FGM

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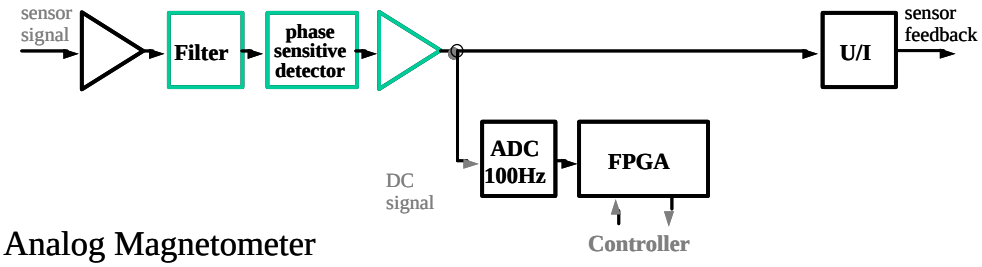
FGM

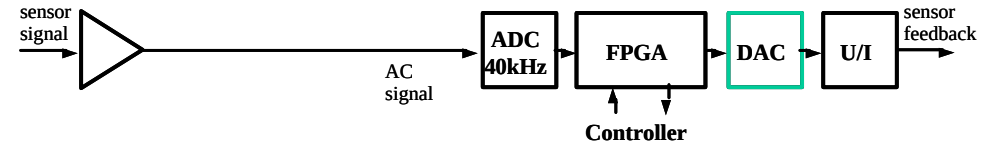
- Overview
  - specifics / subunits / responsibilities / models
- Status Hardware
  - FGS, FGE, FPGA
- Operation
  - Modes and filter characteristics
- Parameter / Expected Accuracy
  - parameter / test results (Venus Express)
- Integration and test program
  - TCU / GSE / Schedule,

Digital vs. analogue FGE

Copy from FGM peer PDR



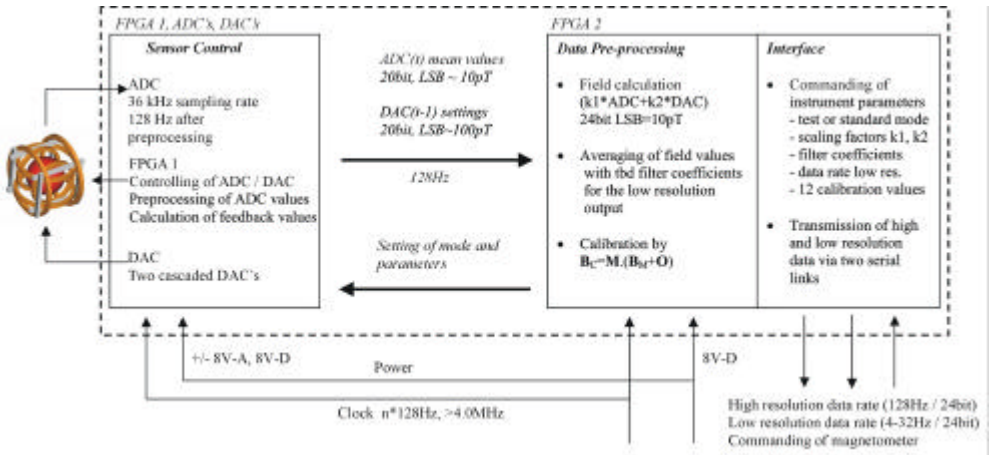
Analog Magnetometer



Digital Magnetometer

FGM Blockdiagram

Copy from FGM peer PDR



FGM Subunits

- Fluxgate Sensor (FGS)
  - Hardware: TU-BS
  - Calibration: TU-BS & IWF
- Fluxgate Electronics (FGE)
  - Hardware: TU-BS (subcontracted to Magson) / UCB
  - FPGA design: IWF & Magson
- “Accessories”
  - Boom: UCB
  - GSE: UCB
  - TCU: UCB / IWF / TU-BS (subcontracted to Magson)
  - Magnetic Cleanliness: UCB / UCLA

FGM Model Philosophy

- Fluxgate Sensor (FGS)
  - STM, available in Berkeley for boom test etc.
  - FM 6 qualification & spare model
  - FM 1-5 flight Models
- Fluxgate Electronics (FGE)
  - Breadboard
  - ETU 1, magnetometer only, permanently in Europe
  - ETU 2, merged layout, permanently in Berkeley
  - ETU 3, qualification model / F6
  - FM 1-5
- GSE
  - Available in Berlin
- TCU
  - Up to sensor delivery: 2 TCU’s in Europe: 1 at UCB
  - Later: 2 TCU’s at UCB: 1 in Europe

FGS Design (1)

- Vector-compensated Ringcore sensor

Two crossed ringcores

Material: 6-81-Mo Permalloy band
non-ferromagn. NiMo30 alloy

Pickup Coil systems

Material: Cu wire isolated by polyesterimid and covered by bond coat (polyamid)

Sensitivity: about 1,5 … 3µV/nT

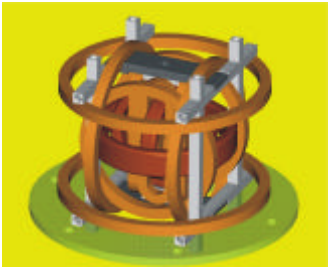
Feedback Coil System

Material: Cu - wire, see pickup

Coil const.: 13-17000nT/mA

CTE: about 24ppm (Cu and Al)

Fixation: by glue (Endfest 300)



FGS Design (2)

Sensor Hut Interface

Material

Hut & base plate: Aluminium

Isolation: glassfibre reinforced plastics

Screws: titanium

Washers: glassfibre reinforced plastics

Surface (Al): Alodine 1200

Mass: 78g

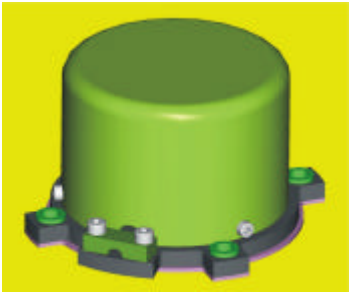
Mechanical Interface

mounting: four M4 screws

orientation: defined by ground plane and two feed side planes (V)

Electrical Interface

10cm pigtail with HD-26P connector

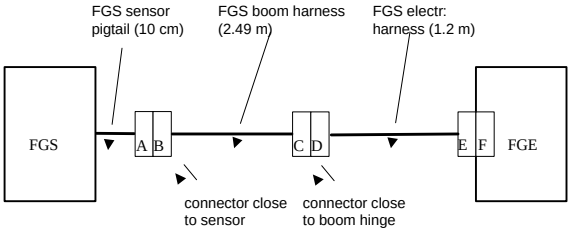


FGS Findings / Actions

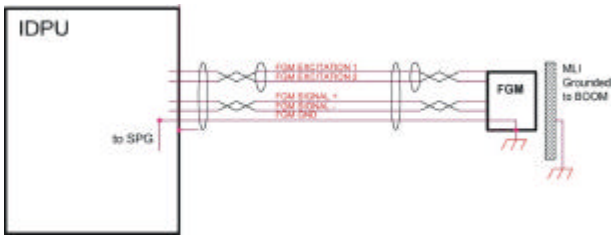
- **Aging:** Extended test program for spare coils added into test matrix. (5 times between -190°C and +120°C)
- **Glue properties:** liquid nitrogen immersion test will be done with GRM sensor (see test matrix)
- **Glue properties:** Tension tests with glued parts
- **Quasi static loads:** Modelling of sensor

FGS Harness / Grounding

- Harness
  - A/B connector bracket on the boom
  - C/D connector bracket on the spacecraft



- Grounding
  - Overall shielding connected to S/C ground (chassis) via connector back shells
  - Sensor aluminum housing, connected to pin 11 of the sensor connector
  - MLI:
    inner layer insulating
    outer layer conductive
    to boom



FGS Test Matrix

Test name	Test description	Ringcores Coils only	STM	FM 1-6
Ringcore selection	Long-term test of ringcores (KHF) *Criteria: output voltage, offset, noise*		X	X
Parts electr. checkout	Resistance of all coils before integration (KHF)		X	X
Coil qualification	-190°C / +120°C five times each (BS) *Criteria: visual inspection, resistance*	X		
Coil aging acceptance	-40°C / +80°C three times each (BS) *Criteria: visual inspection, resistance*		X	X
Ringcore checkout	Test after integration in pickup coils (KHF). *Criteria: output voltage, offset, noise*		X	X
FGS electr. checkout	Test after sensor integration (KHF) *Criteria: Resistance + polarity of all coils*		X	X
FGS aging qualification	-190°C / +120°C five times each (KHF) *Criteria: visual inspection, resistance, output voltage, offset, noise*		X	
FGS aging acceptance	-40°C / +80°C three times each (KHF) *Criteria: visual inspection, resistance, output voltage, offset, noise*			X

FGS Test Matrix

Test name	Test description	STM	FM 6	FM 1-5
Vibration	According to qualification levels (UA) ~~According to acceptance levels~~	With Boom	X	~~X~~
TV	According to qualification levels (WM) ~~According to acceptance levels~~	With Boom	X	~~X~~
Calibration	Berlin / Braunschweig: *Offset, noise at room temperature, versus ~~electronics temperature, versus time~~*			
	Graz: *~~Offset, noise, transfer function versus temp~~*			
	Magnetsrode: *~~Scale value, orthogonality versus temp~~*			

Required temperature range

Operation:	-100°C … +65°C
Survival:	-100°C … +65°C
Estimation by thermal analysis:	-79°C … +35°C

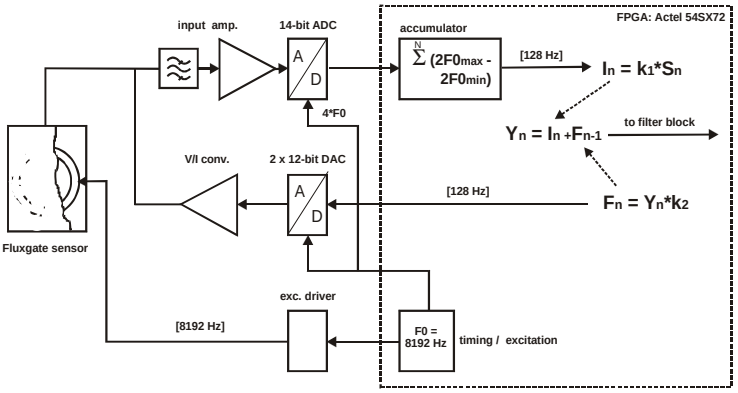
FGE design

Part of FGE

- Excitation
- Preamplifier
- Analog/Digital Converter
- Feedback
- FPGA

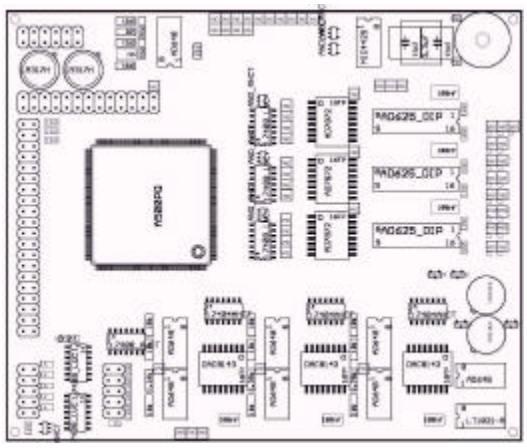
Power Consumption

180mW		
180mW		
150mW		760mW
200mW		
50mW	(85mW)	



FGE Status BB

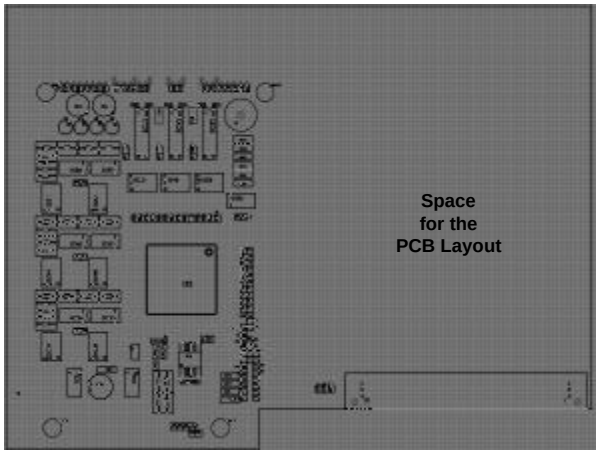
- The Bread Board is used to test the general electronics design and the FPGA design along with a GSE supplied by the IWF Graz



Layout of the Bread Board

FGE design ETU

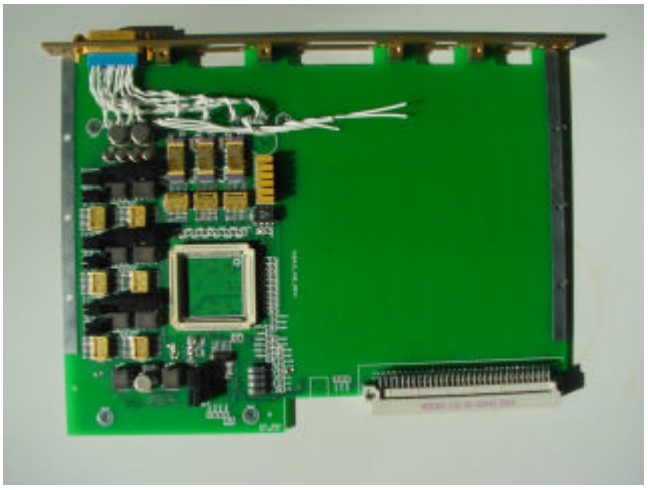
- The FGE will co-reside with PCB on a single 6U board.
- The FGE will be placed on the opposite half of J1 connector site.



6U Board with the FGE Layout

FGE, status ETU

- ETU 1 is under test in Berlin, FPGA (non radiation hard) on socket.
- ETU 2/3 layout is merged, fabrication population of ETU 2 in ongoing



FGE, Changes since PDR

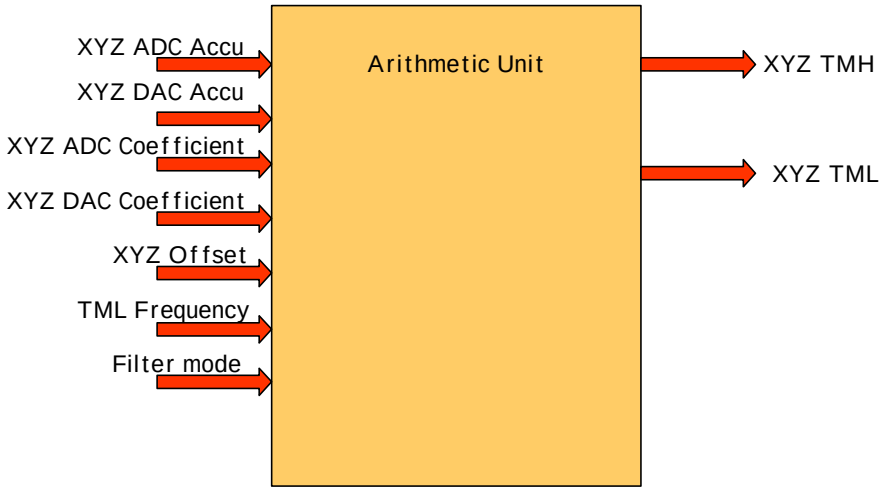
- all DAC's are now placed on the top side
- Megatron precision resistors have been replaced by MIL-qualified Vishay types
- WIMA high value capacitors in the excitation circuitry have been replaced by MIL-qualified Kemet types
- FGE internal grounding concept has been improved:
  - separate ground nets for all functional parts,
  - connected at a star point close to the Power interface
  - RC-filter implemented to react on external power disturbances
- ADC analog interface simplified and improved
  based on experience of Venus Express
- ADC serial interface mode was changed
  the ADC will now be clocked by the system clock instead of using the ADC's internal clock
  - no need to synchronise ADC clock to the system clock
  - reduces potential interfering frequencies on the board

FGE, FPGA design

- The FGE electronics is controlled by a FPGA which overtakes the following tasks:
  - Generating the Excitation Signal
  - Reading the ADC Data
  - Generating the Feedback Values
  - Calculating the Output Data
  - Acting as Command Receiver and Data Transmitter
  - Configuration of FGM
    - data rate TML
    - mode (standard, calibration, feedback on/off, excitation on/off)
    - filter modes
    - ADC and DAC calibration coefficients, offsets

FGE, FPGA design

FPGA Arithmetic Unit

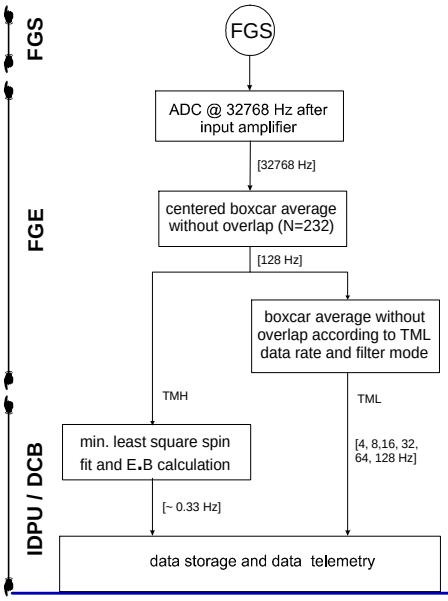


FGE, FPGA Status

- FGE BB Implementation in ProASIC A500K180 (24%)
- FPGA design completely routed in RT54SX72S (80%)
- Actually under test using ETU1, all functions are working well
- Last and final risk is the compatibility of the design with the RadHard Actel

FGM Operation

- FGM signal flow



2 x Boxcar filter

amplitude response

$$|G(w)| = \frac{\sin(w\,T\,N/2)}{N \times \sin(w\,T/2)}$$

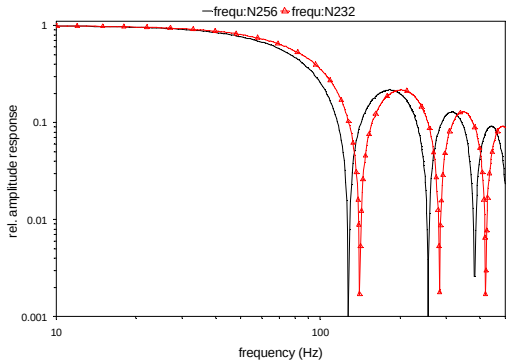
phase response

$$ang(G(w)) = -p\ N\ f\ T$$

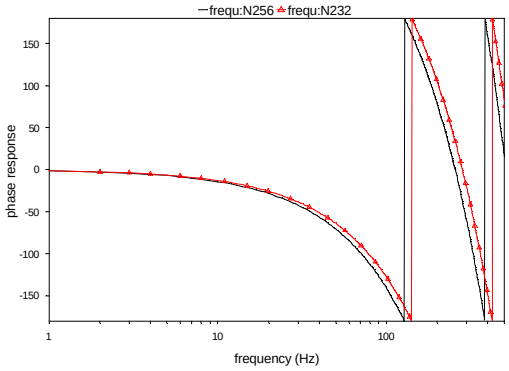
N ... number of accumulated samples
T ... sampling period (1/(4F0) or 128 Hz)

FGM Operation

- FGM raw data frequency response



amplitude response of the 128 Hz raw data



phase response of the 128 Hz raw data

FGM Operation

FGM filter modes

- Filter mode 1:
  - only data decimation (D)
  - 4 Hz data with 5.7 x higher noise
  - huge aliasing
  - no de-spinning problems
- Filter mode 2:
  - filter calc. down to 16 Hz (N_f)
  - decimation from 16 to 4 Hz
  - 4 Hz data with 2 x higher noise
  - less aliasing
  - little de-spinning problems
- Filter mode 3:
  - filter calc. down to 4 Hz
  - little aliasing
  - de-spinning problems

$$|G(w)| = \frac{\sin(w\,T\,N/2)}{N \times \sin(w\,T/2)} \cdot \frac{\sin(w\,T_r\,N_f/2)}{N_f \times \sin(w\,T_r/2)}$$

$$ang(G(w)) = -p\ f\ (N\,T + N_f\,T_r)$$

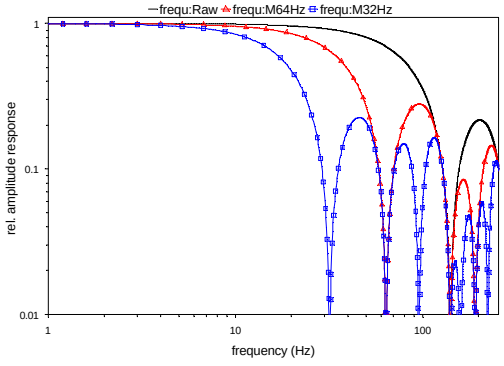
N_f ... number of accumulated samples in table
T_r ... raw data rate (1/128)

TML data rate [Hz]	filter mode 1		filter mode 2		filter mode 3	
	N_f	D	N_f	D	N_f	D
128	-	-	-	-	-	-
64	-	2	4	2	2	2
32	-	4	8	4	4	4
16	-	8	16	8	8	8
8	-	16	-	2	16	16
4	-	32	-	4	32	32

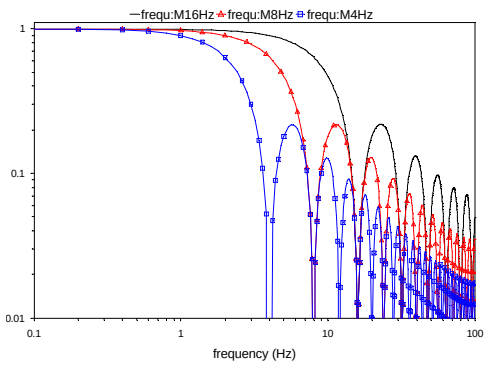
Number of data decimation (D) and accumulation (Nf) according to the selected filter mode

FGM Operation

FGM TML data frequency response



Amplitude characteristics of the 128 Hz raw data as well as the 64 Hz and 32 Hz output data (filter mode 2 and 3)



Amplitude characteristics of the 16 (filter mode 2 and 3), 8 and 4 Hz (filter mode 3) output data

FGM Operation

- FGM operation during all science phases
  - Slow Survey: 1 vector / spin
  - Fast Survey: 4 vectors / sec
  - Particle Burst: 32 vectors / sec
  - Wave Burst 1/2: 128 vectors / sec
- FGM operation during boom deployment
  - Check of the magnetic moment of the S/C
- FGM operation during complete checkout phase
  - Survey of DC and AC magnetic disturbances

FGM Operation

- FGM operation during special mission phases
  - Change of orbit
  - Eclipse
- Special use of FGM data
  - S/C attitude control in perigee
  - Knowledge of FGS axes to spin axis orientation
  - During perigee knowledge of FGS axes relative to a geophysical reference system with 0.1 degree accuracy (request for a 56 nT accuracy in course feedback range)

FGM Operation

FGM default turn on

- At least Start command from Data Control Board
- Default values for phase, sampling, K-values, offsets and averaging mode stored in FPGA
- Start of data acquisition with one second sync
- Field calculation: k1*ADC+k2*DAC+Offset (@ 128 Hz)
- 24 bits per axis (LSB ~ 3 pT - 25,000 nT range)
- TML output: 4 Hz data in filter mode 2

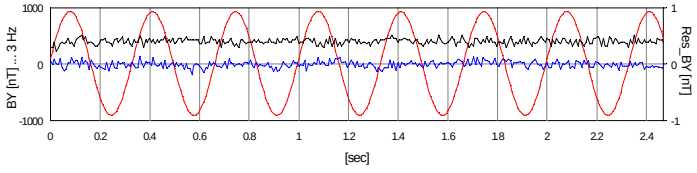
IDPU tasks

- Auto ranging by taking only 16 bits per axis
- Calculation of spin-average data (Slow Survey Modes)

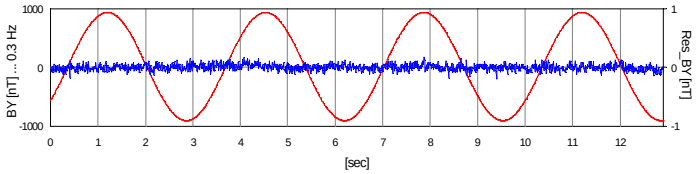
FGM parameter

Large field feedback (VEX-MAG)

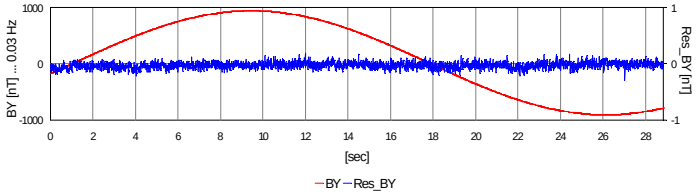
±900 nT; 3 Hz; 128 Hz FB update
max. FB step of 130 nT;
STD residuum: 54 pT
STD noise: 48 pT (0.5 .. 64 Hz)



±900 nT; 0.3 Hz; 128 Hz FB update
max. FB step of 13 nT;
STD residuum: 53 pT (0.1 .. 64 Hz)

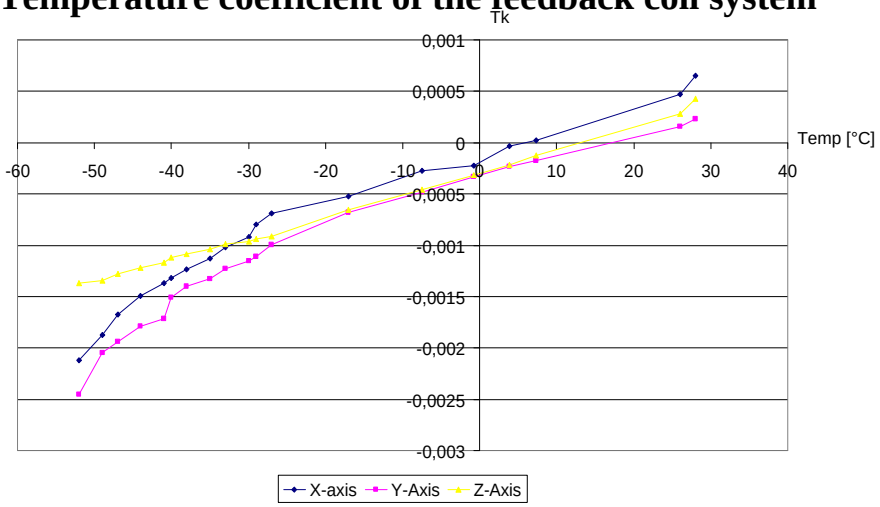


±900 nT; 0.03 Hz; 128 Hz FB update; max. FB step of 1.3 nT;
STD residuum: 56 pT (0.04 .. 64 Hz)



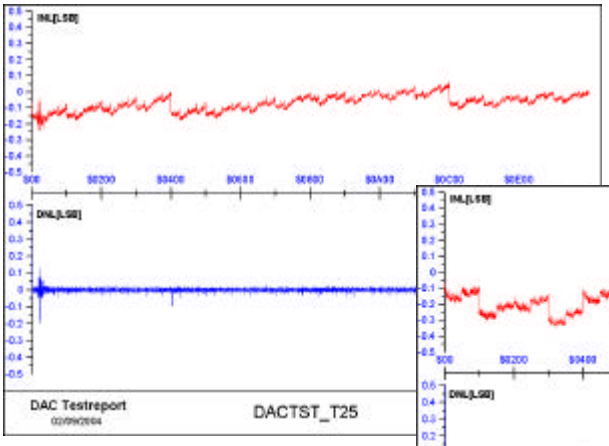
FGM parameter

Temperature coefficient of the feedback coil system



CTE-X: 2,7007E-05 CTE-Y: 2,60801E-05 CTE-Z: 2,21543E-05

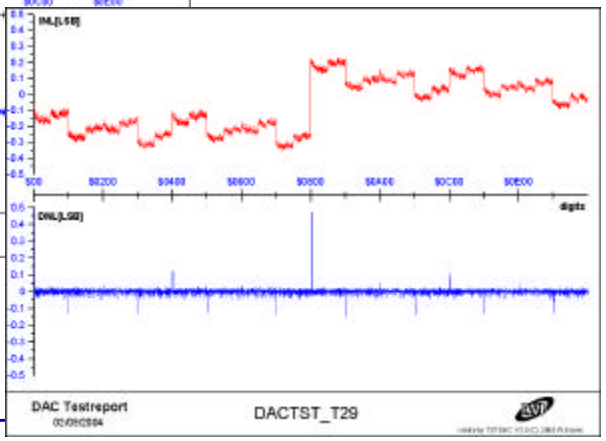
FGM parameter



A good …

DAC differential and integral non-linearity

… and a bad one.

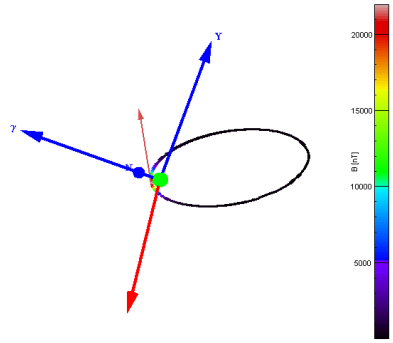


FGM parameter

P2: Expected field magnitude

Per	Apo	Inc	Aper	Raan	a	e
1,2	20	7	15	315	10,6	0,89

B max = 21950nT



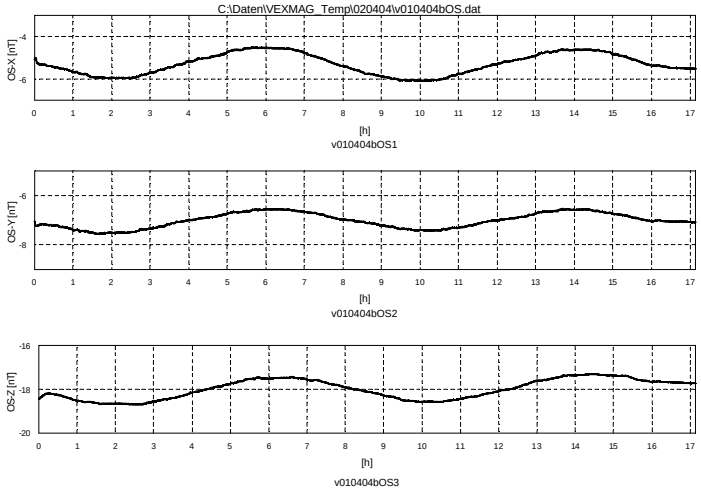
	P1	P2	P3,4	P5
B max [nT]	10480	21950	6450	14330
< 125 nT [%]	94.8	90.3	77.0	77.0
> 125 nT [%]	1.2	2.4	6.4	4.6
> 250 nT [%]	0.9	1.7	3.9	5.4
> 500 nT [%]	0.7	1.3	3.3	4.0
> 1000 nT [%]	2.4	4.3	9.4	9.0

FGM parameter

- Consequences of DAC non-linearity and orbit simulation on measurement accuracy
  - Dynamic range reduced from ± 32.768 nT to ± 25.000 nT
  - Digital resolution of approx. 3 pT (24 bits)
  - Fine (12 bits) and course (6 bits) feedback DAC
  - Dynamic range of fine DAC is ± 390 nT with 0.19 nT resolution
  - Maximum error due to DNL in fine (‚science‘) range of 44 pT
  - Dynamic range of course DAC is ± 32,768 nT with 1024 nT resolution
  - Maximum error due to DNL in course range of 6 nT

FGM Parameter

Venus Express test results

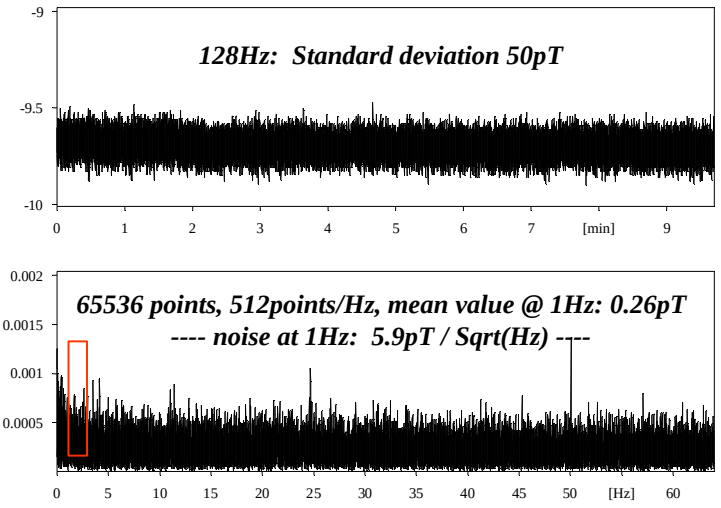


- The absolute stability of the FGM shall be less than 1nT
- The relative stability of the FGM shall be less than 0.2nT/12hrs

THEMIS

FGM Parameter

Venus Express test results



- The FGM noise level @ 1Hz shall be less than 0.03nT/sqrt(Hz)

FGM Parameter

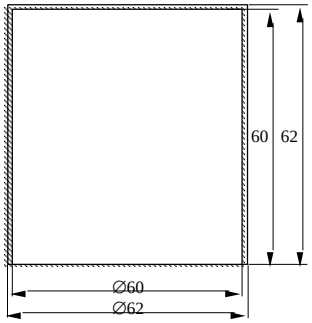
- The FGM science range shall exceed 0-1000nT
  - Max. range 25.000nT
  - Limitation in upper ranges by DLN
- The FGM digital resolution shall be less than 0.1nT
  - 25.000nT / 23bit = 3.0pT (transmission to IDPU)
  - Selection of significant 16bit (by IDPU)
    3.0pT if B < 100nT
    6.0pT if B < 200nT
    …..
    0.8nT if B > 12500nT

S/C I&T

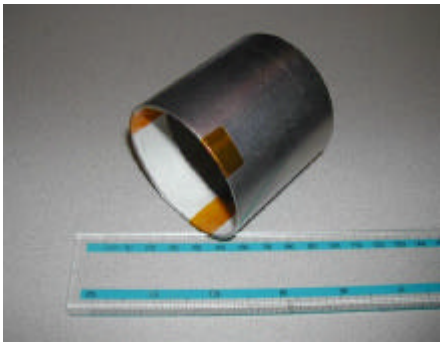
FGM Sensor configuration during S/C I&T

- Level 0 - without sensor
  - B-field about zero if FGM in Cal Mode (preferred mode)
  - B-field saturated if feedback is closed
  - Interface full functional
  - Power consumption reduced by 200mW
- Level 1- Sensor in Mu-metal cup
  - B-field about 10.000nT, Noise about 1nT
  - Full functionality, but B-field value not representative
- Level 2 - Sensor in TCU with extended harness
  - B-field < 10nT, Noise <10pT/sqrt(Hz)
  - B-field has to be available in full quality
  - Delta in calibration coefficients known

Level 1: Mu Metal Can

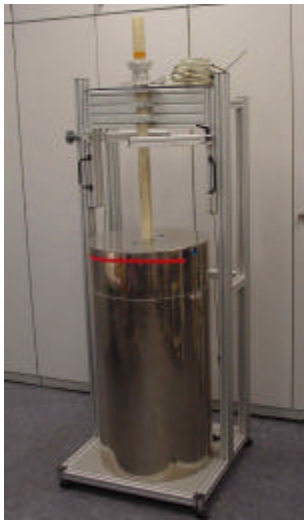


Shielding factor of 10-50



FGM MGSE which can be put over the sensor

Themis Calibration Unit



- Consists of
  - Three layer mu-metal can
  - Three axis coil system
  - Mechanics incl. sensor rotation opportunity
- Future locations
  - Braunschweig (Berlin)
  - Graz
  - Berkeley (Swales)

Purpose of TCU

- Noise & interference determination
  - Noise < 10pT/Sqrt(Hz)
  - Disturbances > 50pT
- Offset determination
  - By sensor rotation in X-Y direction with 0.1nT accuracy
- Scale value determination
  - In Z direction with 0.1% accuracy
- Transfer function determination
  - Up to 1kHz
- Sensor stimulation
  - In all three axes, e.g. Earth orbits, satellite rotation

Schedule

- Basic Functions as well as all magnetometer relevant parameters are tested with Venus Express Magnetometer
  - Identical sensor
  - 90% identical electronics (all active parts)
- FGE Interface and functionality is tested with BB & ETU1
  - Available at Magson
- FPGA permanently under development
- FGS in time
- ETU's status deviates from original plan
- FGE FM's: no showstoppers visible