: HK structure ID=00 - voltage and current threshold numbers.Signed INT is in two's complement implementation.*

#### *2.9.4.3 TIMING*

To achieve a synchronisation of the MAG instrument to the OBC time base, the OBC sends its time counter via the TC **0x30** to the MAG instrument. An accuracy of the synchronisation of 1sec is sufficient. It is foreseen that the Timestamp command is sent to the MAG only once after switch on. No subsequent synchronisation is necessary.

#### *2.9.4.4 COMMAND USAGE*

The MAG instrument comprises a FGPA based processor which controls the data acquisition. Configuration and Calibration parameters for the MAG instrument are stored in the FPGA'S Flash. After switch on of the MAG instrument, it will start operation with these default parameters in the default mode. So, after instrument switch on no additional telecommands are needed to initialize the MAG instrument. Only the “Mag Timestamp” command has to be sent to synchronize the internal clock. Nevertheless it is possible to overwrite the default parameters by command, in case some of the default parameters became - due to whatever reason – invalid.

Also during cruise it might be useful to set the instrument in different operation modes to check out the instrument performance.

The instruments electronics comprises a latch up protection circuitry. When this circuitry detects an over current in the analog electronics, the FPGA switches the analog voltages of for a certain time (LUP_OffOn-Delay) and switches the voltages on again while ignoring the latch up dectection for a certain time (LUP_Blank-Delay) to blank out the inrush currents.

LUP_OffOn-Delay and LUP_Blank-Delay are preset in the FPGA RAM but these default values can be overwritten via the “Mag LUP”-telecommand.

A complete reconfiguration of the MAG instrument can be performed by sending the telecommands “Mag Timestamp”, “Mag LUP”, “Mag Mode” and “Mag Config 1” to “Mag Config 7”.

While the commands can only overwrite the register copies of the Flash stored parameters, the commanded parameters become invalid after the next power cycle and have to be commanded again.

The FPGA based processor will have a flash based firmware, which is not changeable during flight, but modified firmware can be uploaded in the FPGA’s RAM and the processor rebooted with the RAM option. That makes the processor run the RAM based firmware.

The firmware can be uploaded in the RAM mirror via the “Mag Prog RAM”-telecommand. When the processor is rebooted by sending “Mag Boot Operation”-telecommand with the reset flag and the RAM option, the content of the RAM mirror it transferred in the RAM and the processor executes the RAM based firmware. “Mag Dump RAM”-telecommand can initiate a RAM dump of the specified length starting at the specified address. The RAM dump is transferred the “Mag Dump”-telemetry packet.

The length of the RAM mirror is 16kbit.

#### *2.9.4.5 DATA ACCQUISITION*

The MAG instrument operates with a sampling rate of 10Hz based on the instrument’s clock. The OBC is requested to send every second a “Mag Data Request” command. Because MAG and OBC operate asynchronously on different clocks, Mag will have acquired 9 to 11 samples within 1 second of the OBC clock as far as both clocks differ less than 10%, which can be regarded as sure. The number of samples acquired by MAG is given in the status bytes of the data packet cargo.

The rate of HK requests issued by the OBC should not be lower than once per 10 seconds.

### 2.9.5 Instrument Autonomy

#### *2.9.5.1 MAG AUTONOMY CONCEPT AND OPERABILITY*

The MAG Instrument performs low level monitoring and actions autonomously. Ground station actions can intervene autonomous or OBC controlled actions.

#### *2.9.5.2 GENERAL INSTRUMENT AUTONOMY REQUIREMENTS*

The MAG instrument during the surface operations will operate fully autonomously. The requirements toward the system are to switch on the MAG before separation. Switch off shall be done for safety reasons (over current) and at the end of nominal MAG operations.

#### *2.9.5.3 EVENTS REACTION*

| *Event* | *Reaction* |
|---|---|
| Voltage at +5VA-Line outside thresholds | OBC power cycles the MAG instrument |
| Voltage at -5VA-Line outside thresholds | OBC power cycles the MAG instrument |
| Voltage at +3.3VA-Line outside thresholds | OBC power cycles the MAG instrument |
| Current at +5VA-Line outside thresholds | OBC power cycles the MAG instrument |
| Current at -5VA-Line outside thresholds | OBC power cycles the MAG instrument |

| | |
|---|---|
| Current at +3.3V-Line outside thresholds | OBC power cycles the MAG instrument |
| Sensor Temperature outside thresholds | NO action |
| Board Temperature outside thresholds | NO action |

Table 8: Events reaction.

#### *2.9.5.4 Operating Modes*

| *Mode type* | *Mode name* | *Description* |
|---|---|---|
| OFF | | |
| Stand-by Mode | | Mag idle, only FPGA, I/F, and HK on. Waiting for commands. |
| Science Mode | Closed Loop with Compensation | Default measurement mode with fine resolution and possible offset compensation setup. |
| | Closed Loop Fullrange | Measurement in a full instrument range. |
| Calibration Mode | Open Loop | Feedback inhibited. Readout of the ADC values only for AD converter calibration purposes. |
| | Step-Function | MAG sends pre-set counter to check the communication channel between MAG FPGA, Lander,S/C and ground segment. |

Table 9: Operating modes.

### 2.9.6 Instrument Data Compression

The MAG instrument does not make use of data compression.

### 2.9.7 Instrument Data Rate

| *Mode type* | *Data rate nominal [bit/s]* | *Data rate peak [bit/s]* | *Description* |
|---|---|---|---|
| Stand-by Mode | 97.6 | 97.7 | HK acquisition with 0.1 Hz rate. 45.6 bit/s for HK00 and 52 bit/s for HK01. |
| Both Science Mode | 1010.4 | 1154.4 | Scientific data package transmission with 1Hz rate with 10 (12 max.) measurements per TM package (measurement with 10Hz), HK transmission with 0.1 Hz rate. |
| Both Calib. Mode | 1010.4 | 1154.4 | Scientific data package transmission with 1Hz rate with 10 (12 max.) measurements per TM package (measurement with 10Hz), HK transmission with 0.1 Hz rate. |

Table 10: Instrument data rates.

### 2.9.8 Inflight Testing

The inflight testing comprises of several check-out during commissioning. The procedure will consist of health check sequence, that will be similar to the sequence used for ground testing purposes.

### 2.9.9 Startup/shutdown procedures

| MAG Startup procedure | | |
|---|---|---|
| Step | Action | Wait [sec.] |
| 001 | Power ON MAG | 5 |
| 002 | Check the current consumption and voltage values. | 1 |
| 003 | Start planned activities (e.g. Health check or magnetic data acquisition) | |

| MAG shutdown procedure | | |
|---|---|---|
| Step | Action | Wait [sec.] |
| 001 | Power OFF MAG | |
| | | |

### 2.9.10 Failure Detection, Isolation And Recovery

OBC shall monitor MAG power lines for voltage/current values. Thresholds for the values are given in Table 14. In case of detection of a value, that exceeds threshold limits, OBC shall do the action given in Table 15.

Each telecommand shall be monitored for correct transmission via TC Acknowledge (TC ck) packet. TC Ack packet contains error codes as given in 2.9.4.2. The error recovery action to each error is specified in Table 18. When the same error appears more than 2 times consecutively, the OBC shall power cycle MAG instrument.

| *Error code* | *Error description* | *Recovery action* |
|---|---|---|
| 0: LE_LESS3 | Length error: message length must be greater or equal to 3 | Resend correct TC |
| 1: LE_GREATER255 | Length error: message is too long and will not fit into the message buffer | Resend correct TC |
| 2: LE_EOMMSB | Length error: no EndOfMessage MSB at the expected position | Resend correct TC |
| 3: LE_EOMLSB | Length error: no EndOfMessage LSB at the expected position | Resend correct TC |
| 4: UC_ERROR | Unknown command address error | Resend correct TC |
| 5: CC_TOLONG | Cargo consistence error: cargo block too long for the current command type | Resend correct TC |
| 6: CC_TOSHORT | Cargo consistence error: cargo block too short for the current command type | Resend correct TC |
| 7: TO_PROCREPLY | Timeout: RISC Processor didn't deliver science data packet after request | OBC power cycles the MAG instrument |
| 8: TO_RECEIVE | Timeout: message wasn't received completely after StartOfMessage | Resend correct TC |
| 9: MAXRAMADDRREACHED | PRAM write to an address outside the PRAM address range (0x000…0x7FF) | OBC power cycles the MAG instrument |
| 10: BUFFER_OVERRUN | TC buffer overrun; all commands in the buffer will be discarded | OBC power cycles the MAG instrument |
| 11: WRONG_UID | Command includes a wrong Unit ID | Resend correct TC |
| 12: UNKNOWN_SID | HK request with an unsupported HK structure ID | Resend correct TC |

*Table 11: Error recovery actions.*

The timeout for the TCAck reception packet is 500ms . In case of timeout of the TC Ack OBC shall power cycle the MAG instrument.

In case of necessary power cycle, the OBC shall wait 5 seconds before switch on again. In case of repetitive failure (at least 3 times), the OBC shall switch to redundant interface and repeat the power ON. In case of 3 consecutive failures also via redundant interface, the instrument shall be considered lost.

# 3 GROUND SUPPORT EQUIPMENT DESIGN AND INTERFACES

## 3.1 Ground Support Equipment Design and Interface Requirements

The EGSE is a stand alone equipment that consist of EGSE H/W and laptop PC, both powered via mains electricity (100-240V, 50-60 Hz). No special requirements are necessary.

## 3.2 Ground Support Equipment Design

Ground support equipment for MAG consists of PCB board, laptop PC, and EGSE software. The connection diagram is shown in Figure 2. EGSE - PC is running control center software to operate the instrument and acquire data. EGSE - H/W is connected to the PC via LAN interface and transfers the commands to the instrument electronics (MAG-E) and vice-versa the acquired data from the instrument back to the PC. The power for instrument electronics is provided by the EGSE.

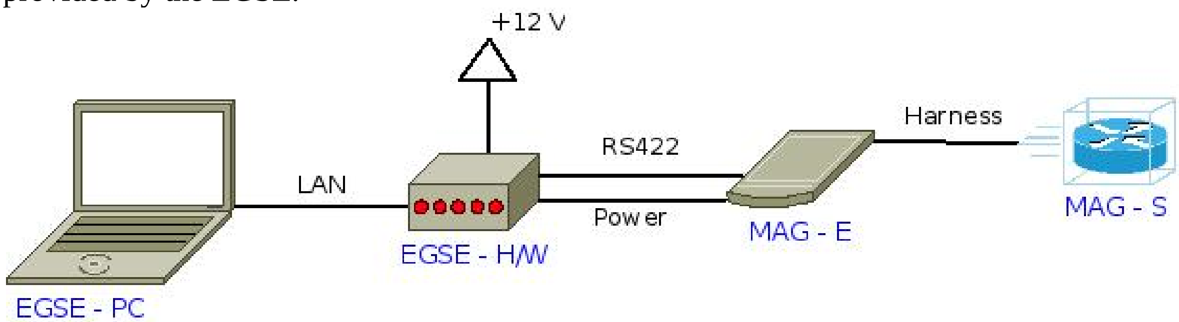



*Figure 3: EGSE connection diagram*

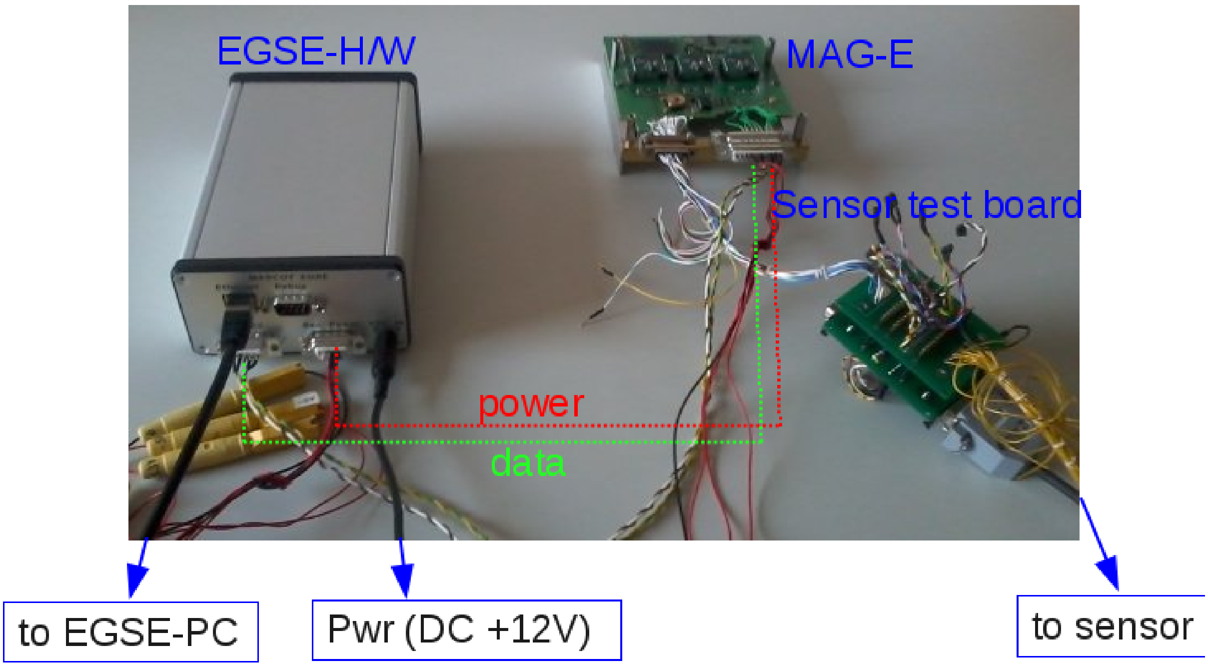



*Figure 4: Connection setup.*

### 3.2.1 EGSE - H/W

The EGSE provides electrical and data interface to the magnetometer board. It is powered by 12V using an adapter (from 220V AC to 12V DC). It provides RS422 interface to the MAG data and +5V, -5V, and +3.3V voltage levels as the power inputs for MAG telecommanding and acquired data from MAG are send via LAN interface to a laptop running EGSE software. The front panel of EGSE H/W with connector descriptions is shown in Figure 4.

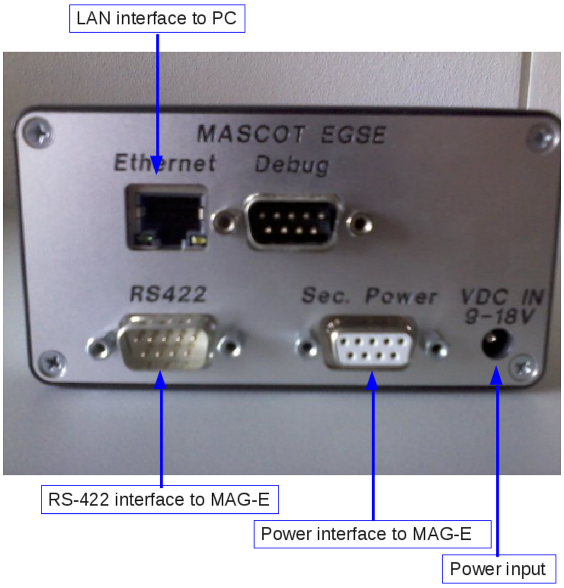



*Figure 5: EGSE - H/W*

### 3.2.2 EGSE software

The EGSE software is windows-based stand alone application, that enables MAG instrument commanding and data aquisition. The communication is via EGSE H/W using a standard TCP/IP communication protocol. The software provides all TC commanding as described in section 2.9.4.1-Telecommands. It shows the real time acquired data in graphical well as in ASCII format and enables also the data logging for further analysis.

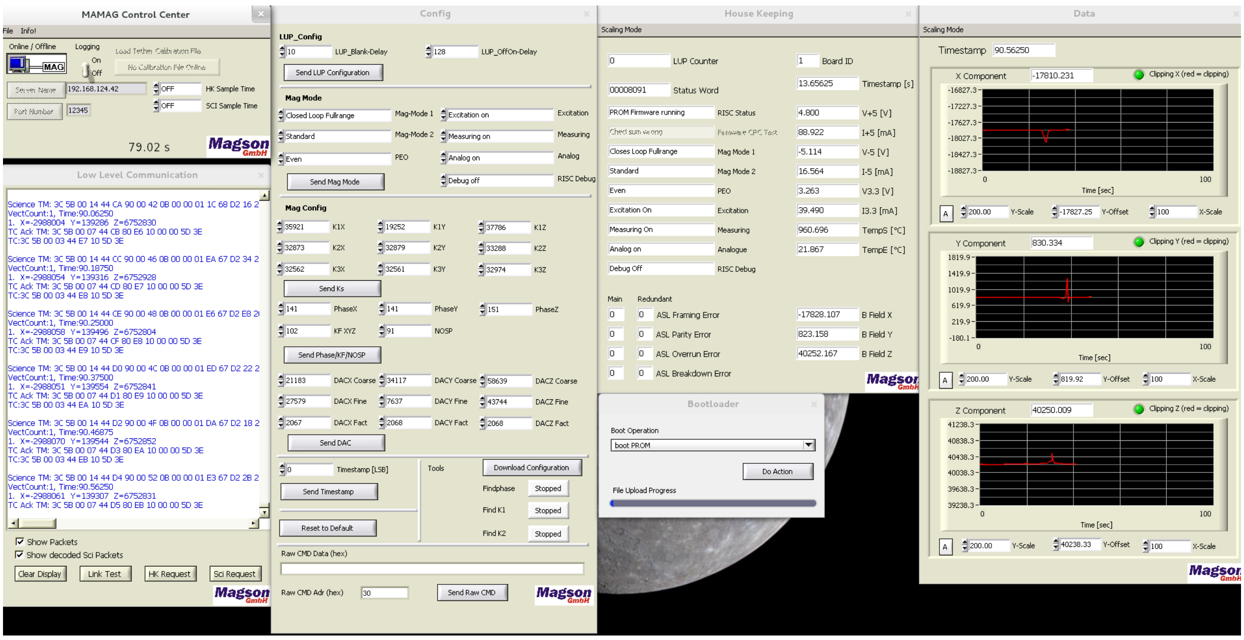



*Figure 6: MasMag control center screenshot.*

## 3.3 Ground Support Equipment Interface

An EGSE as described above will be ready for testing and integration. It is not part of the delivery with the EQM and FM models. The EGSE will be operated by a MAG team member.

# 4 INSTRUMENT ASSEMBLY, VERIFICATION AND TEST PLAN

## 4.1 GENERAL

The MAG project shall follow a classical design approach. The complete instrument shall be bread- boarded before proceeding to an engineering qualification model, which is a deliverable to the project. The breadboard shall be continuously updated as the design progresses. The breadboard model shall be the test target for flight software development through EQM and FM phases.

## 4.2 MODEL PHILOSOPHY

MAG model philosophy is as follows:

- BBM - Bread Board Model for design validation and functionality tests, the BBM is developed using commercial equivalent components assembled on a flight equivalent PCB.
- STM - Structural Thermal Model of the sensor
- EQM - Engineering and Qualification Model for electrical functions, interfaces and performances as well for qualification process.
- FM - Flight Model
- FS - Flight Spare
- GRM - Ground Reference Model (flight representative for on-ground testing and evaluation during mission)

### 4.2.1 Bread Board Model (BBM)

The Bread Board Model will consist of separate PCB board to be developed indepently on the sensor development. The demonstration of functionality will be limited verified using a standard fluxgate sensor (of the shelf) used for on ground measurement purposes. The goal of the BBM part remains the test of the design and functionality and fitting of the design to given PCB mechanical dimensions and requirements.

### 4.2.2 Structural Thermal Model (STM)

Structural Thermal Model of the sensor will be mechanical representative of the Flight sensor. The PCB board will not be delivered.

### 4.2.3 Engineering Qualification Model (EQM)

The Engineering Model shall follow after BBM verification. Necessary modification to the design will be incorporated into the EM design. The main purpose of the EQM model are:

- To confirm proper functionality of the design.
- To confirm electrical interfaces compatibility within the MASCOT system.
- To verify performances of the MAG instrument.
- To perform qualification of the MAG instrument.

The qualification of the sensor will be doe by Similarity.

The qualification test for MAG electronics will consists of:

- Structural tests
  - Vibration test

The EQM will be flight representative in electrical properties (functionality and electrical interfaces), functional properties (firmware/software design at least in terms of interfaces), and also mechanical properties. The components shall be flight components or proto-parts to the FM selection. EQM will be tested with EGSE and MGSE. The EQM will be calibrated.

### 4.2.4 Flight Model (FM)

The Flight Model will be compliant to the Mascot EID-A requirements. Acceptance tests will be performed in order to confirm proper functionality, however not full qualification will be performed in order to lower the FM H/W stresses. Test TC sequences will be defined and performed. Calibration of the FM will take place.

### 4.2.5 Flight Spare (FS)

The EQM sensor becomes FS. If needed, the EQM electronics will be refurbished to FS.

### 4.2.6 Ground Reference Model (GRM)

The EQM sensor GRM after launch. The GRM electronics will be flight representative.

### 4.2.7 Build standards summary

Table 19 summaries the build standards of the MAG models.

*Flight representative* means:

- EEE parts of same type and packaging and compatible with the qualification progress, but not

necessarily screened to space-quality level nor radiation guaranteed.

- Mechanical parts fabricated according to the materials and processes list .

*Flight equivalent* means

- Full compatibility to Flight Model

| | *BBM* | *STM* | *EQM* | *FM* | *GRM (FS)* |
|---|---|---|---|---|---|
| Sensor | testing sensor, development spare | Dummy sensor, Mechanical representative | flight equivalent sensor | flight sensor | EQM sensor is to be used as the GRM sensor |
| Electronics | PCB board, mechanical design FM representative, Electrical components - commercial equivalent to flight parts, except connector to backplane | no | PCB board (electrical, mechanical) FM representative, (incl. components) | flight electronics | flight representative |
| Harness | engineering harness, used with testing board to adapt to PCB board | no | flight equivalent | flight harness | flight equivalent |
| Thermal H/W | no | no | MLI | MLI | no |
| Instrument | flight represent- | | flight represent- | flight firmware | flight equivalent |

| | | | | | |
|---|---|---|---|---|---|
| firmware | ative of the FPGA firmware | | ative of the FPGA firmware | | of the FPGA firmware |
| EGSE Workstation[1] | Laptop running EGSE Software and connected to EGSE Board via LAN interface. | | | | |
| EGSE Board[1] | EGSE PCB providing interface between MAG-E board and EGSE Workstation | | | | |
| EGSE Software[1] | MasMag control center (win based software for instrument commanding and data acquisition | | | | |
| MGSE | no | no | mechanical frame for PCB, TB used for mechanical support during testing | mechanical frame for PCB, TB used for mechanical support during testing | no |
| 1) EGSE is not part of delivery. One EGSE used (and updated if need be) during the whole project. | | | | | |

*Table 12: Build standards summary.*

## 4.3 Deliverables

The project deliverables are listed here below.

### 4.3.1 H/W deliverables

- EQM - electronics board, sensor, sensor harness
- FM - electronics board, sensor, sensor harness
- GRM - electronics board, sensor, sensor harness

### 4.3.2 Documentation deliverables

| | *CDR* | *FR* | *Note* |
|---|---|---|---|
| Design Document | X | X | |
| EID-B | X | X | |
| AIV Plan | X | | Merged into EID-B |
| PA Plan | X | | Merged into EID-B |
| EICD | X | | Merged into Design Document |
| MICD | X | | Merged into Design Document |
| TICD | X | | Merged into Design Document |
| Parts & Material List | X | X | |
| Reliability Analysis (FMEA, SPFA, FTA, CIL) | | | |
| Configuration Item Data List | X | | Merged into Design Document |
| Ops Plan | X | | Merged into EID-B |
| Test Procedures | | X | |
| Tech Notes (incl. Test results & analysis), | | X | |

| | | | |
|---|---|---|---|
| STM, EM, EQM Model Build Standard | X | | Merged into Design Document |

## 4.4 Development plan

### 4.4.1 Qualification approach

The MAG instrument will be qualified via dedicated qualification model (EQM). The EQM shall comprise a flight representative example of

- The electronics PCB.
- The sensor
- The sensor thermal hardware.
- The sensor harness.

### 4.4.2 Unit development

The development plan is predicated on the fact that the sensor and it's associated sensor electronics can be developed, manufactured and functionally tested independently. This is in order to enable to proceed independently on both units. For electronics functional tests representative sensor (of the shelf) will be used. For calibration as well qualification, performance, and acceptance tests the MAG electronics and MAG sensor will be tested together.

### 4.4.3 Firmware development

The instrument is controlled by an FPGA. The firmware will be written in VHDL code and will be in accordance with the ECSS Q-ST-60-02C standard.

### 4.4.4 GSE development

The GSE for the MAG experiment shall comprise:

- EGSE Workstation for running the EGSE Software
- EGSE Software for the instrument control and data acquisition
- EGSE Board for connecting the EGSE Workstation to MAG instrument
- MGSE including transport case and mechanical frame for electronics

## 4.5 Work flow

The work flow logic is illustrated in the Figure 7. The work is divided into three main areas: electronics, sensor and other programmatic workpackages. The details of individual steps in the project are given below in the following sections.

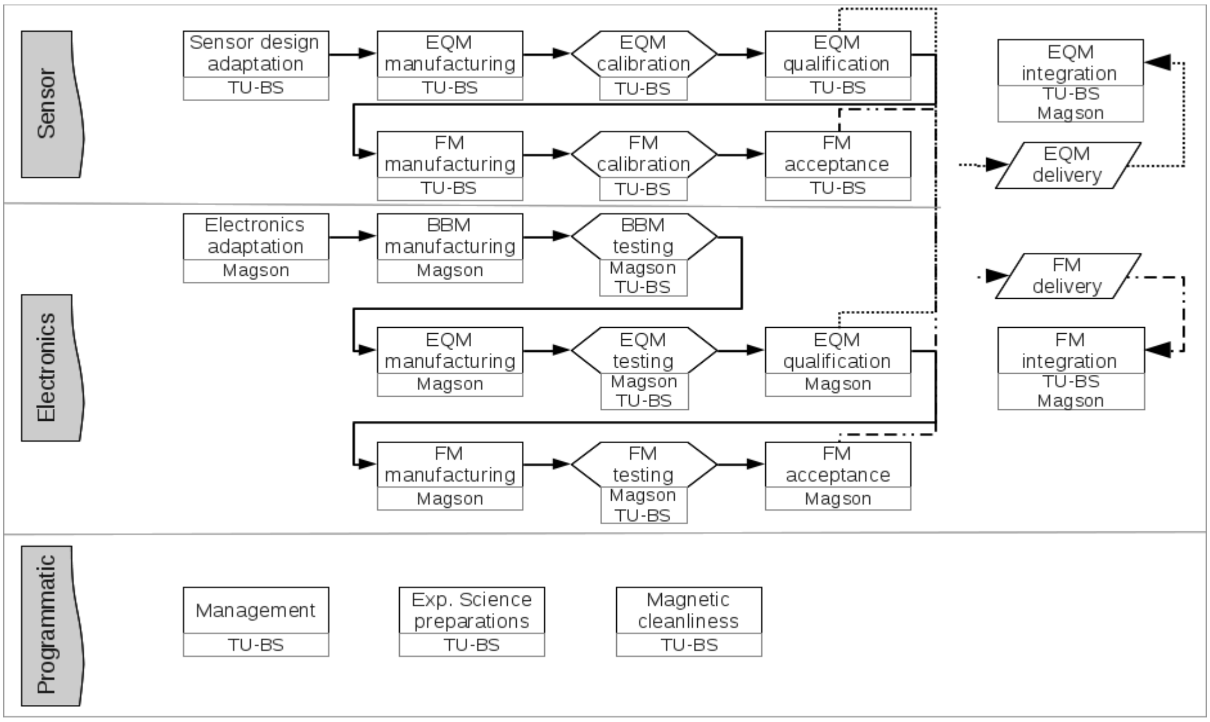



*Figure 7: The MAG instrument work flow logic with task and responsible body identification.*

### 4.5.1 Phase A/B activities

The main activities of the phase A/B will lead to BBM development and manufacturing in order to demonstrate proper functionality and adapt previous design of the MAG electronics to Mascot requirements. The MAG requirements will be defined as a response to spacecraft requirements and MAG scientific objectives. Preliminary design of the electronics will then start followed by the breadboarding activities. In particular the activities will consist of:

- Review of system requirements.
- Definition of scientific and technical requirements.
- Preliminary design and analyses of the functionality.
- Definition of electrical architecture and interfaces.
- Thermal control concept definition.
- Breadboarding of electronic board.
- Verification of BBM functionality.

Phase B will aim to PDR review that shall review proposed design. PDR results will be incorporated in an update of the design.

### 4.5.2 Phase C/D Activities

Phase C will be focused on the main design activities, that shall translate BBM design and PDR review modifications into Engineering model. The design and performance will be reviewed during the CDR milestone. The main activities of phase C are:

- Interfaces specification confirmation and validation.
- Final electrical design.
- Final mechanical design.
- EQM development, manufacturing and verification.
- EGSE and MGSE modification and production.

- EQM qualification.
- FM manufacturing, assembly and integration.
- FM acceptance testing.
- FM delivery and integration into the S/C
- Integrated FM functionality verification.
- GRM manufacturing, verification and integration.

## 4.6 Manufacturing activities

The manufacturing activities will be divided in two main parts. Manufacturing of the electronics will be done in Magson GmbH premises and the sensor will be manufactured within TU-BS, IGeP laboratories.

### 4.6.1 Mechanical parts

The mechanical design of the sensor will be an adaptation of previously developed sensors (Themis, Rosetta, BepiColombo). Particular design and mechanical drawings will be subcontracted to certified company. The mechanical structure of the sensor will be subcontracted. Mechanical structure of the electronics board will be compliant to the system requirements.

### 4.6.2 Electronic board

Electronics boards are standard printed circuit boards using FR4 material. The PCBs are manufactured by a space qualified company according to space rules.

### 4.6.3 Harness

Harness from the electronics to the sensor will be manufactured by a qualified company using Gore-Tex® cables. This kind of harness has been already used for BepiColombo mission. Micro-D 25 (PCB Socket, Pigtail Pin) connector will be used as an interface to electronics board.

## 4.7 Assembly & integration activities

### 4.7.1 Electronics unit assembly

Mag consists of a single PCB only. The board will be equipped with a support structure in order to enable safe handling during testing. The structure will be remove before integration.

### 4.7.2 Sensor assembly

The sensor will be assembled within the TU-BS laboratory and connected to the sensor harness. The harness will be equipped with a connector to connect to the electronics.

### 4.7.3 Calibration

The whole instrument (EQM and FM electronics with respective sensors) will be calibrated in a 2.5 m three axes Braunbek coil system at the Magnetsrode calibration laboratory at the Technical University of Braunschweig.

### 4.7.4 System integration

The whole MAG instrument (electronics and sensor) shall be integrated to the Mascot structure within the Integrator premises by a qualified personnel. At least one member of the MAG team will be present during the integration and will proceed with functionality verification after.

#### 4.7.5 The assembly and integration requirements

The MAG instrument shall be integrated into the Mascot structure within a DLR premises by a dedicated qualified staff. During the integration and consecutive testing at least one MAG team member shall be present. The integration of the MAG shall be done with the environmental constraints

described herein after.

- ESD

The electronics is ESD sensitive. Their performances could be degraded temporarily or definitely,

if they receive an electrostatic discharge. For all the integration activities, anti-static ground in the integration room and ESD wrist are required.

- Cleanliness

The integration and handling shall follow ECSS-Q-ST-70-01C standard.

### 4.8 TEST & VERIFICATION ACTIVITIES

#### 4.8.1 Verification objectives and control

The objectives of the MAG design verification process are to demonstrate:

- Qualification of the instrument design
- Acceptance of the instrument flight models
- Acceptability for the spacecraft environment
- Performance of the instrument, and capability to fulfill the mission objectives
- Instrument integrity post-launch and in the mission operational environment

These objectives are applicable to the instrument models:

- EQM
- FM
- GRM

Verification comprises all processes, test, and procedures leading to functionality verification and instrument qualification. The verification will consist of following procedures:

| *Test Description* | *BBM* | *STM* | *EQM electronics* | *EQM sensor* | *FM/GRM electronics* | *FM/GRM sensor* |
|---|---|---|---|---|---|---|
| Visual inspection | X | X | X | X | X | X |
| Dimensions Verification | | X | X | X | X | X |
| Physical properties | | X | X | X | X | X |
| Full Functional test | X | | X | X | X | X |
| Sine vibration | | X(S) | X | X | X(AS) | X(AS) |
| Random vibration | | X(S) | X | X | X(AS) | X(AS) |
| Shock test | | | - | - | - | - |
| Functional test II | | | X | X | X | X |
| Thermal vacuum test | | X(S) | X(S) | X(S) | X(AS) | X(AS) |
| Thermal balance test | | | X(S) | X(S) | | |
| Functional test III | | | X | X | X | X |
| EMC | | | X(S) | X(S) | X(S) | X(S) |
| Thermal test | | | X(S) | X(S) | X(S) | X(S) |
| Grounding/bonding/ | | | X | X | X | X |

| | | | | | | |
|---|---|---|---|---|---|---|
| isolation | | | | | | |
| Calibration | | | X | X | X | X |
| (A) - acceptance levels<br>(S) - on the system level | | | | | | |

### 4.8.2 Verification approach

#### *4.8.2.1 Verification by Similarity*

The MAG instrument bears significant heritage from previous flight instruments. The sensor itself is similar to previous flight proven instruments (Rosetta, Themis). Therefore, it is expected, that sensor design will be fully verified by the similarity. In accordance with EID-A requirement AIV-TP-0050 the sensor is category A instrument. A verification by other means will focus in particular to this aspect. If need be, e.g., when the tests requirements will exceed the qualification levels of previous proven sensors, verification by test will be discussed.

#### *4.8.2.2 Verification by Inspection*

Verification by inspection shall be applied to visual inspection (before and after testing).

#### *4.8.2.3 Verification by Analysis*

The verification by analysis of the structural mathematical model will not be implemented. The mechanical design of the sensor will be verified by similarity. Therefore only the instrument thermal design shall be supported by mathematical analysis. Moreover, the mechanical and thermal design shall also be verified by test.

#### *4.8.2.4 Verification by Test*

The interface requirements listed below shall be verified by test at acceptance or qualification level as appropriate:

- Mechanical properties
  - Sine vibration
  - Random vibration
- Thermal properties
  - Thermal test to check the MAG performances vs. temperature
- Electromagnetic properties
  - Grounding, bonding & isolation
- Functional performance
- Measurement Performance
  - Calibration
- Electrical interface measurements
- Physical properties
- Dimensions

The test requirements and levels will be in accordance to requirements defined in the EID-A. Thermal vacuum cycling and balance tests will not be done on the instrument level as these tests will be done at Mascot level. Therefore there is no need to perform individual tests, when the qualification levels will be achieved at the system level.

### 4.8.3 Verification at model levels

#### *4.8.3.1 Verification at Bread Board Model level*

The requirements listed below shall be verified on the breadboard model:

- Functional Performance
- Measurement Performance (in part)

The Build Standard of the breadboard model is therefore:

- Commercial quality EEE parts
- Non flight-representative mechanical and thermal design

##### 4.8.3.2 Verification at EQM level

The requirements listed below shall be verified on the qualification model of the electronics (MAG-E):

- Mechanical properties
  - Sine vibration (qualification level)
  - Random vibration (qualification level)
- Thermal properties
  - Thermal test
- Electromagnetic properties
  - Grounding, bonding & isolation
- Measurement performance
  - Calibration

The Build Standard of the qualification model is therefore:

- Flight-equivalent EEE parts ('proto' parts or suitable non hi-rel parts in the same package as the flight version)
- Flight-representative mechanical and thermal build standard

The sensor EQM model will be fully qualified by Similarity with previous qualification campaigns for other projects.

##### 4.8.3.3 Verification at FM level

The requirements listed below shall be verified on the flight model of the whole MAG instrument

- Mechanical properties
  - Sine vibration (acceptance level)
  - Random vibration (acceptance level)
- Thermal properties
  - Thermal test (performance vs. temperature)
- Electrical interface measurement
- Functional performance
- Measurement performance and calibration

The FM is built to full flight standard.

#### 4.8.4 Verification Facilities

##### 4.8.4.1 Vibration facilities

Astro Feinwerktechnik, Berlin.

### 4.8.5 Calibration and science performance assessment plan

#### *4.8.5.1 Crucial parameters definition*

The instrument performance parameters are given in Table 20.

| *Performance Parameter* | *Requirement* |
|---|---|
| Instrument overall noise performance | < 10 pT/√Hz at 1Hz |
| Measurement Offset (3 axes) | < 10 nT |
| Offset Stability (3 axes) | < 1 nT / 24 hours |
| Offset Temperature Coefficient | < 0.1 nT / °C |
| Scale Factor Error (Linearity) | < 0.05% |
| Axis-to-axis Alignment Error (knowledge) | < 0.5° |
| Magnetic Field Magnitude, Calibrated Accuracy | 1 nT |
| Magnetic Field Vector Direction, Calibrated Accuracy | 0.2° |

Table 13: Instrument performance parameters.

These parameters are valid over the operating range of the sensor with the exception of offset stability, which measures the long-term stability at a constant temperature. During non-operational periods the temperature may exceed the operational limits, however when the temperature returns within operational limits then the critical performance listed here shall still be attained. This shall be verified by test.

#### *4.8.5.2 Calibration approach*

The MAG team has access to calibration facilities which will enable all of the critical performance parameters listed in Table 20 to be measured or verified. Each of the sensor models FM and EQM (transferred to GRM) shall undergo a complete instrument calibration. For each of these models, the calibration shall occur after the environmental test of the instrument but before delivery to the project. Performance verification will be monitored during the development, manufacture, test and calibration phases.

#### *4.8.5.3 Calibration facilities*

A magnetic calibration facility consists of a 2.5 m three axes Braunbek coil system at the Magnetsrode calibration laboratory at the Technical University of Braunschweig. The coil system consists of 12 coils, i.e. four coils for each of the three orthogonal axes. Each coil contains windings for geomagnetic field compensation, static and dynamic magnetic field generation and diurnal variation control. Artificial DC and low-frequency AC magnetic fields of up to 100000 nT can be generated in this coil system. This allows an active compensation of the local geomagnetic field as well as the application of an artificial field representing the geomagnetic field at every point of the Earth' surface and near-Earth interplanetary space (including the Moon). Magnetometers for the GIOTTO, AMPTE, CLUSTER, CASSINI, EQUATOR-S, DEEP SPACE 1, THEMIS, VENUS EXPRESS, ROSETTA and BEPI-COLOMBO missions have been calibrated there. The following parameters can be calibrated: Linearity, sensitivity, sensor misalignment, offsets, frequency response, crosstalk between sensor components, and its temperature dependency in a wide temperature range between –120°C and +180°C.

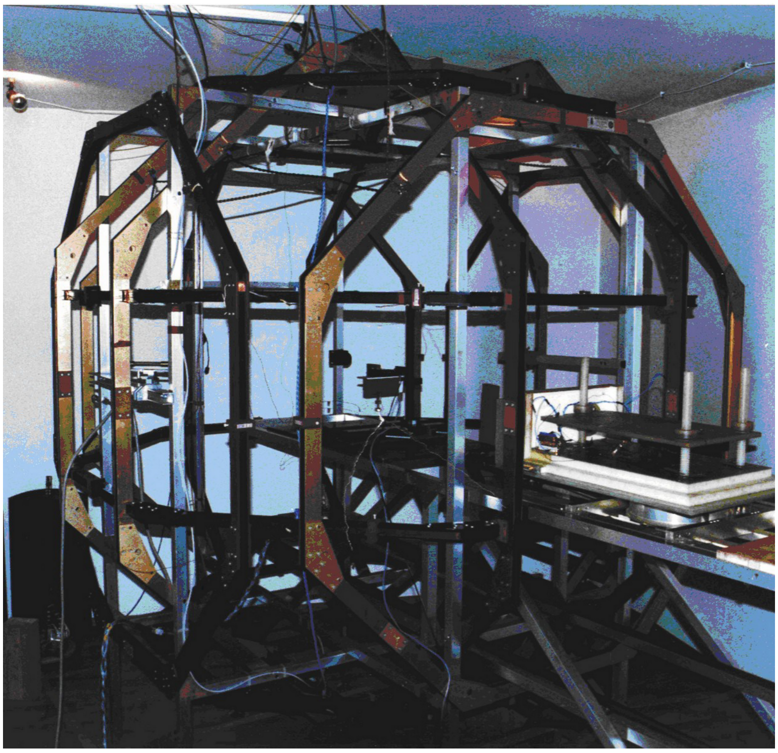


*Figure 8: Coil system with thermal box baseplate in Magnetsrode, Braunschweig (photo: Ingo Richter, TU-BS).*

The primary parameters to be measured at this facility are:

- Scale factor
- Linearity
- Axis-to-axis alignment measurement
- Absolute magnetic field calibration, magnitude and vector direction

Additionally, it is possible to measure also the parameters listed below:

- Offset (3 axes)
- Offset Stability
- Offset Temperature Coefficients

## 4.9 Test Programme

Short functional test (Health Check) after each test step will be performed. For details on the Health Check procedure see the procedure description ([AD09]).

### 4.9.1 Vibration test

As MAG-S interfaces to the spacecraft changed slightly, in respect to previous space flown sensor designs, vibration tests has been done with actual MAG-S design (EQM). The test was compliant with system defined vibration levels.

## 4.10 Test Facilities Requirements

There are no special requirements on the part of the MAG instrument concerning shielding since the MAG instrument is suitable to measure within the range of Earth's magnetic field.

# 5 OPERATIONAL REQUIREMENTS AND PLANNING

## 5.1 Ground Operations Requirements

Magnetometer measurement range of

1) EQM unit is suitable for measurements within Earth's magnetic field.Therefore no special ground operations requirements are needed.

2)FM unit is +/- 12000nT, therefore for performance and HealthCheck tests, the MASCOT shall be placed in magnetic shielded chamber. If in Earth's magnetic field, the sensor will be saturated, which means no harm to the instrument. For in-flight operations, the range is sufficient.

## 5.2 Flight Operations Requirements

The MAG instrument performs continuous measurements. There are no special flight operational requirements besides the operational temperature range.

## 5.3 Operational Plan

### 5.3.1 Default TC sequence

The table below provides fdefault operations of the MAG unit.

| *TC 100 - Default Scientific* | | | |
|---|---|---|---|
| *Phase* | *Phase name* | *Description* | *Duration* |
| TC-100-1 | Power ON | powering ON MAG includes timestamp settings synchronization with MOBT. | ~ 5 s |
| TC-100-1 | Default Science START | Default scientific mode initialization and mode settings as described in detail in SFT [AD12]. | ~ 14 s |
| TC-100-2 | Default Science MAIN LOOP | Default scientific mode main loop operation - 1 Hz MAG data request and 0.1 Hz MAG HK data request | as long as posible |

### 5.3.2 Ground operations

Short fuctional tests shall be done with default scientific operations TC 100. More detailed functionality test that should be processed after tests, integration and before launch will be done via Health Check as described in [AD10]. For testing the FM, the whole MASCOT shall be placed inshide mu-metal shield provided by MAG team.

For SFT (short functional testing), procedure described in [AD12] shall be used.

### 5.3.3 In-flight operations

In-flight operations cover commissioning and necessary calibration of the instrument. All necessary check-outs will be done via Health Check defined in [AD10].

### 5.3.4 Surface operations

The surface operations will start just after the MASCOT deployment of the Hayabusa-II spacecraft. The operations shall continue during the descent, surface operations, and also hopping maneuver until the end of planned MAG surface operations. In case of interruption of the measurements and MAG switch off, the operations shall be resumed as soon as possible. The main operation will consist of default scientific mode represented by Default Scientific sequence (TC-100) defined above. The operation is as follows:

1. Power MAG ON
2. Start up of the measurements with TC-100-0
3. Continue with the measurements and data acquisition within the main loop
   - repeat TC-100-1 in a loop until end of planned surface operations (7-8 hours TBC)
   - i.e. acquire MAG data at 1Hz sampling rate and HK data at 0.1Hz sampling rate
4. Power MAG OFF

# 6 PRODUCT ASSURANCE AND SAFETY PLAN

## 6.1 General

The MAG development will comply with the ESA PA requirements as set out in the ECSS series. In particular, these will be considered as reference documents to be tailored to the specific needs of the MAG development.

## 6.2 Product Assurance Management

The PA program provides the assessment and control of risks control of the quality assurance of the materials and processes used for MAG development. The plan will require:

- The availability of sufficient manpower and resources to perform PA functions effectively.
- To be consistent with project objectives, requirements and constraints.
- To ensure contractors, suppliers and Co-Investigators perform proper PA monitoring and control.
- To ensure progress monitoring, reporting and visibility of all PA matters.

### 6.2.1 Organization

TU Braunschweig has no PA line organization. The MAG PI will appoint a PA manager for the MAG investigation. The PA Manager will report directly to the instrument manager however he/she will have unimpeded access to the PI. The PA manager has all necessary authority and resources to implement the product assurance program in line with the Mascot project requirements.

### 6.2.2 Product Assurance Plan

The PA plan will be maintained throughout the project life-cycle.

### 6.2.3 Prime Contractor Right of Access

The PA manager will make arrangements to permit designated Prime contractor personnel free access to all technical and programmatic documentation, areas and operations within the facilities of the PI and his/her contractors and suppliers in which work related to the MAG development is being performed.

### 6.2.4 Contractor Supplier Surveillance

The PA manager will impose on sub-contractors and co-investigators a set of product assurance requirements derived from this plan and tailored to the services being provided.

### 6.2.5 Documentation and reviews

Necessary PA/QA documentation Quality will be available any time in the project upon request and as a part of documentation to major reviews.

### 6.2.6 Critical Items identification and Control

The PA manager will be responsible to identify and evaluate critical items in respect of

- Magnetometer design performance
- Procurement

- Fabrication
- Test/inspection and handling

In each of these areas, there will be defined the QA activities and risk reduction measures. The PA manager will maintain Critical Items List and Risk Assessment

## 6.3 Quality Assurance Management

### 6.3.1 General Requirements

Since TU Braunschweig has no PA line function, the PI and PA manager will establish a tailored QA system derived from ESA ECSS requirements.

The QA system will be applicable to all flight hardware, manufacturing, assembly and test facilities, MGSE, EGSE and calibration facilities. Personnel affected will have sufficient training to comply with the QA requirements.

### 6.3.2 Traceability and Logbook

The PA manager will prepare and maintain equipment logbooks.

### 6.3.3 Metrology and Calibration

Calibration of equipment will be assured by internal facility.

### 6.3.4 Non- Conformance Control

Non-conformance control, classification and dispositioning will follow procedures which are compliant with ECSS-Q-ST-10-09C. Each non-conformance will be reported via non-conformance report and subbmited to MASCOT PA/QA deparment. The status of each NCR will be tracked in the Design Document.

### 6.3.5 Deviation Control

Deviation control procedure will be implemented. Each deviation will issue a deviation form, that will be submitted to the MASCOT PA/QA department for approval. Each deviation and its status will be tracked in the Design Document.

### 6.3.6 Handling, Storage and Preservation

The MAG team will apply standards compliant with ESA requirements.

### 6.3.7 QA Requirements for Design and Verification

The PA Manager is responsible to ensure that the design rules and guidelines are adhered to.

### 6.3.8 QA Requirements for Procurement

Procurement will be done directly by Magson, GmbH for electronics and by IGeP, TU-BS for sensor and harness.

### 6.3.9 Integration and Testing

The PA Manager will prepare the AIT planning to cover all test requirements for development, qualification and acceptance test phases for the different models.

Test procedures will be prepared for all tests on deliverable items as a minimum.

The PA manager will

- Determine the suitability of test facilities.

- Witness key tests and formal qualification/acceptance activities..
- Document deviations or non-conformances and track these.
- Perform test readiness and post test reviews.
- Validate and approve test reports.

## 6.4 Safety Assurance

The PA manager will implement a safety assurance programme comprising:

- The identification and control of all safety related risks with respect to the design, development and operations of the instrument.
- The assessment of the risks based on qualitative and quantitative analysis as appropriate.
- The application of a hazard reduction precedence and of control measures of the residual risks.

ECSS-Q-ST-40-02C and ECSS-Q-ST-40C are applicable.

## 6.5 Dependability Assurance

The PA manager will provide necessary inputs to the reliability and safety analyses of the MASCOT system upon request. No FMECA, WCA, PSA analysis is foreseen to be performed on the unit level.

## 6.6 EEE Parts Selection and Control

### 6.6.1 Component Selection

The PA Manager will ensure proper space qualified components control preferably from ESA PPL or qualified from previous missions. The responsibility for parts selection and procurement will remain with the Instrument Manager. However, this process will be overseen by the PA Manager. The PA Manager will identify early on any long-lead items and any items which require special qualification. Such critical items will have the risk to the schedule quantified and suitable backup options will be identified.

### 6.6.2 DCL

PA Manager will compile and maintain Declared Component List (DCL) over the project duration. The DCL will be compatible with ECSS-Q-ST-60C.

### 6.6.3 Component Quality Assurance

The PA Manager is responsible to ensure component QA control.

## 6.7 Materials and Process Selection and Control

### 6.7.1 Material and process selection

The PA Manager will be responsible for assessing the suitability for all materials and processes proposed for use in the MAG instrument. This includes sub-contractors. Forbidden materials will be eliminated. Materials compatibility, corrosion & stress corrosion, aging & environmental affects will all be taken into account.

#### 6.7.2 DML & DPL

The PA Manager will provide required documentation including DML and DPL to ESA.

#### 6.7.3 Materials Control

All materials procured will be covered by a procurement specification and release standard.

#### 6.7.4 Process Control

All processes applied will be covered by a process specification or standard. ESA ECSS standards will be applied where possible.

### 6.8 Cleanliness and Contamination Control

Though the MAG experiment is not in itself contamination sensitive the PA manager will ensure that the MAG flight hardware contains no residual contaminants which may affect spacecraft or payload. To this end will be considered the provisions, activities and verification methods necessary to achieve the cleanliness levels through all stages of fabrication, handling, transportation and testing.

### 6.9 Compliance Matrix

A compliance matrix will be provided for all the requirements specified in EID-A. The document will be maintained during all the project phases.

### 6.10 Materials and Processes

See Declared Material List (DML) - [AD04] and Declared Process List (DPL) - [AD05]

### 6.11 EEE Parts and Components

See declared Component List (DCL) - [AD06]

### 6.12 Software Product Assurance

N/A

# 7 INSTRUMENT MANAGEMENT

## 7.1 ORGANISATION AND RESPONSIBILITIES

The project is lead by Institut für Geophysik und extraterrestrische Physik (IGEP), TU-Braunschweig represented by PI - Prof. Dr. K.-H. Glassmeier. The IGeP is responsible for the sensor development, instrument assembly, calibration and integration. The instrument electronics, will is provided by Magson GmbH represented by Markus Wiedemann.

| *IGeP, TU-BS* | *Magson GmbH* |
|---|---|
| Institut für Geophysik und extraterrestrische Physik (IGEP)<br>TU Braunschweig<br>Mendelssohnstr. 3<br>38106 Braunschweig<br>Tel: +49 0531/391 5218 | Carl-Scheele-Str. 14<br>D-12489 Berlin |

### 7.1.1 MAG team members

| *Name* | *Affiliation* | *Role* | *E-mail* |
|---|---|---|---|
| Prof. Dr. K.-H. Glassmeier | IGeP, TU-BS | Principal Investigator | kh.glassmeier@tu-bs.de |
| Prof. Dr. A. Hoerdt | IGeP, TU-BS | MAG CoI | |
| Dr. H.-U. Auster | IGeP, TU-BS | Technical management | uli.auster@tu-bs.de |
| K.-H. Fornacon | IGeP, TU-BS | Sensor production | |
| Dr. I. Richter | IGeP, TU-BS | Calibration | |
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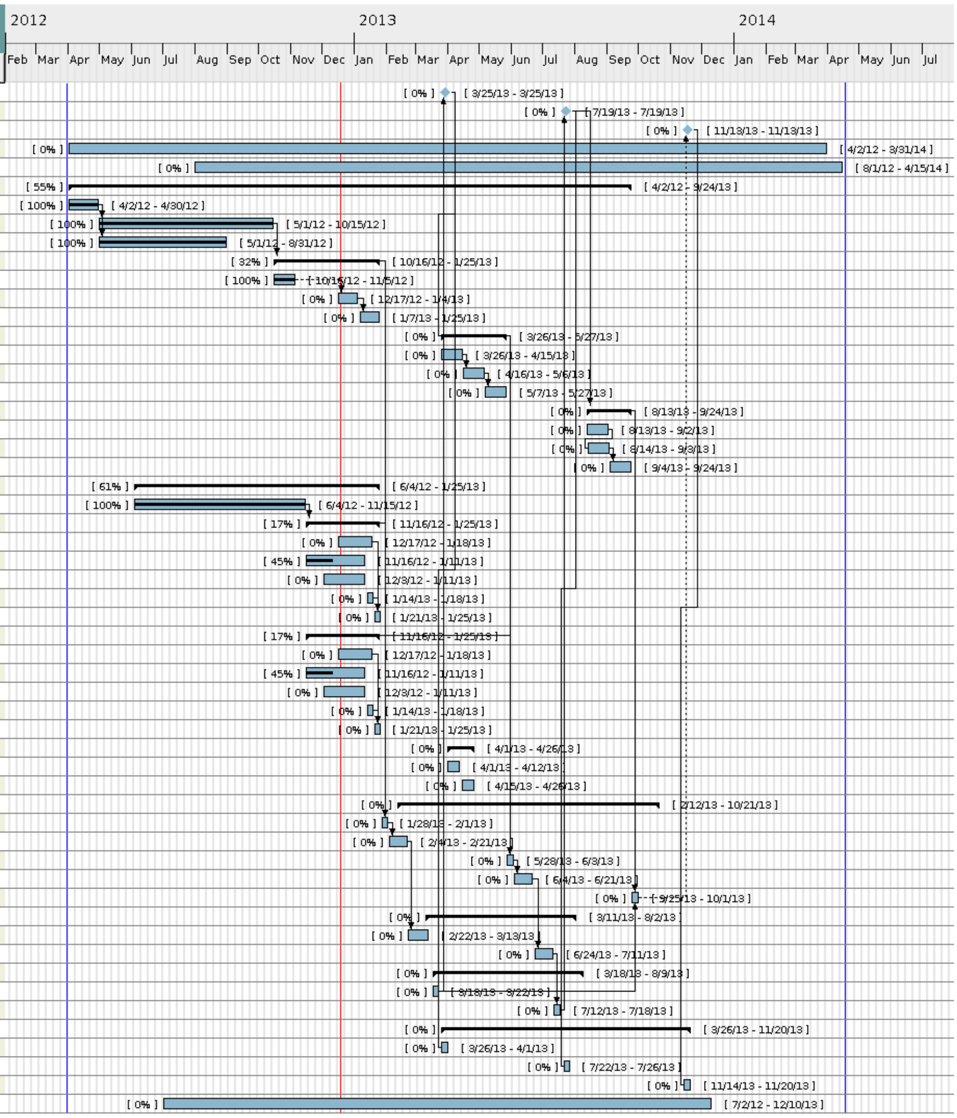
| Ben Weiss | MIT, USA | MAG CoI | bpweiss@mit.edu |
| Markus Wiedmann | Magson GmbH, Berlin | Project management | markus.wiedemann@magson.de |
| Ronald Kroth | Magson GmbH, Berlin | Electronics design | ronald.kroth@magson.de |

### 7.1.2 Cooperation partners

| *DLR Berlin* | *DLR Bremen* | *ISAS* |
|---|---|---|
| Institut für Blanetenforschung<br>Rutherfordstraße 2<br>12489 Berlin | Institut für Raumfahrtsysteme<br>Robert Hooke-Str. 7<br>28359 Bremen | 3-1-1 Yoshinodai, Chuo-ku,<br>Sagamihara, Kanagawa<br>252-5210, JAPAN |

## 7.2 PROJECT PHASING AND PLANNING

| Name | Duration | Begin d... | End date |
|---|---|---|---|
| EQM delivery | 1 | 3/25/13 | 3/25/13 |
| FM delivery | 1 | 7/19/13 | 7/19/13 |
| GRM delivery | 1 | 11/13/13 | 11/13/13 |
| Management | 521 | 4/2/12 | 3/31/14 |
| Exp. scient. prep | 445 | 8/1/12 | 4/15/14 |
| MAG electronics | 387 | 4/2/12 | 9/24/13 |
| Redesign ROMAP electronics | 21 | 4/2/12 | 4/30/12 |
| Parts procurement | 120 | 5/1/12 | 10/15/12 |
| BBM manufacturing | 89 | 5/1/12 | 8/31/12 |
| EQM electronics manufacturing | 74 | 10/16/12 | 1/25/13 |
| EQM PCB production | 15 | 10/16/12 | 11/5/12 |
| EQM PCB population | 15 | 12/17/12 | 1/4/13 |
| EQM Electronics start-up | 15 | 1/7/13 | 1/25/13 |
| FM electronics manufacturing | 45 | 3/26/13 | 5/27/13 |
| FM PCB production | 15 | 3/26/13 | 4/15/13 |
| FM PCB population | 15 | 4/16/13 | 5/6/13 |
| FM Electronics start-up | 15 | 5/7/13 | 5/27/13 |
| GRM electronics manufacturing | 31 | 8/13/13 | 9/24/13 |
| GRM PCB production | 15 | 8/13/13 | 9/2/13 |
| GRM PCB population | 15 | 8/14/13 | 9/3/13 |
| GRM Electronics start-up | 15 | 9/4/13 | 9/24/13 |
| MAG sensor | 170 | 6/4/12 | 1/25/13 |
| Sensor adaptation | 119 | 6/4/12 | 11/15/12 |
| EQM sensor manufacturing | 51 | 11/16/12 | 1/25/13 |
| EQM mechanical parts | 25 | 12/17/12 | 1/18/13 |
| EQM harness | 41 | 11/16/12 | 1/11/13 |
| EQM sensor | 30 | 12/3/12 | 1/11/13 |
| EQM sensor harness connection | 5 | 1/14/13 | 1/18/13 |
| EQM sensor + mechanical part | 5 | 1/21/13 | 1/25/13 |
| FM sensor manufacturing | 51 | 11/16/12 | 1/25/13 |
| FM mechanical part | 25 | 12/17/12 | 1/18/13 |
| FM harness | 41 | 11/16/12 | 1/11/13 |
| FM sensor | 30 | 12/3/12 | 1/11/13 |
| FM sensor harness connection | 5 | 1/14/13 | 1/18/13 |
| FM sensor + mechanical part | 5 | 1/21/13 | 1/25/13 |
| Thermal H/W tailoring | 20 | 4/1/13 | 4/26/13 |
| EQM MLI | 10 | 4/1/13 | 4/12/13 |
| FM MLI | 10 | 4/15/13 | 4/26/13 |
| Assembly | 180 | 2/12/13 | 10/21/13 |
| EQM assembly | 5 | 1/28/13 | 2/1/13 |
| EQM thermal test | 14 | 2/4/13 | 2/21/13 |
| FM assembly | 5 | 5/28/13 | 6/3/13 |
| FM thermal test | 14 | 6/4/13 | 6/21/13 |
| GRM assembly | 5 | 9/25/13 | 10/1/13 |
| Calibration | 105 | 3/11/13 | 8/2/13 |
| EQM calibration | 14 | 2/22/13 | 3/13/13 |
| FM calibration | 14 | 6/24/13 | 7/11/13 |
| Qualification & tests | 105 | 3/18/13 | 8/9/13 |
| EQM vibration test | 5 | 3/18/13 | 3/22/13 |
| FM acceptance tests | 5 | 7/12/13 | 7/18/13 |
| Integration | 172 | 3/26/13 | 11/20/13 |
| EQM integration | 5 | 3/26/13 | 4/1/13 |
| FM integration | 5 | 7/22/13 | 7/26/13 |
| GRM integration | 5 | 11/14/13 | 11/20/13 |
| Magnetic cleanliness | 377 | 7/2/12 | 12/10/13 |



## 7.3 REVIEWS

The development process will be divided by milestones in order to verify design in respect to system requirements and confirm proper functionality, maturity, and compliance with ESA standards. The milestones are basic reviews that confirm possibility to proceed with the project. The instrument reviews will respect system schedule and will be planned in accordance with it, so that delivery dates are met. Detail schedule indicating all the work activities will be maintained and updated by PI. Following instrument reviews will be held as a main milestones of the project:

- Instrument Preliminary Design Review (IPDR) April 2012
- Instrument Midterm Review (IMTR) February 2012
- Flight Acceptance Review (FAR) July 2014 (TBC)

For each milestone review a datapackage with specified documentation will be delivered to DLR ahead of the review. The MTR stand for instrument CDR.

## 7.4 DELIVERABLE ITEMS

### 7.4.1 H/W deliverables

| *Deliverable* | *STM* | *EQM* | *FM* | *SF* |
|---|---|---|---|---|
| Dummy sensors | X | | | |
| Thermal H/W (MLI) | | X | X | |
| EQM electronics | | X | | |
| EQM sensor | | X | | X |
| FM electronics | | | X | |
| FM sensor | | | X | |
| GRM electronics | | | | X |

### 7.4.2 Documentation deliverables

| *Deliverable* | *PDR* | *CDR* | *FAR* |
|---|---|---|---|
| Design Document | X | X | X |
| EID-B | X | X | X |
| AIV Plan | X | X | |
| PA Plan | X | X | |
| EICD | X | X | |
| MICD | X | X | |
| TICD | X | X | |
| Parts & Material List | X | X | X |
| Reliability Analysis (FMEA, SPFA, FTA, CIL) | | | |
| Configuration Item Data List | X | X | |
| Ops Plan | | X | |
| Test Procedures | X | X | X |
| Tech Notes (incl. Test results & analysis), | X | X | X |
| STM, EM, EQM Model Build Standard | | X | |
| Calibration report | | | X |

# 8 ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| BOL | Beginning Of Lifetime |
| DML | Declared Material List |
| DMPL | Declared Mechanical Part List |
| DPL | Declared Parts List |
| EOL | End Of Lifetime |
| FM | Flight Model |
| GRM | Ground Reference Model |
| HK | Housekeeping |
| LUP | Latch Up Protection |
| TRP | Temperature Reference Point |
| OBC | Data Handling System |
| MOBT | MASCOT OnBoard Time |
| SFT | Short functional Test |