

ADVISORY: This document has NOT been reviewed for export control and therefore may be subject to ITAR regulations or requirements.

MESSENGER Magnetometer Ground Calibration Data Description

B. J. Anderson
March 2006

Referenced Documents

MESSENGER Magnetometer Instrument Flight Software Specification: JHU/APL 7387-9041 [MAG-IFSW]

MESSENGER Magnetometer (MAG) Calibration Report: JHU/APL 7384-9464 [MAG-CALREP]

1. Introduction

Raw digital data for all MAG ground calibrations use the same formats. These data were acquired through GSEOS playback/record and subsequently reformatted to separate time ordered ASCII data files consisting each of up to five different data packets. These extracted ASCII data files will be delivered as ASCII columnar data separated by packet type giving one set of up to five files for each test. The descriptions of these files are given in Section 2.

Two types of calibration activities for MAG were conducted and they have somewhat different supporting documentation. The first calibration activity was the determination of absolute scale factors and relative sensor orientation. Documentation for this activity was recorded in log books. Supporting documentation for these data will consist of scanned log book pages, digital (ASCII) reduced data (e.g. averages over specified ranges of raw data file entries), together with a description of the contents of each. This document gives the nominal form for the supporting document descriptions in Section 3.

The second type of calibration activity was inter-calibration, either between different data channels/filters with the intrinsic 20/s data stream or of the low voltage power supply with the science A/D channels. For these tests the supporting documentation consists of descriptions of each test and descriptions of the files. For each inter-calibration test a description gives the nature of the test, the objective, specification of the relevant data items, and the time range in the data listings relevant to the inter-calibration activity together with any reduced data that may be required to understand which sections of the data are pertinent to the test. This document gives the nominal form for the test descriptions in Section 4.

Descriptions of magnetometer operation, data rates and data types are given in the flight software specification document – MESSENGER Magnetometer Instrument Flight Software Specification: JHU/APL 7387-9041 [MAG-IFSW].

2. Raw Calibration Data Formats

There are up to five types of data generated by the magnetometer instrument and each type of data was saved during calibration activities in separate files. The instrument always creates the first three files so co-temporal values corresponding to the time

resolution of each of these data are guaranteed to be available. The status or the burst type data may or may not be saved in addition to the other three data types. Status data is always passed from MAG to the Data Processing Unit (DPU) and saving of status data by the DPU is optional and occurs at a rate set by command to the DPU. Saving of burst data is also optional and is controlled by commands to MAG. Burst data is collected only within in a commanded MET window when the logAC value exceeds a trigger level specified by command. The MAG-FSW document provides details regarding the collection of burst data including pre-burst data buffering, timing and relation to other data types. Either one, both or neither status and burst data can be saved. The types of data together with the filename mnemonic are as follows:

- (1) *_sci.dat – science data which are the output of the vector samples at the commanded sample rate;
- (2) *_AC.dat – AC channel data which are the output of the 1-10Hz bandpass amplitude channel;
- (3) *_lrhsk.dat – low rate magnetometer samples, 1-10 Hz bandpass amplitude data and instrument health and safety data;
- (4) *_stat.dat – status magnetometer data consisting of A/D samples of the magnetometer outputs via the on-board power supply low resolution A/D converters;
- (5) *_bst.dat – burst data consisting of 480 second records of unfiltered 20/s sample vector data.

Descriptions of these data files follow together with a segment of each type of file.

For a given test the filenames are “YYYY_MMDD_test_label_TYPE.dat” where the date of the test is given by the four digit year YYYY, the month MM and the day of the month DD, that the test was conducted. The field ‘test_label’ is a brief test name or descriptor, such as ‘wallops’ for the Wallops VA calibration test. TYPE is the data type descriptor corresponding to one of the five labels for the five data types just described.

The time, *t_met* or *st_met*, in all of these files is the time in seconds since the MET provided by the Data Processing Unit (DPU) simulator was reset, either by command or by having the DPU simulator powered off. Since the DPU simulator was routinely powered down during calibration activities and since correlation with UTC was not needed to perform calibration analysis this time field has no correlation with an absolute time reference. This time provides a time reference only within each test for analysis of that test’s data.

2.1 Science Data File Description: *_sci.dat

Each record of the science data file consists of the following:

t_met, range, cx, cy, cz

where

t_met is the DPU MET to the nearest 0.05s;

range is the instrument range (0 or 1);

cx, cy and *cz* are the science A/D counts in signed integers.

The FORTRAN format statement that writes each record is: `format(1x,f14.2,i2,3(1x,i8))`.
The sample below is from 2003_0331_wallops_sci.dat

2029.00	1	3210	154	-34
2029.05	1	3209	155	-33
2029.10	1	3210	155	-34
2029.15	1	3209	155	-34
2029.20	1	3210	155	-33
2029.25	1	3210	155	-33

The instrument range is either 0 for fine scale or 1 for coarse scale. See the MAG-FSW document for detailed descriptions of the MET, range and signed count values.

2.2 AC Channel Data File Description: *_AC.dat

Each record of the AC data file consists of the following:

t_met, *AC_axis*, *logAC*, *count_AC*

where

t_met is the DPU MET to the nearest 0.05s;

AC_axis is the instrument axis (X=0, Y=1, Z=2) used as input to the *logAC* evaluation on-board;

logAC is the 8-bit concatenated mantissa-log corresponding to the amplitude of the 1-10 Hz filtered data from the AC-axis instrument axis;

AC_count is the integer value of the 1-10 Hz amplitude in the same units as the counts in the science data.

The *logAC* contains a 4-bit mantissa and a 4-bit powers of two exponent and are extracted using FORTRAN as follows:

$$AC_exp = \text{trunc}(logAC/16)$$

$$AC_mant = logAC - 16 * AC_exp$$

from which the *AC_count* is calculated in FORTRAN using:

$$AC_count = (\text{float}(AC_mant) + 0.5) * (2. ** (AC_exp - 4))$$

See the MAG-FSW document for other details about the AC channel data regarding the output rate and the time span represented by a given AC channel record. Because the instrument generates a science packet covering the same time span as an AC packet the instrument range is not echoed in the AC data file.

The FORTAN format statement that writes each record is:
format(1x,f14.2,i2,1x,i5,1x,i8). The sample below is from 2003_0331_wallops_AC.dat.

```

2330.50 2  0  0
2331.50 2  0  0
2332.50 2 62  7
2333.50 2 90 21
2334.50 2 91 23
2335.50 2 92 25
2336.50 2 91 23
2337.50 2 77 13
2338.50 2 62  7
2339.50 2 56  4
2340.50 2 42  2
2341.50 2 24  1
2342.50 2  8  0

```

2.3 Low Rate Housekeeping Data File Description: *_lrhsk.dat

Each record of the low rate housekeeping data file consists of the following:

t_met, *range*, *count_AC*, *cx*, *cy*, *cz*, *T_elec*, *T_probe*, *I_dc*

where

t_met is the DPU MET to the nearest 0.05s;

range is the instrument range (0 or 1);

AC_count is the integer value of the 1-10 Hz amplitude in the same units as the counts in the science data;

cx, *cy* and *cz* are the science A/D counts in signed integers;

T_elec is the MAG electronics temperature in degrees Centigrade;

T_probe is the probe temperature in degrees Centigrade;

I_dc is the current drawn by the MAG DC/DC power converter in amperes.

The *t_met*, *range*, *AC_count*, *cx*, *cy*, and *cz* are the same as defined above for science and AC data.

The low rate housekeeping data was designed to be of low volume so that it could be guaranteed to be downlinked daily. The packet contents were chosen to provide monitoring of instrument health, data quality and observations overview. This allows both prompt reaction to instrument events as well as science planning without relying on ground reception of the science data which could be delayed by more than a month due to low downlink margins at some times during operations.

The *T_probe* value is meaningless in some cases and this is noted in the test description. The reason for this is as follows. The circuit that powers the sensor survival

heater includes the temperature measurement circuit and is powered separately from the magnetometer electronics. On the spacecraft, the sensor survival heater is commanded by the spacecraft and is always on in the absence of a severe power problem. To accommodate this requirement, the probe survival heater electronics is powered separately from the rest of the magnetometer electronics. For many bench level and calibration tests the spacecraft/probe heater interface was not simulated because it was not needed. When the spacecraft/probe heater interface is missing the probe temperature is meaningless, as for instance in the example when $T_{probe} = 468$ °C. The test description includes a flag indicating whether the spacecraft/probe heater interface simulator was present or not.

See the MAG-FSW document for other details about the low rate housekeeping data including the available commanded rates and relationship to the science and AC channel data. Because the AC-axis is only changed by instrument command, the AC-axis is not echoed in the low rate housekeeping data file. By contrast, the instrument range can change automatically and the instrument range is echoed in the low rate housekeeping data so that the low rate data can be analyzed unambiguously without the science packet data.

The FORTAN format statement that writes each record is:
format(1x,f14.2,i2,4(1x,i8),2(1x,f9.2),1x,f8.4). The sample below is from
2003_0331_wallops_lrhsk.dat.

1656.00 0	0	916	957	-219	25.55	468.40	0.1094
1706.00 0	1	607	947	-225	25.55	468.40	0.1094
1756.00 0	0	598	940	-222	25.55	468.40	0.1094
1806.00 0	0	595	926	-220	25.55	468.40	0.1094
1856.00 0	0	579	1234	-212	25.55	468.40	0.1094
1906.00 1	0	15	33	-9	25.55	468.40	0.1094
1956.05 1	0	3210	155	-33	25.55	468.40	0.1094
2006.05 1	0	3210	155	-33	25.55	468.40	0.1094
2056.05 1	0	2045	2511	17	25.55	468.40	0.1094

2.4 Status Data File Description: *_stat.dat

Each record of the low rate housekeeping data file consists of the following:

st_met, st_x, st_y, st_z

where

st_met is the DPU MET to the nearest second;

st_x, *st_y* and *st_z* are the low resolution (14-bit) signed integer count values from the low voltage power converter for the three axes of the magnetometer;

The low voltage power supply was standard across all instruments on MESSENGER and includes 16 14-bit A/D channels of which five were available for instrument specific use. For MAG it was decided to use three of these as parallel data paths for low resolution data as a backup.

See the MAG-FSW document for other details about the low voltage power supply A/D data timing and path and the MAG-CALREP document for the relationship between the status field samples and the science samples. Science data is always generated when status data is generated so the range is not echoed in these data.

The FORTAN format statement that writes each record is: `format(1x,i12,3(1x,i7))`. The sample below is from 2003_0331_wallops_stat.dat.

2030	845	52	2
2032	845	50	1
2034	846	52	0
2036	845	50	1
2038	845	49	2
2040	846	49	1

2.5 Burst Data File Description: *_bst.dat

Each record of the burst data file consists of the following:

t_met, cx, cy, cz

where

t_met is the DPU MET to the nearest 0.05s;

cx, cy and *cz* are the science A/D counts in signed integers.

Regardless of the commanded science sampling rate, burst data are always acquired at 20 samples/s. When the science rate is also 20 samples/s the burst and science data are identical. The burst collection capability allows capture of a 480s block of high time resolution data when the logAC level exceeds a commanded level during a commanded time window. The intention is to capture segments of high time resolution data when the signal amplitude is enhanced during periods of the mission when continuous high rate data collection is not possible due to limited downlink volumes. See the MAG-FSW document for other details about the burst data commanding, timing, trigger level, and relationship to other data types. Science data is always generated when burst data is generated and range changes are not allowed during a 480s burst collection interval so the range is not echoed in these data.

Since burst and science data can be acquired simultaneously the burst feature was used during calibration to verify the timing and frequency characteristics of filtered science data relative to the native 20 sample/second data recorded by the burst mode.

The FORTAN format statement that writes each record is: `format(1x,f14.2,3(1x,i8))`. The sample below is from 2003_0113_rate9_tim_bst.dat

14487.35	18988	-15485	-5349
14487.40	18857	-15379	-5312
14487.45	18727	-15272	-5275
14487.50	18596	-15166	-5238
14487.55	18465	-15059	-5201
14487.60	18335	-14953	-5163
14487.65	18204	-14846	-5126
14487.70	18073	-14740	-5089
14487.75	17943	-14633	-5052
14487.80	17812	-14527	-5014
14487.85	17682	-14421	-4978

3. Absolute Calibration Supporting Documentation

The supporting documentation for the absolute and relative sensor axes orientation calibration is presented in two forms: log book pages and ASCII tabular data files. The log book pages are scanned electronic image files. Each sensor rotation calibration (SRC) test consists of the same set of measurements: A/D counts for all three axes (X, Y, Z) recorded for each of 27 different orientations of the sensor. The imposed field calibration (IFC) tests consist of sets of calibration facility coil currents and the corresponding counts in the axis being tested at the time, X, Y or Z, in both coarse and sensitive ranges.

Sensor rotation calibration tests were conducted at Wallops, VA, for fields of 10,001.5 nT and 50,008 nT in the coarse range and at JHU/APL also in coarse range under Earth field before and after environmental testing. The Wallops tests provide the absolute gain knowledge and highest quality data for relative sensor axes orientation. The JHU/APL tests were performed to verify that the sensor axes relative gain and orientations did not change in environmental testing.

Imposed field calibration tests were conducted at JHU/APL prior to and after environmental testing to verify stability of absolute scale factors before and after environmental testing and to transfer the absolute calibration in coarse range to the fine range.

3.1 Log Descriptions

The calibration log book pages are included in form of digital images in PNG format accompanied by a text description of the recorded quantities. The naming convention for the scans and the narratives is as follows:

Sensor Rotation Calibration:

MAG_SRC_ yyyy_mmdd_Page_nn.png

MAG_SRC_ yyyy_mmdd_Notes.txt

Imposed Field Calibration:

MAG_IFC_ yyyy_mmdd_Page_nn.png

MAG_IFC_ yyyy_mmdd_Notes.txt

where ‘yyyy’ and ‘mmdd’ are the four digit year and month and day of month that the tests were conducted. The page number ‘nn’ corresponds to the page number in the scan archive and begins with ‘01’. The image file names are cross-referenced in the *_Notes.txt files, which describe the quantities recorded during the test. Examples for the log book page scans of the sensor rotation tests (MAG_SRC_2003_0331_Page_01.png) and the imposed field tests (MAG_IFC_2003_0521_Page_01.png) are given in the Appendix.

3.2 Supporting Reduced Digital Data Descriptions

Digital data both raw and processed for each SRC and IFC test are provided. The raw digital time ordered data recorded during the tests are provided. These are considered the primary archive as they are independent of any log book entries. The time index corresponds to the instrument time noted in the log book. Derived averaged SRC and IFC data consisting of values derived from the raw data are also provided indicating the point numbers of the raw data used in calculating the average values at each sensor orientation or facility coil current during the test.

3.2.1 Derived Averaged SRC Data File Description

Derived averaged SRC data consisting of values derived from the raw data are provided indicating the point numbers of the raw data used in calculating the average values at each sensor orientation during the test. The SRC data files follow the naming convention MAG_YYYY_MMDD_AveragedData_XX.TXT, where YYYY is the year, MM the month, and DD the days of the test, and XX is the test number. The contents of the data files consists of the following header and data. The sensor axis configuration is also noted because as initially delivered for testing, two of the axes were interchanged. This was corrected subsequently during development. The dates and details of these changes as they affect interpretation of the calibration data are captured in the MESSENGER MAG Calibration Description/Log document being prepared to accompany the calibration data. The SRC data file is as follows (*italics indicate values that will appear in the actual file*):

Filename

MESSENGER MAGNETOMETER

Sensor Rotation Calibration

Averaged data

Input data file: *filename*

Test date: *date*

Test conditions:

Applied field = *value in nT*

Instrument range = *coarse/fine*

Test site = *Wallops/JHU-APL*

Sensor axis configuration = *initial delivery/flight-configuration*

Data:

Sensor orientation index, averaging interval beginning point number, averaging interval ending point number, X-axis A/D counts, Y-axis A/D counts, Z-axis A/D counts

Orientation index	Beginning point no.	Ending point no.	X-axis A/D counts	Y-axis A/D counts	Z-axis A/D counts
1	0	393	3209.83	154.80	-33.61
2	587	980	2045.66	2511.27	18.00
3	1103	1496	-79.00	3228.32	47.01
4	1799	2192	-2496.11	1998.28	43.94
5	2529	2922	-3179.00	-70.89	9.98
6	3230	3623	-1955.02	-2493.99	-40.96
7	3733	4126	138.02	-3161.13	-69.07
8	4392	4785	2261.90	-2229.10	-69.15
9	5376	5769	3206.32	165.96	-31.62
10	7765	8158	-49.94	141.07	3092.39
11	8328	8721	-2.00	2376.00	2118.03
12	8938	9331	57.04	3227.98	-72.03
13	9584	9977	90.97	2222.99	-2251.66
14	10331	10724	84.94	-91.07	-3109.01
15	10863	11256	39.31	-2225.03	-2221.54
16	11597	11990	-22.04	-3162.29	78.09
17	12169	12562	-57.03	-2125.09	2265.99
18	12802	13195	-50.11	171.04	3092.67
19	13488	13881	-47.95	9.29	3094.72
20	14084	14477	-2189.99	17.46	2240.03
21	14674	15067	-3180.32	35.06	-92.18
22	15239	15632	-2187.12	52.01	-2256.77
23	15803	16182	111.77	61.90	-3109.97
24	16338	16717	2394.62	56.09	-2079.72
25	16960	17339	3205.23	39.10	159.83
26	17547	17926	2074.25	21.00	2363.96
27	18171	18550	-34.00	12.98	3095.51

3.2.2 Derived Averaged IFC Data File Description

The imposed field calibrations were performed by placing the sensor in the JHU/APL facility Helmholtz coils, approximately nulling the field, and then energizing the facility coil in one axis, first in coarse steps with the MAG in coarse range, and then in fine steps with the MAG in sensitive range. The procedure was repeated for each sensor axis. The calibration is transferred from coarse to fine by taking the ratio of the

counts/coil current between the coarse and fine ranges. For each step in voltage the approximate MET was recorded in the log book and the step determined in the data stream. Separate derived data files are provided for each sensor axis and range.

Derived averaged IFC data consist of values derived from the raw data together with the range of data points for each average. Average values and the point ranges are provided for each facility current value applied during the test. All IFC tests were performed at the JHU/APL facility. The IFC data file consists of the following header and data. The MAG software version is recorded because the offset values internal to the software were changed during development. The sensor axis configuration is also noted because as initially delivered for testing, two of the axes were interchanged. This was corrected subsequently during development. The dates and details of these changes as they affect interpreting the calibration data are captured in the MESSENGER MAG Calibration Description/Log document being prepared to accompany the calibration data. The IFC data file is as follows (*italics indicate values that will appear in the actual file*):

Filename

MESSENGER MAGNETOMETER

Imposed Field Calibration

Averaged data

Input data file: *filename*

Test date: *date*

Test conditions:

Instrument axis = *X, Y, or Z (in this case Z)*

Instrument range = *coarse/sensitive (in this example sensitive)*

Sensor axis configuration = *initial delivery/flight-configuration*

Data:

A/D counts (Z-axis)/Sensitive range, imposed coil current, averaging interval beginning point number, averaging interval ending point number

A/D counts (Z) – Sensitive range	Coil current (amps)	Beginning point no.	Ending point no.
59.0	0.00	58702	59232
-1781.2	0.10	60035	60559
-3621.3	0.20	61083	61471
-5464.0	0.30	62325	62713
-7305.3	0.40	63383	63771
-9147.0	0.50	64468	64856
-10989.6	0.60	65664	66052
-12832.8	0.70	66582	66970
-14677.0	0.80	67724	68112
-10991.7	0.60	68754	69142
-7306.3	0.40	69697	70085
-3623.9	0.20	70558	70946
56.8	0.00	71597	71985
1898.2	-0.10	72584	72972

58.2	0.00	73841	74229
------	------	-------	-------

4. Performance Characterization Test Documentation

A number of tests were done to characterize various features of instrument performance including evaluations of filter roll off, time delay in the intrinsic A/D conversion, time delay through the digital filters, inter-calibration of status and science A/Ds, offset checks and verification that the probe survival heater had no detectable magnetic signature. These tests were conducted with the sensor in a mu-metal can to eliminate background field and as necessary with an imposed field generated by a solenoid coil energized by a signal generator. Each of these tests was somewhat different so a separate test description that also provides the relevant MET for analysis and supporting graphics documentation will be provided. The header for each test description is similar to those for the SRP and IFC descriptions.

Sample Performance Characterization Test Description:

Test Name: *testname*

Test Objective:

Test Description:

Supporting Documents: *list of additional supporting documents specific to this test*

Input data file: *filename*

Test date: *date*

Test conditions:

Instrument range = *coarse/sensitive*

Sensor axis configuration = *initial delivery/flight-configuration*

Appendix: Example Log Book Page Scans

Sensor Rotation Calibration Example: MAG_SRC_2003_0331_Page_01

3/31/03				29			
AD COUNTS				$\begin{pmatrix} 466 \\ 1293 \\ 34 \end{pmatrix} \begin{pmatrix} 626 \\ 1293 \\ -382 \end{pmatrix}$			
O FIELD				180°			
X	5	241	867	195	895	180	180
Y	32	1198	1229	1230	1236	180	180
Z	-2	28	-345	18	-345	180	180
FLIP SIDE				180°			
X	899	210	165	197	924	180	180
Y	1004	1005	1377	936	1004	180	180
Z	-199	-128	-121	-119	-203	180	180
CAL				10,000 NORTH POS			
X	543	578	(15)	3209	3	10,000 NORTH POS	10,000 NORTH POS
Y	1191	1236	(33)	154	3209	10,000 NORTH POS	10,000 NORTH POS
Z	-186	-215	(-10)	-32	3209	10,000 NORTH POS	10,000 NORTH POS
ZERØ				(2038)			
Pos 2				Pos 3			
2045				-72			
2512				3228			
18				47			
(2072)				2106			
Pos 4				Pos 5			
-2496				-3179			
1999				-71			
44				10			
2134				2164			
Pos 6				Pos 7			
-1955				-188			
-2494				-3161			
-41				-69			
2202				2230			
Pos 8				Pos 9			
2262				3206			
-2229				166			
-69				-31			
2264				2320			
Pos 10				Pos 11			
-48				-50			
141				2376			
3092				2118			
Pos 12				Pos 13			
57				91			
3228				2223			
-72				-2252			

Imposed Field Calibration Example: MAG_IFC_2003_0521_Page_01

[A] I		0.0	0.1	0.2	0.4	0.6	0.8	(46)
coil z-Axis	x	3	-47	-97	-196	-294	-393	
	y	-37	-14	11	59	104	148	
	z	-72	1769	3609	7290	10972	14658	
MET		3164	3232	3348	3448	3552	3692	
I[A]		0.4	0.2	0.0	-0.1	-0.2	0.0	
Counts	x	-196	-97	3	53	1	3	
	y	58	12	-37	-62	1	-38	
	z	7291	3609	-71	-1911	1	-76	
	MET	3838	3948	4044	4142		4578	
12-ans Fine Range, Version 6								
I[A]		0.00	0.00	0.01	0.02	0.03	0.04	
Counts	x	185	208	45	-149	-251	-433	
	y	-1114	-1131	-1075	-1013	-905	-806	
	z	-2341	-2392	3693	9962	16066	22131	
	MET	4656	4704	4824	4930	5034	5136	
I[A]		0.02	0.00	-0.01	-0.02	-0.03	-0.04	
Counts	x	-107	247	407	589	770	966	
	y	-947	-1112	-1243	-1325	-1391	-1536	
	z	9838	-2586	-8700	-14853	-21106	-22522	
	MET	5232	5354	5454	5576	5696	5796	