ACTIVE MAGNETIC FIELD COMPENSATION SYSTEMS – A COMPARATIVE STUDY

Field Management Services, Inc (FMS)

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Abstract: As part of a Design-Build project to create 4 electromagnetically quiet electron microscope (EM) rooms for the new Irvine Materials Research Institute at UC Irvine, FMS evaluated several of the leading commercially available magnetic field active compensation (ACS) systems. There were substantially different performance requirements across the 4 planned instrument rooms; the objective of the tests was to select a product which met all of the criteria, within the constraint of a "room configuration" design. Comparative tests were performed in a single room, selected for being closest to a perfect geometric cube, with cable coils attached to the walls, floor and ceiling of the room – a "room configuration". Six products were tested against 2 EMI specifications < 10 nT, p-p and < 2.8 nT, p-p. All systems met the < 10 nT p-p specification. Only the product designated ACS4 met the Nion "Ideal" specification of < 2.8 nT, p-p, and ultimately achieved < 1nT, p-p simultaneously in all three vectors (X, Y, Z). The results suggest that all of the major manufacturers can achieve low field levels, but 1/f internal noise will present a challenge to achieve exceedingly low field levels. It is reasonable to assume that these exceedingly lower levels will be required by future instruments.

1. The Irvine Materials Research Institute (IMRI)

The new UC Irvine Materials Research Institute (IMRI) is among the worlds' leading centers for the characterization of material. It serves as an interdisciplinary nexus for the research and development of engineered and natural materials, systems and devices.

The Institute supports the highest-performance transmission electron microscopes (TEMs) available today (the Nion UltraSTEMTM 200 HERMES and JEOL JEM-ARM300F Grand ARM), an advanced Cryo TEM (JEOL 2100F) equipped with the state-of-the-art direct electron detecting camera and a workhorse High-Throughput TEM (JEOL 2800) as well as a complete range of sample preparation instruments, offering researchers powerful tools for looking at the structure of matter – from millimeter to sub-angstrom scales – and revealing the functional properties of materials.

2. Field Management Services (FMS).

FMS is a Professional Engineering firm with a specialty in measurement and mitigation of electric and magnetic fields across the electromagnetic spectrum. Although, during our 20+ years in this business, FMS has purchased and deployed many commercially available ACS systems, including most of those in this study. However, FMS is not a distributor of, nor a dealer for, any ACS system. While there were performance differences among these tested systems, all of the systems were judged to be high quality and competent.

3. Discussion of ACS systems

Most commercially available ACS systems utilize a negative feedback loop and proportion, integral (PI), proportional, integral, derivative (PID), digital signal processing (DSP), or similar signal processing technology. Commonly, the negative feedback loop consists of a high-end magnetometer, most commonly a fluxgate magnetometer, placed inside a Helmholtz coil volume. The magnetometer

records continuous measurements of the environment that are processed by a signal processor. The signal processor sends a compensation signal to an amplifier that then drives current through the Helmholtz coils creating a canceling field. While the technology is far more complicated, in the simplest terms an ACS is generating a cancelation field that is 180 degrees out of phase with the offending field.

Since the reference ambient fields are detected at the system magnetometer, the "sweet spot" for the system is at the location of the magnetometer; the closer to the magnetometer, the greater the ambient field suppression, and conversely.

Over the course of this study, FMS tested products from 4 manufacturers, totaling 6 products (2 of the manufacturers were represented by 2 separate products). Of those 6 products, 4 are represented in this study (one of the products performed essentially the same as another from the same manufacturer and one manufacturer was not available for a significant part of the early testing).

Although the principal results of the tests are contained in this report, the identity of the manufacturers and model numbers are held in confidence, forestalling the use of these data for marketing purposes. The products are identified as ACS1; ACS2; ACS3 and ACS4 – and specific comparative details and performance data are held in confidence, by FMS.

4. The Primary Objective of the Tests

The new UC Irvine TEM facility currently has 4 Transmission Electron Microscope suites, with different EMI requirements. FMS was tasked, under a design/build contract, to deliver a facility which would comfortably meet the EMI environment demanded by each instrument manufacturer, through the design and installation of passive shielding, supplemented by an Active Compensation System.

In the majority of cases, the passive shielding was designed to meet the EMI criteria for AC (60 Hz) magnetic fields and any DC shielding was included to "groom" the DC field gradient to enable higher performance of the ACS systems. The ACS systems would help bring the facilities into broadband compliance and would add an additional layer of confidence against any possibility of changes in ambient field levels in the foreseeable future.

Since the EMI requirements of the tools vary across a wide performance range and since the cost of the ACS systems would be a fraction of the total project cost, we determined that the customer would be best served by testing ACS systems under identical conditions which would provide the basis for selecting a single ACS product which would:

A. Meet the performance criteria of the most demanding tool (the "Ideal" specifications of the NION UltraSTEM 200 HERMES under ambient background conditions.
B. Meet the performance criteria of the most demanding tool (the "Ideal" specifications of the NION UltraSTEM 200 HERMES under "significant stress" background conditions.

C. Meet the performance criteria of all sensitive tools, within an ACS "room scale" design (coils on the perimeter surfaces of the room).

Of secondary importance, we were curious to see the extent to which manufacturer claims of performance would be reflected in our test data, and might help guide and end user through a purchase decision. We have seen marketing data sheets that claim 30, 40, 50 and even 60 dB attenuation.

From these tests, such blanket performance claims appear to be based on idealized conditions which are narrowly defined, whereas the real world of EMI field mitigation contains numerous, uncontrolled variables, often in conflict with each other.

Given that all ACS systems are essentially Helmholtz coils (see discussion, above), all of these systems could be optimized as paired coils, separated from each other at ½ the coil diameter. All of the manufacturers can (and do) supply frame-mounted systems which would locate the coils closer together than was the case for our tests, which would likely improve performance. However, our customer wanted to avoid anything that would limit access to their instruments or long-term flexibility in program growth. Accordingly, we were tasked to achieve the required performance with a system that was mounted to the walls, floor and ceiling of each room. While it is likely that an ACS that more closely follows the ideal definition of a Helmholtz coil will produce a more coherent "quiet" volume, a room-scale system will create a larger quiet volume with possibly less control. For instruments which require (or customers prefer) that a greater portion of the instrument or room is protected, the room-scale system is preferred.

Important to this study, a successful system would achieve a comparative performance advantage over its competitors within the boundaries of a room-scale test configuration AND strictly meet the environmental specification of all instruments.

5. Test Conditions

Each of the 4 TEM labs is dimensionally unique and, to some extent, has a different ambient background EMI environment. The room which most closely approximates a perfect cube was chosen as the "test room" which would produce comparable data and allow a ranking of the 4 systems. However, it was understood that the final test of performance of the preferred unit will be its performance inside ALL of the rooms, meeting the EMI environmental specifications of the EM manufacturer.

The coils for each test were optimized and constructed according to manufacturer instructions/ specifications. The coils were attached to identical 4" stand-offs, mounted to the walls, floor and ceiling of the test room. The tests used ACS sensors provided by the manufacturer. The independent FMS measurement system consisted of a Bartington Spectramag 6-channel Spectrum Analyzer mated to two (2) Low Noise Bartington Mag 03 probes (1 probe inside and 1 probe outside the test room).

The ACS sensor and the FMS measurement sensor were located at the approximate geographical center of the test room, at 1 meter elevation on non-ferrous tripods. The Spectramag was set to a sample rate of 1 kHz and a test duration of 30 minutes. Tests were performed at various times during a regular business day but comparable data was gathered during the late-afternoon rush hours.

6. Test Parameters/Protocol Summary:

A. Two DC (Quasi-DC – 0-10 Hz) specifications (X, Y, Z) :

Room 1131C; JEOL Cryo TEM 2100F **< 10 nT, p-p**
Room 1151C; Nion UltraSTEM™ 200 HERMES: **< 2.8 nT, p-p**

B. Standard Coil configuration – Coils inside the room, at the perimeters of walls, ceiling and floor offset by a minimum of 4".
C. Standardized measurement at 1-meter elevation
D. Simultaneous measurements inside and outside the shielded room
E. Extremely high-resolution measurement system – Bartington Spectramag, 1K/s rate mated to Bartington Low Noise probes.

7. Results:

During the course of the tests, FMS provided confidential test results and comments back to each of the ACS manufacturers, who made recommendations and alterations to their systems, in virtually all cases, improving their results. These exchanges led to productive, incremental performance improvements in base systems, support materials and subsystems - and in one case, an entirely new system design.

After some 12 months of test and improvements, all of the systems were able to meet the DC specification of < 10 nT, p-p. But only the new model (ACS #4) met the more stringent < 2.8 nT, p-p specification in the test room with controlled stressors - the elevators locked out. Further, only the ACS#4 product met the 2.8 nT spec during tests performed with uncontrolled stressors - an active passenger elevator across the hall and an adjacent swinging steel emergency door.

Finally, only the ACS#4 was able to record values under 1 nT, simultaneously, in all three vectors (X, Y, and Z) inside the STEM1 (NION) room with uncontrolled stressors – active elevators and swinging steel emergency door.

The tables below present the summary results of each series of tests. All values are in nanoTesla (nT), peak-to-peak (p-p).

Following the Tables, the Appendix lists the Table # and the relevant graphic presentation of data from that table.

TABLE 1.

May, 2016; Test Room 1131C

Description	Data Recorded 30 May 2016 - Test Room 1131C		
Quasi-DC (0-10 Hz)	Bx	By	Bz
Background	38 nT	44 nT	42 nT
ACS1	9 nT	14 nT	9 nT
ACS2	7 nT	8 nT	8 nT
ACS3	6 nT	17 nT	11 nT
Testing Completed with Elevators Locked Out		10 nT = 0.1 mG	

During the first round of tests, only ACS2 met the 10 nT, peak-peak specification. Doors and Elevators were controlled during testing.

TABLE 2.

June, 2016; Test Room 1131C

Description	Data Recorded 23 June 2016 - Test Room 1131C		
Quasi-DC (0-10 Hz)	Bx	By	Bz
Background	75 nT	69 nT	48 nT
ACS1	4 nT	5 nT	3 nT
ACS2	10 nT	12 nT	5 nT
ACS3	3 nT	3 nT	2 nT
ACS3* Background	405 nT	230 nT	582 nT
ACS3*	7 nT	5 nT	7 nT
*Testing Completed During Elevator Operations		10 nT = 0.1 mG	

Background fields roughly doubled during the June tests and all manufacturers had the benefit of system improvements/modifications. ACS2 horizontal performance degraded under the higher fields, but both ACS1 and ACS3 comfortably passed the 10 nT peak-peak specification. With the best performance so far, ACS3 was selected for much higher background fields caused

by Elevator Operations. Although the compensated values suffered, performance of ACS3 remained within the 10 nT spec. None of the tests passed the "Ideal" Nion Spec of 2.8 nT.

During August and September, a prototype of a new product was tested, designated ACS4. Preliminary tests indicated that ACS4 could meet the Nion "Ideal" specifications. Accordingly, testing was focused on this new product, first in Test Rm. 1131C and then in Test Rm. 1151C.

TABLE 3. (See Graphics in APPENDIX)
June/July 2016; Test Room 1131C

Description	Data Recorded 6 Oct 2016 - Test Room 1131C		
Quasi-DC (0-10 Hz)	Bx	By	Bz
Background	86 nT	68 nT	42 nT
ACS4	2.31 nT	2.12 nT	2.29 nT
Testing Completed with Elevators Locked Out		10 nT = 0.1 mG	

Under the identical test protocol conditions of prior tests (Room 1131C), ACS4 met the "Ideal" requirements of the Nion UltraSTEM™ 200 HERMES in all three vectors and was relocated to Rm 1151C for final testing.

TABLE 4. (See Graphics in APPENDIX)
October 7, 2016; Test Room 1151C

Description	Data Recorded 7 Oct 2016 - Test Room 1151C		
Quasi-DC (0-10 Hz)	Bx	By	Bz
Background - Outside Room	78 nT	33 nT	46 nT
ACS4 - ON	1.14 nT	1.39 nT	1.39 nT
Background* - Outside Room	400 nT	488 nT	190 nT
ACS4* - ON	1.22 nT	1.41 nT	1.30 nT
*Testing Completed During Elevator Operations		10 nT = 0.1 mG	

ACS4 meets the Nion "Ideal" spec under ambient and stressed (Elevator and swinging steel door) conditions.

TABLE 5. (See Graphics in APPENDIX)
October 7, 2016; Test Room 1151C

Description	Data Recorded 7 Oct 2016 - Test Room 1151C		
AC (10 - 1,000 Hz)	Bx	By	Bz
ACS4 - ON	0.07 nT	0.01 nT	0.07 nT
10 nT = 0.1 mG			

ACS4 comfortably meets the Nion AC field spec.

TABLE 6. (See Graphics in APPENDIX)
May 12, 2017; Test Room 1151C

Description	Data Recorded 12 May 2017 - Test Room 1151C		
Quasi-DC (0-10 Hz)	Bx	By	Bz
Background* - Outside Room	125 nT	129 nT	104 nT
ACS4* - ON	0.91 nT	0.93 nT	0.96 nT
*Testing Completed During Elevator Operations		10 nT = 0.1 mG	

Following a software revision to ACS4, the system achieves sub-nanoTesla values, simultaneously in all three vectors, with elevators operating.

8. Conclusions

All of the ACS systems met the specs of the most stringent JEOL EM, the 2100F when tested in Room 1131C. Only the ACS4 met the most demanding "Ideal" specification of the Nion UltraSTEM™ 200 HERMES, both in the Test Room and in its purpose-designed room (1151C).

The data suggests and our experience in this work supports several conclusions:

A. Future leading-edge EMs will likely require more restrictive EMI environmental criteria for maximum performance
B. The current set of available ACS systems may, with improvements in coil configuration, sensors and/or electronics, meet the new specifications, but these data suggest that they may struggle to achieve that improved level of performance.
C. Regarding manufacturer performance specs: While it may be possible for an ACS to achieve a specific cancellation value (say, -40 dB or -50 dB) under certain circumstances, it will not achieve that performance under all conditions, and perhaps under only very limited circumstances. It is not clear from the data of this test program that such specifications are a valid metric for performance comparison between products for any given purpose. The real-world potential for EMI variables make such comparisons or projections, speculative.
D. Further, as can be seen in the data, achievement of a specific percentage or dB reduction becomes much more difficult with lower target EMI values, largely due to 1/f noise (noise which is inversely proportional to frequency). Thus, noise power will drop quickly as the system approaches a broadband region, but ACS systems are limited in their ability to compensate for this, as they are principally operating from 1mHz to 10Hz, where the noise power will be at its worst.
E. As mentioned in the above report, it is possible that optimizing the cable design to more closely approximate a classic Helmholtz coil may adequately improve performance, but at the sacrifice of future flexibility.

Acknowledgement - Footnote: We anticipated that the testing would take no more than 2 months and could be inserted into the project schedule without harm. In the end, it could be argued that the testing took roughly 15 months and, fortunately, did not delay the project. FMS bore all costs associated with this work. But it must be said that none of this would have been possible without the trust and willing participation of the manufacturers of the tested ACS systems. FMS restricted distribution of all detailed results to the manufacturer of the ACS system under test. Neither would this work been possible without the forbearance of the University of California Irvine, in particular its Design and Construction professionals lead by Brian Pratt, Vice Chancellor and Campus Architect. On the technical side, we received invaluable direction and insight from the leadership of the University researchers, Dr. Xiaoqing Pan and Dr. Matt Law who set and enforced performance and facility goals well beyond the currently foreseeable future. Finally, we are equally grateful for the chance to work for PCL Construction and their Project Manager, Dana Wiehe, who mercilessly held her subcontractors' feet – including FMS' – to the fire.

APPENDIX

Table 3	**Test Room 1131C**	**Figure 1A**
		Figure 1B
Table 4	**Test Room 1151C**	**Figure 2A**
		Figure 2B
		Figure 7A
		Figure 7B
Table 5	**Test Room 1151C**	**Figure 8A**
Table 6	**Test Room 1151C**	**Figure 3A**
		Figure 3B

PCL - University of California - Irvine
CRYO TEM 3 - 2100F - Room 1131C
EMI Analysis - DC Magnetic Field Strength
Data Recorded 1 Meter A.F.F.

Date Recorded: 10/6/2016

Probe 2 - Located Outside in Corridor
Active Compensation System: ON
Part of 30 Minute Series

Values Displayed in nT

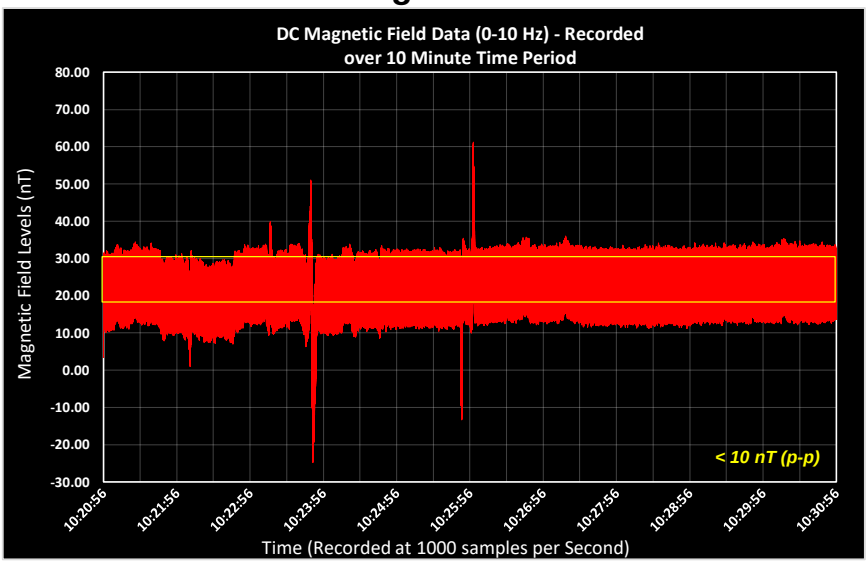
Figure 1A

Specification:

less than (<) 10 nT (p-p)

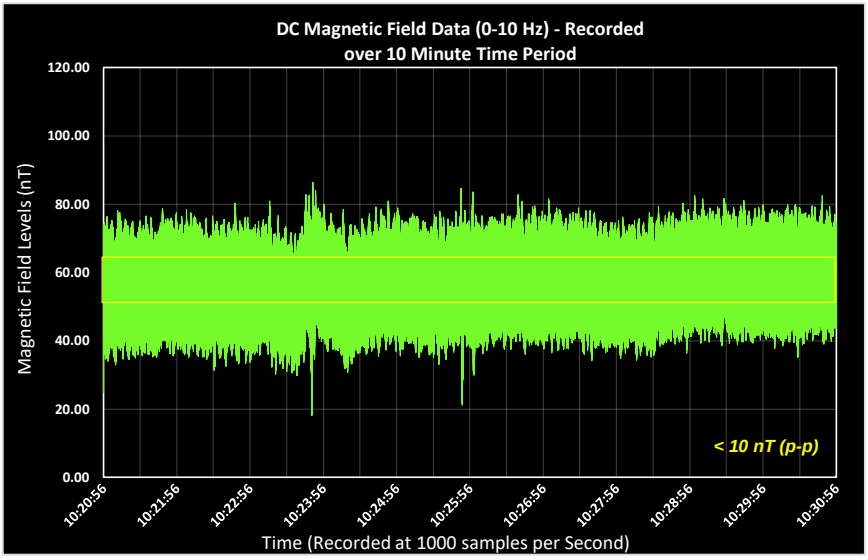
Unit Conversion

0.1 mG = 10 nT



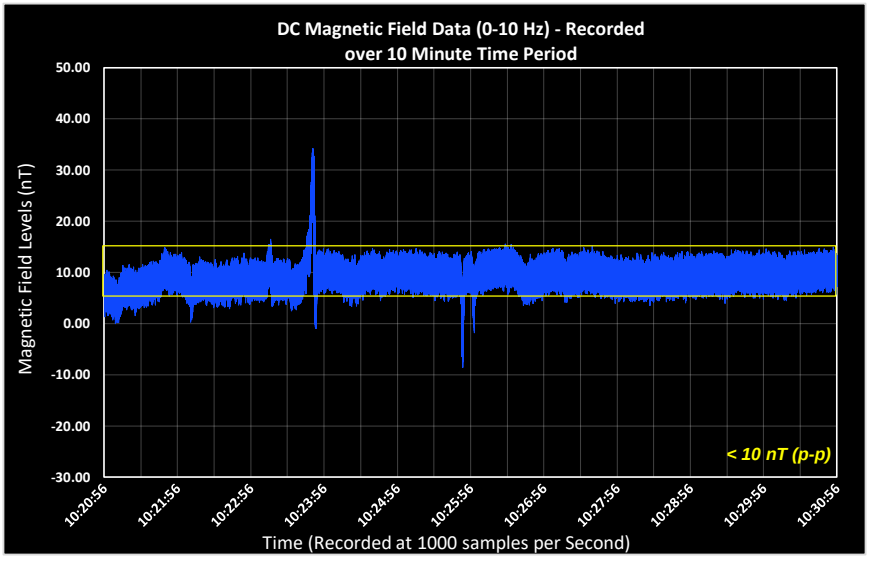
X-Axis (Horizontal)

Magnetic Field Levels	
Minimum	-24.68
Maximum	61.14
Total Delta (P-P)	85.82



Y-Axis (Horizontal)

Magnetic Field Levels	
Minimum	18.20
Maximum	86.29
Total Delta (P-P)	68.09



Z-Axis (Vertical)

Magnetic Field Levels	
Minimum	-8.55
Maximum	34.22
Total Delta (P-P)	42.77

DC (0-10 Hz) Magnetic Field Strength Levels - Data Recorded @ 1-Meter Level

FMS
Field Management Services Corp.
New York - Los Angeles

PCL - University of California - Irvine
CRYO TEM 3 - 2100F - Room 1131C
EMI Analysis - DC Magnetic Field Strength
Data Recorded 1 Meter A.F.F.

Date Recorded: 10/6/2016

Probe 1 - Located Inside Instrument Room
Active Compensation System: ON
Part of 30 Minute Series

Values Displayed in nT

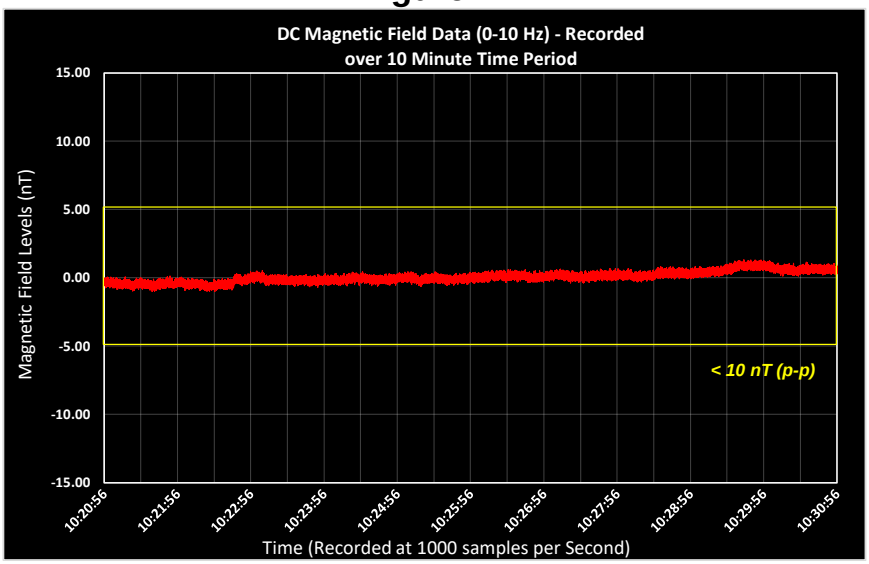
Figure 1B

Specification:

less than (<) 10 nT (p-p)

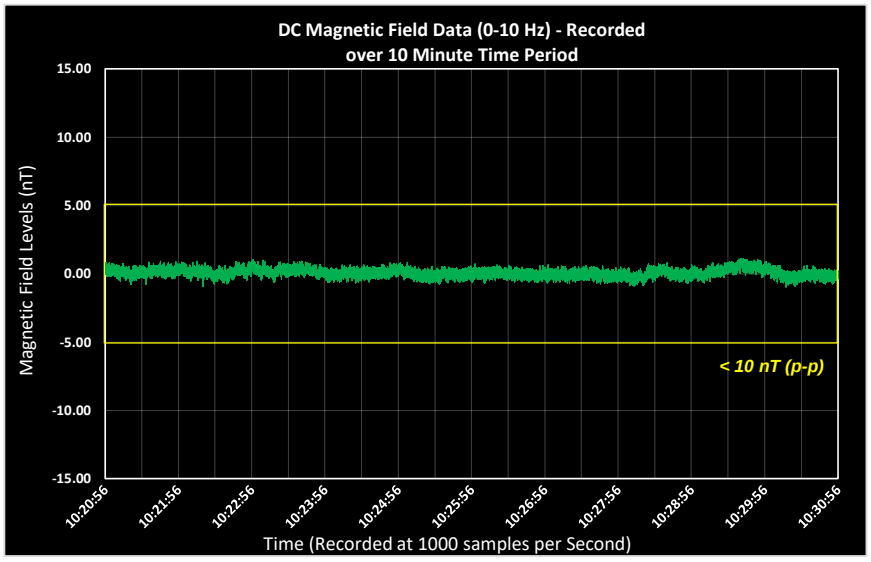
Unit Conversion

0.1 mG = 10 nT



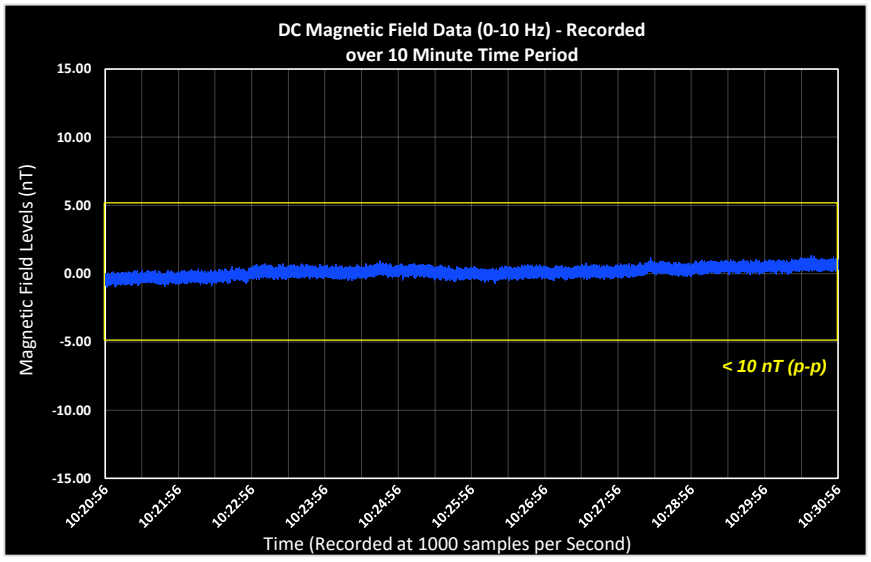
X-Axis (Horizontal)

Magnetic Field Levels	
Minimum	-1.01
Maximum	1.30
Total Delta (P-P)	2.31



Y-Axis (Horizontal)

Magnetic Field Levels	
Minimum	-0.99
Maximum	1.13
Total Delta (P-P)	2.12



Z-Axis (Vertical)

Magnetic Field Levels	
Minimum	-0.98
Maximum	1.31
Total Delta (P-P)	2.29

DC (0-10 Hz) Magnetic Field Strength Levels - Data Recorded @ 1-Meter Level

FMS
Field Management Services Corp.
New York - Los Angeles

PCL - University of California - Irvine
CRYO TEM 3 - 2100F - Room 1131C
EMI Analysis - DC Magnetic Field Strength
Data Recorded 1 Meter A.F.F.

Date Recorded: 10/6/2016

Probe 1 - Located Inside Instrument Room
Active Compensation System: ON
Part of 30 Minute Series

Values Displayed in nT

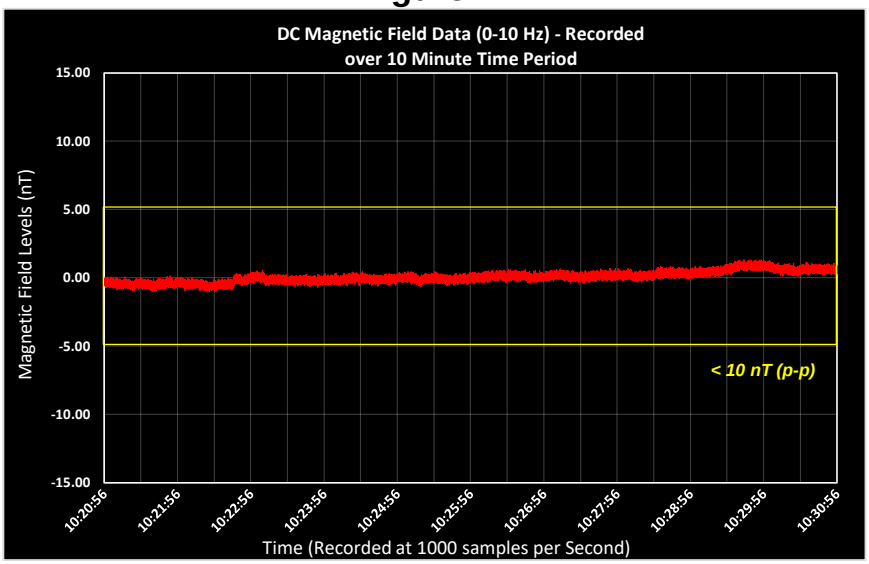
Figure 1B

Specification:

less than (<) 10 nT (p-p)

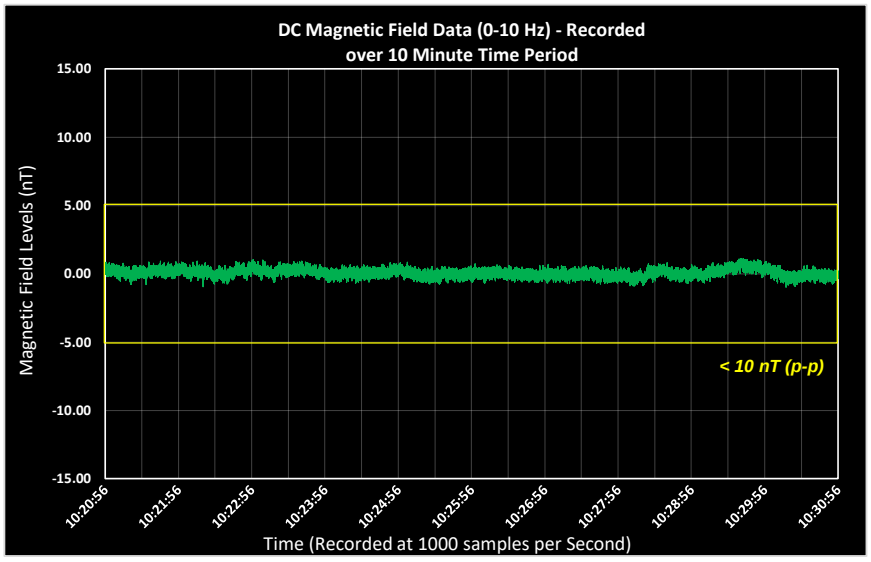
Unit Conversion

0.1 mG = 10 nT



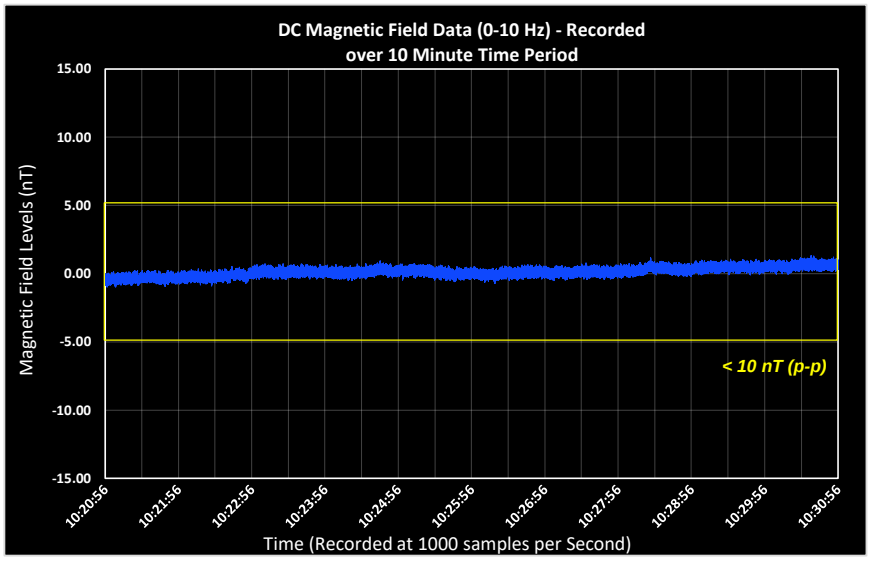
X-Axis (Horizontal)

Magnetic Field Levels	
Minimum	-1.01
Maximum	1.30
Total Delta (P-P)	2.31



Y-Axis (Horizontal)

Magnetic Field Levels	
Minimum	-0.99
Maximum	1.13
Total Delta (P-P)	2.12



Z-Axis (Vertical)

Magnetic Field Levels	
Minimum	-0.98
Maximum	1.31
Total Delta (P-P)	2.29

DC (0-10 Hz) Magnetic Field Strength Levels - Data Recorded @ 1-Meter Level

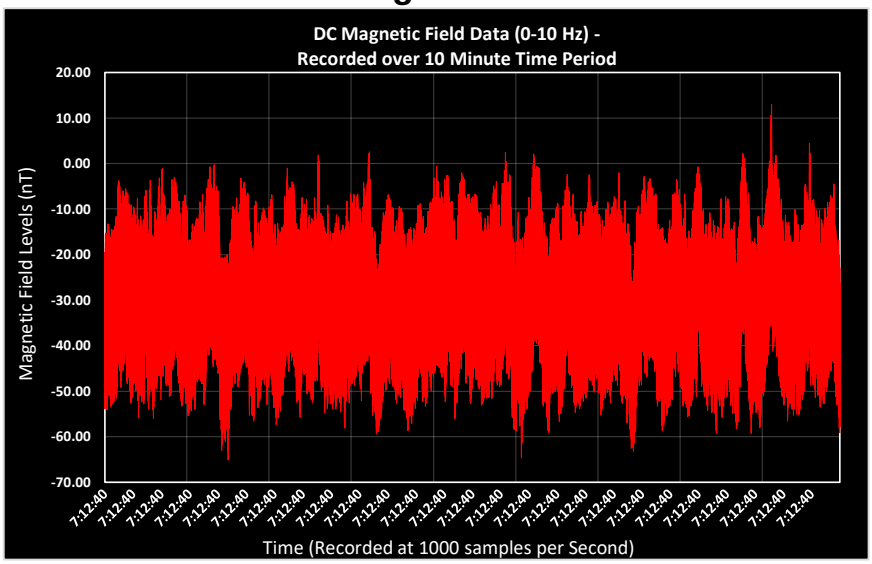
FMS
Field Management Services Corp.
New York - Los Angeles

University of California - Irvine
STEM 1 - Nion Room 1151C
EMI Analysis - DC Magnetic Field Strength
Data Recorded 1 Meter A.F.F.

Date Recorded:10/7/2016

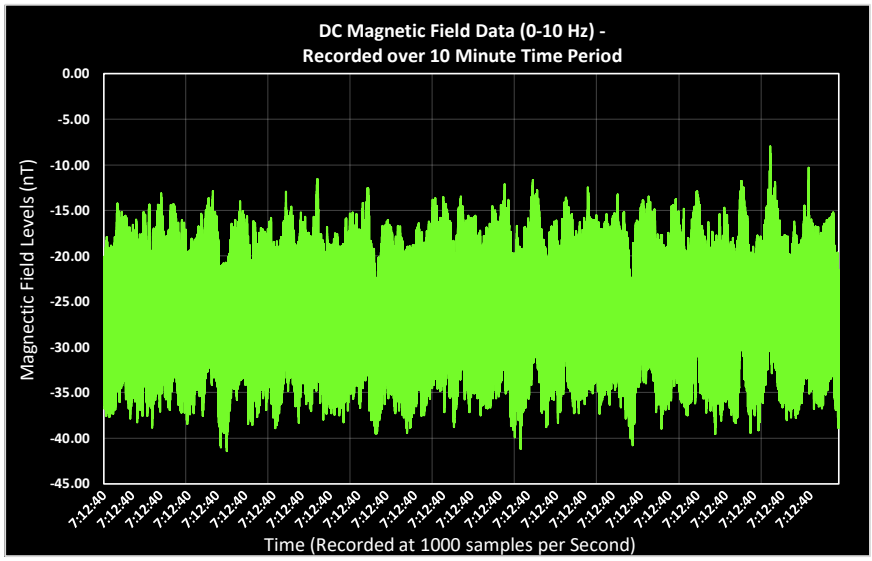
Probe 1 - Located Outside Room - Hallway
Part of 30 Minute Series

Figure 2A



X-Axis (Horizontal)

Magnetic Field Levels	
Minimum	-65.14
Maximum	13.00
Total Delta (P-P)	78.14

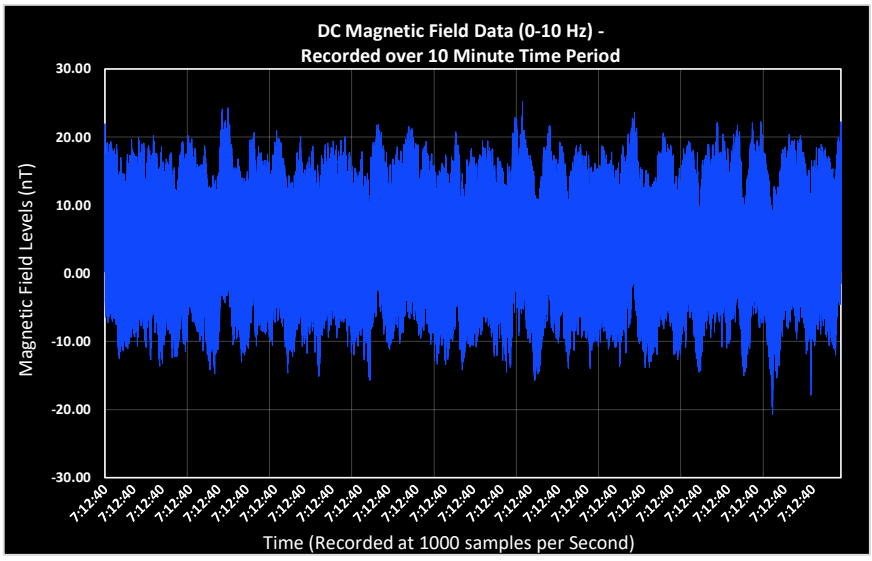


Y-Axis (Horizontal)

Magnetic Field Levels	
Minimum	-41.42
Maximum	-7.99
Total Delta (P-P)	33.43

Unit Conversion

0.1 mG = 10 nT



Z-Axis (Vertical)

Magnetic Field Levels	
Minimum	-20.71
Maximum	25.18
Total Delta (P-P)	45.89

AC (1-500 Hz) Magnetic Field Strength Levels - Data Recorded @ 1-Meter Level

FMS
Field Management Services Corp.
New York - Los Angeles

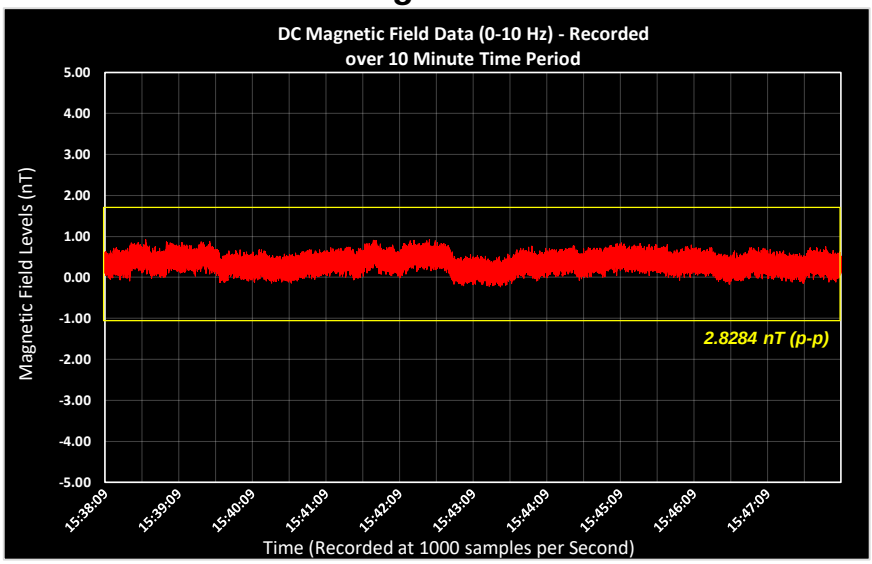
University of California - Irvine
STEM 1 - Nion Room 1151C
EMI Analysis - DC Magnetic Field Strength
Data Recorded 1 Meter A.F.F.

Date Recorded: 10/7/2016

Probe 1 - Located Inside Instrument Room
Active Compensation System: ON
Part of 30 Minute Series

Values Displayed in nT

Figure 2B



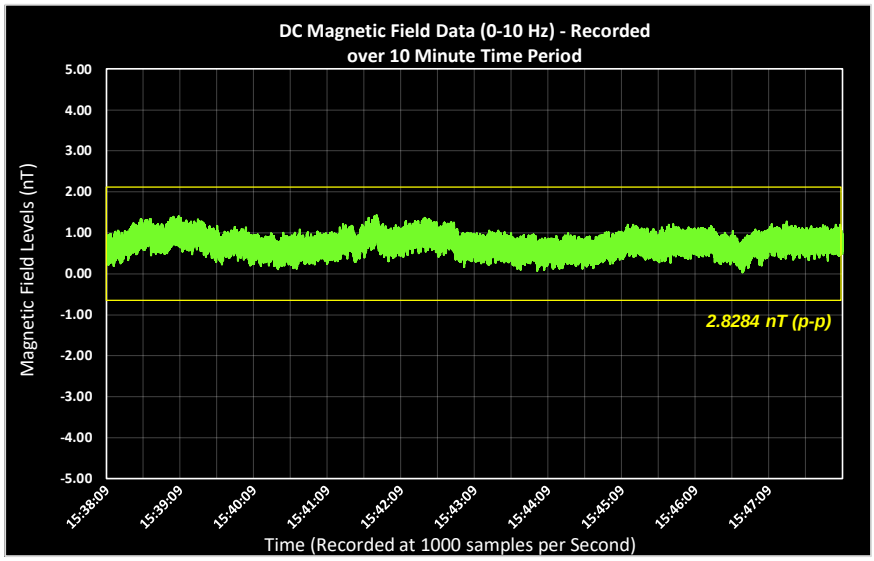
X-Axis (Horizontal)

Magnetic Field Levels	
Minimum	-0.23
Maximum	0.91
Total Delta (P-P)	1.14

Specification:

2.8284 nT (p-p) - 1.0 nT (RMS)

0.028 mG (p-p) - 0.01 mG (RMS)

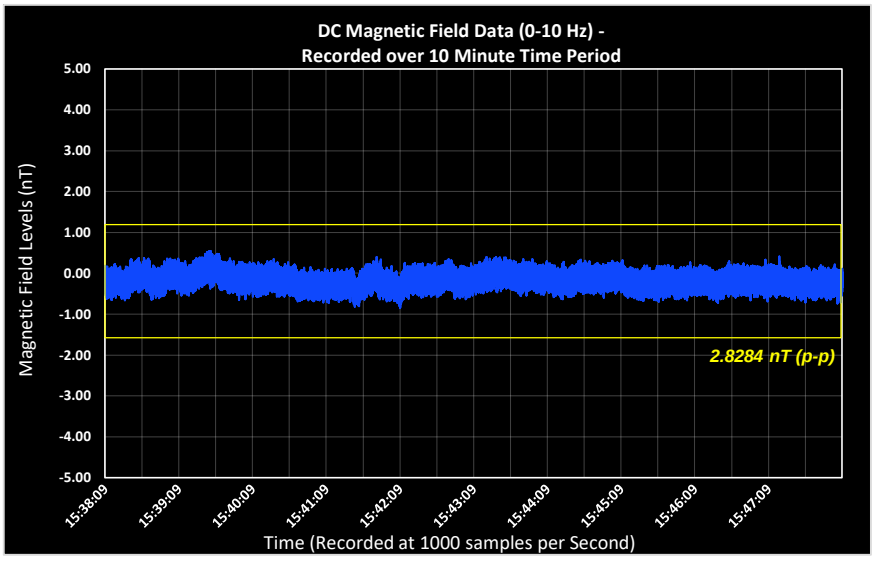


Y-Axis (Horizontal)

Magnetic Field Levels	
Minimum	0.04
Maximum	1.43
Total Delta (P-P)	1.39

Unit Conversion

0.1 mG = 10 nT



Z-Axis (Vertical)

Magnetic Field Levels	
Minimum	-0.84
Maximum	0.54
Total Delta (P-P)	1.39

DC (0-10 Hz) Magnetic Field Strength Levels - Data Recorded @ 1-Meter Level

FMS
Field Management Services Corp.
New York - Los Angeles

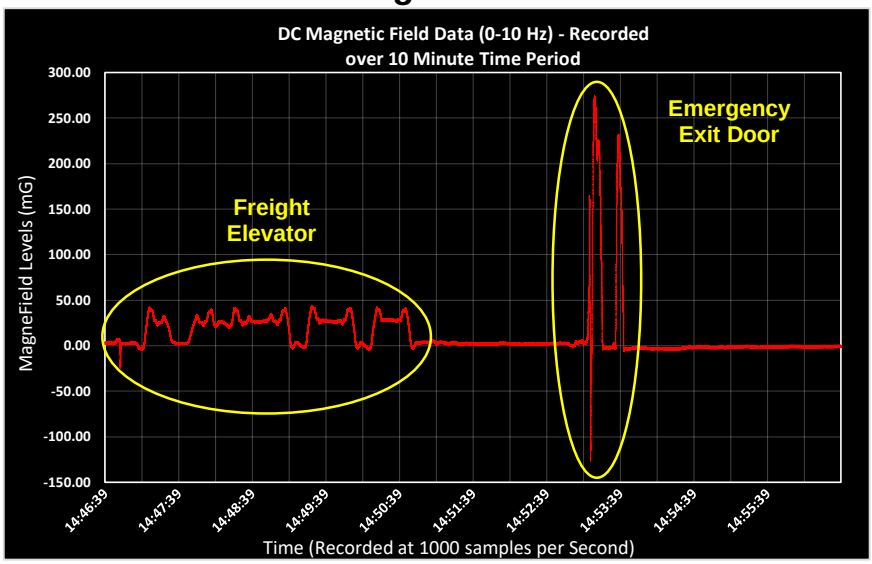
University of California - Irvine
STEM 1 - Nion Room 1151C
EMI Analysis - DC Magnetic Field Strength
Data Recorded 1 Meter A.F.F.

Date Recorded: 10/7/2016

Probe 2 - Located Outside in Corridor
Active Compensation System: ON
Elevator & Door Testing

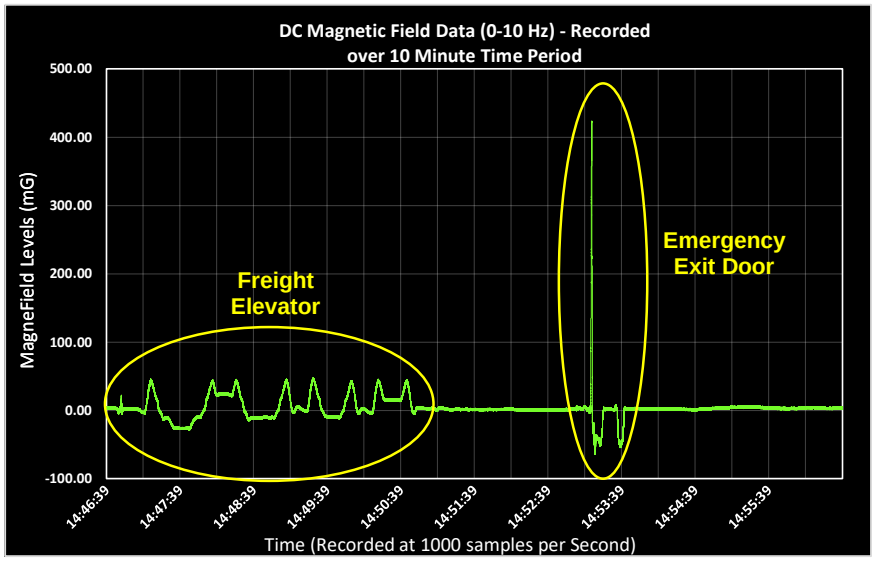
Values Displayed in nT

Figure 7A



X-Axis (Horizontal)

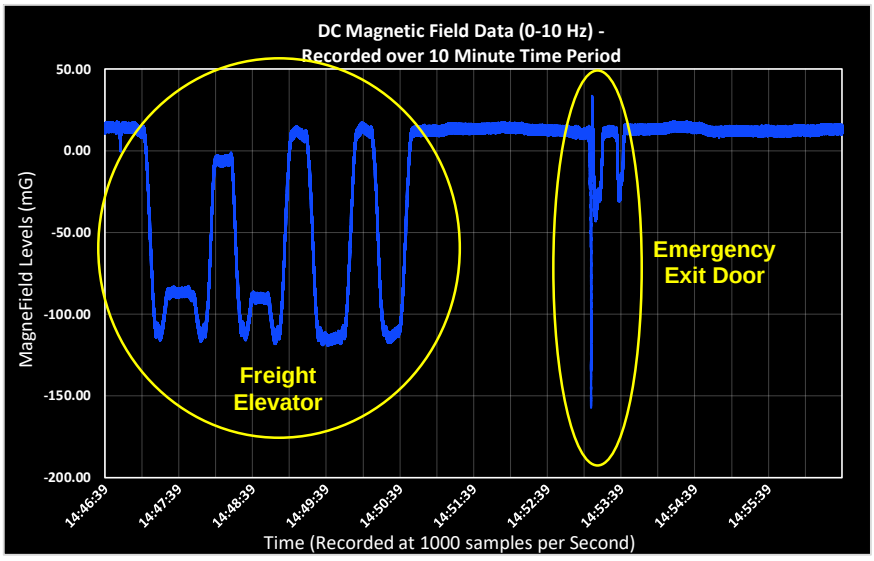
Magnetic Field Levels	
Minimum	-126.64
Maximum	273.76
Total Delta (P-P)	400.40



Y-Axis (Horizontal)

Magnetic Field Levels	
Minimum	-63.83
Maximum	423.94
Total Delta (P-P)	487.77

Unit Conversion
0.1 mG = 10 nT



Z-Axis (Vertical)

Magnetic Field Levels	
Minimum	-157.09
Maximum	33.34
Total Delta (P-P)	190.43

DC (0-10 Hz) Magnetic Field Strength Levels - Data Recorded @ 1-Meter Level

FMS
Field Management Services Corp.
New York - Los Angeles

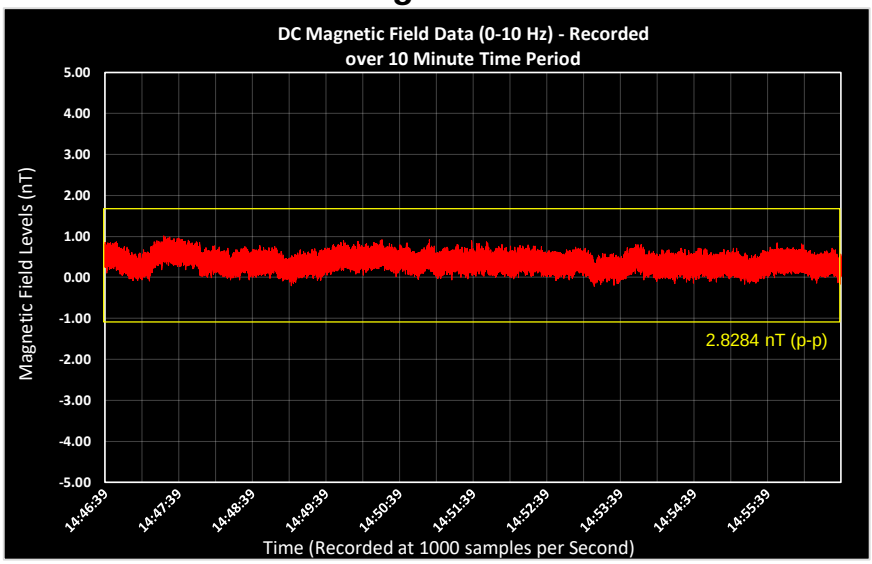
University of California - Irvine
STEM 1 - Nion Room 1151C
EMI Analysis - DC Magnetic Field Strength
Data Recorded 1 Meter A.F.F.

Date Recorded: 10/7/2016

Probe 1 - Located Inside Instrument Room
Active Compensation System: ON
Elevator & Door Testing

Values Displayed in nT

Figure 7B



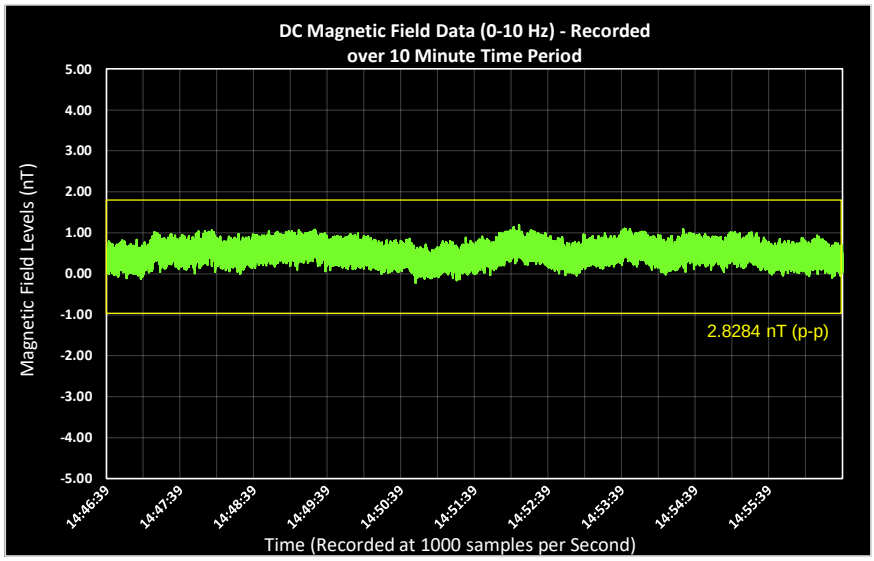
X-Axis (Horizontal)

Magnetic Field Levels	
Minimum	-0.21
Maximum	1.00
Total Delta (P-P)	1.22

Specification:

2.8284 nT (p-p) - 1.0 nT (RMS)

0.028 mG (p-p) - 0.01 mG (RMS)

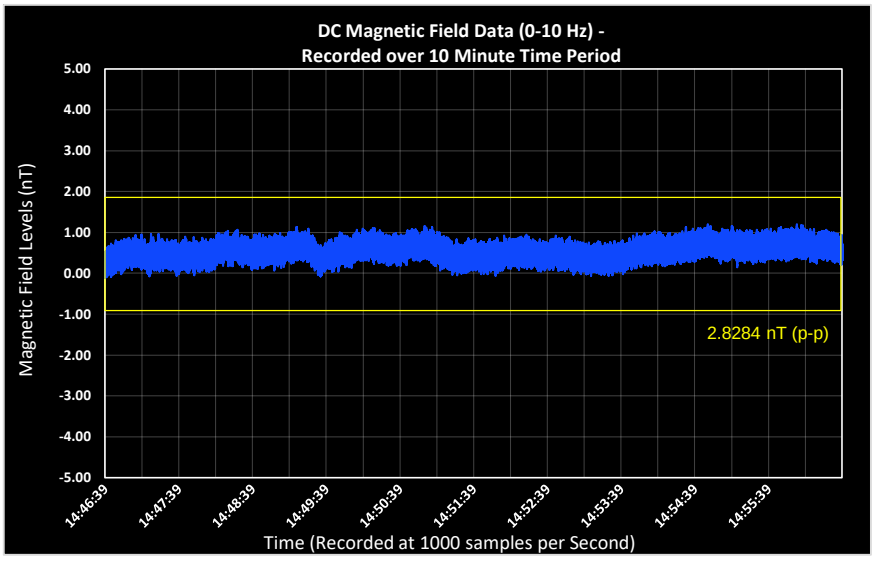


Y-Axis (Horizontal)

Magnetic Field Levels	
Minimum	-0.22
Maximum	1.20
Total Delta (P-P)	1.41

Unit Conversion

0.1 mG = 10 nT



Z-Axis (Vertical)

Magnetic Field Levels	
Minimum	-0.11
Maximum	1.19
Total Delta (P-P)	1.30

DC (0-10 Hz) Magnetic Field Strength Levels - Data Recorded @ 1-Meter Level

FMS
Field Management Services Corp.
New York - Los Angeles

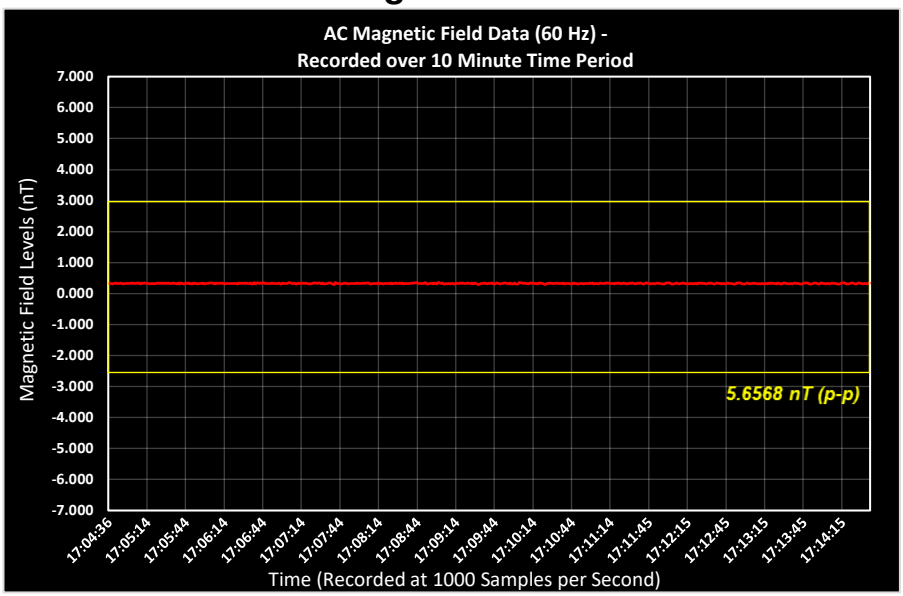
University of California - Irvine
STEM 1 - Nion Room 1151C
EMI Analysis - AC (60 Hz) Magnetic Field Strength
Data Recorded 1 Meter A.F.F.

Date Recorded: 10/7/2016

Probe 1 - Located Inside Instrument Room
Active Compensation System: ON

Values Displayed in nT

Figure 8A



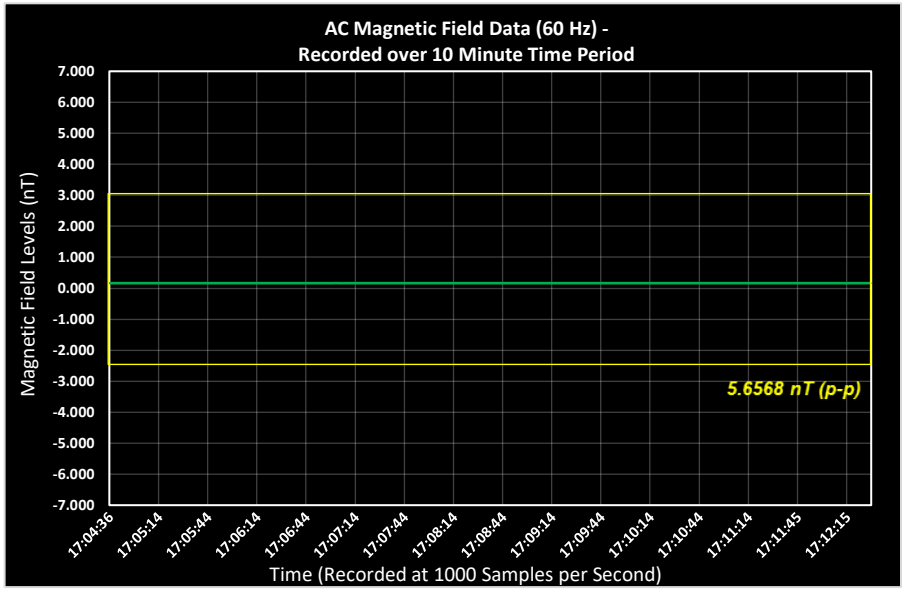
X-Axis (Horizontal)

Magnetic Field Levels	
Minimum	0.288
Maximum	0.359
Total Delta	0.071

Specification:

5.6568 nT (p-p) - 2.0 nT (RMS)

0.057 mG (p-p) - 0.02 mG (RMS)

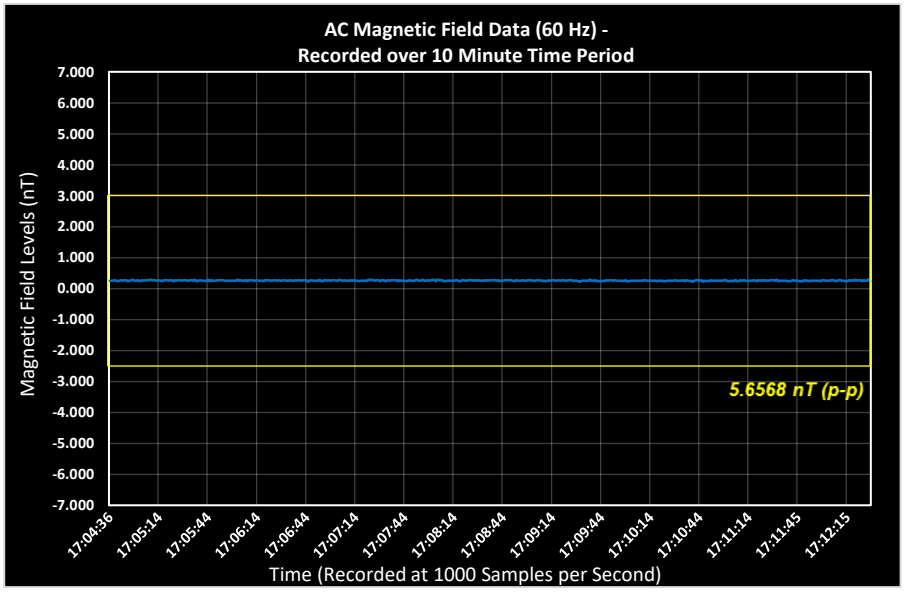


Y-Axis (Horizontal)

Magnetic Field Levels	
Minimum	0.156
Maximum	0.168
Total Delta	0.012

nT to mG Conversion

10 nT = 0.1 mG



Z-Axis (Vertical)

Magnetic Field Levels	
Minimum	0.226
Maximum	0.293
Total Delta	0.068

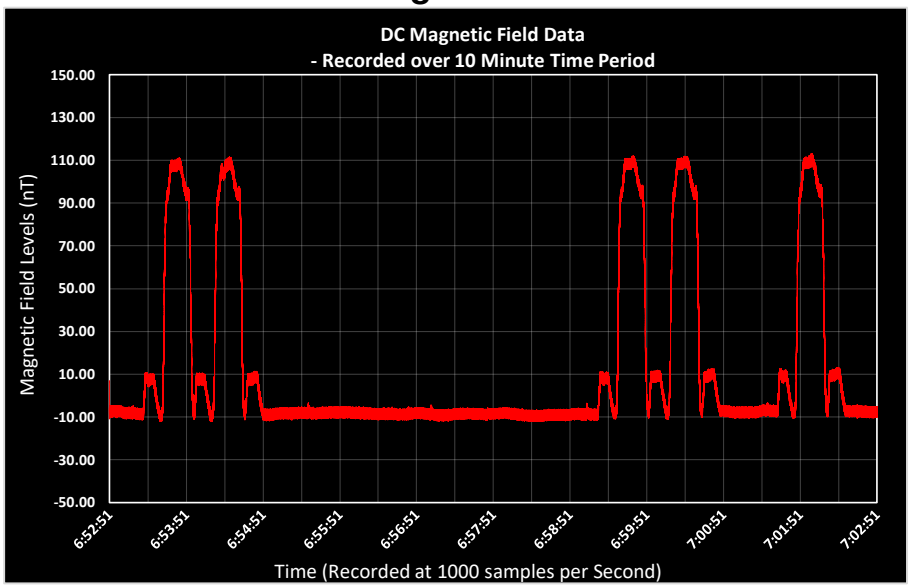
AC (60 Hz) Magnetic Field Strength Levels - Data Recorded @ 1-Meter A.F.F.

University of California - Irvine
CTEM - STEM 1
EMI Analysis - DC Magnetic Field Strength
Data Recorded @ Outside Room (Hallway)

Date Recorded: 5/12/2017

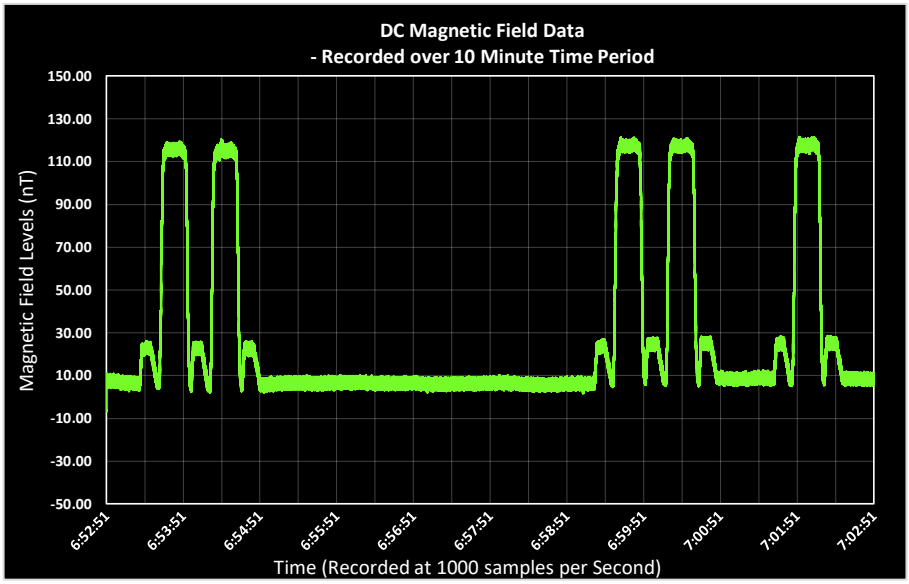
Probe 2 - Hallway
Active Compensation System: **On**
Ambient Background w/Elevators Running

Figure 3A



X-Axis (Horizontal)

Magnetic Field Levels	
Minimum	-12.18
Maximum	113.13
Total Delta (P-P)	125.31

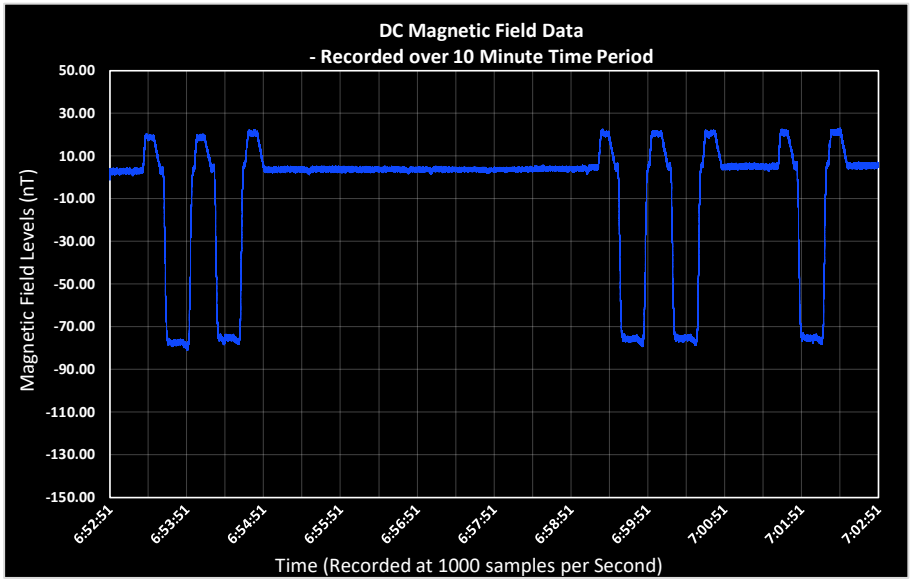


Y-Axis (Horizontal)

Magnetic Field Levels	
Minimum	-6.89
Maximum	121.65
Total Delta (P-P)	128.54

Unit Conversion

10 nT = 0.1 mG



Z-Axis (Vertical)

Magnetic Field Levels	
Minimum	-80.99
Maximum	23.04
Total Delta (P-P)	104.04

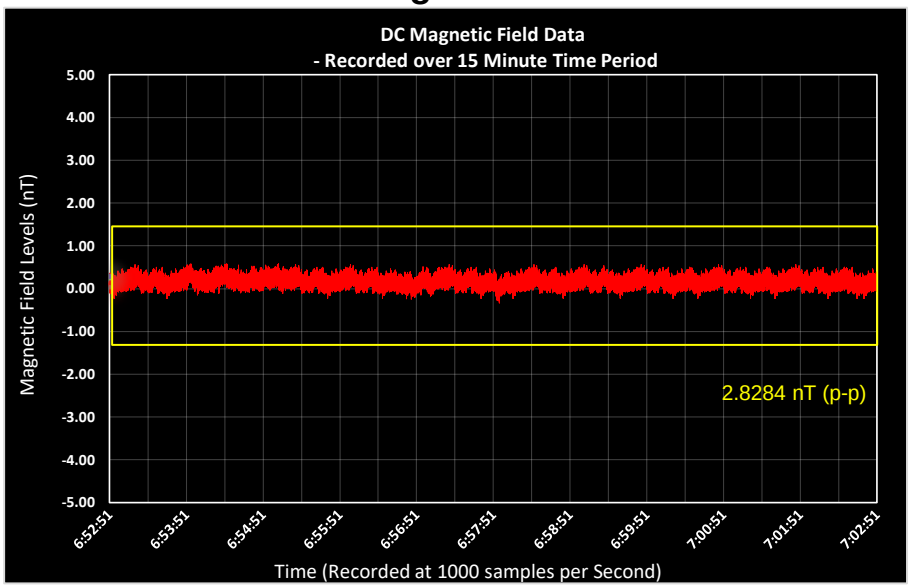
FMS
Field Management Services Corp.
New York - Los Angeles

University of California - Irvine
CTEM - STEM 1
EMI Analysis - DC Magnetic Field Strength
Data Recorded @ Location of ACS Probe

Date Recorded: 05/12/2017

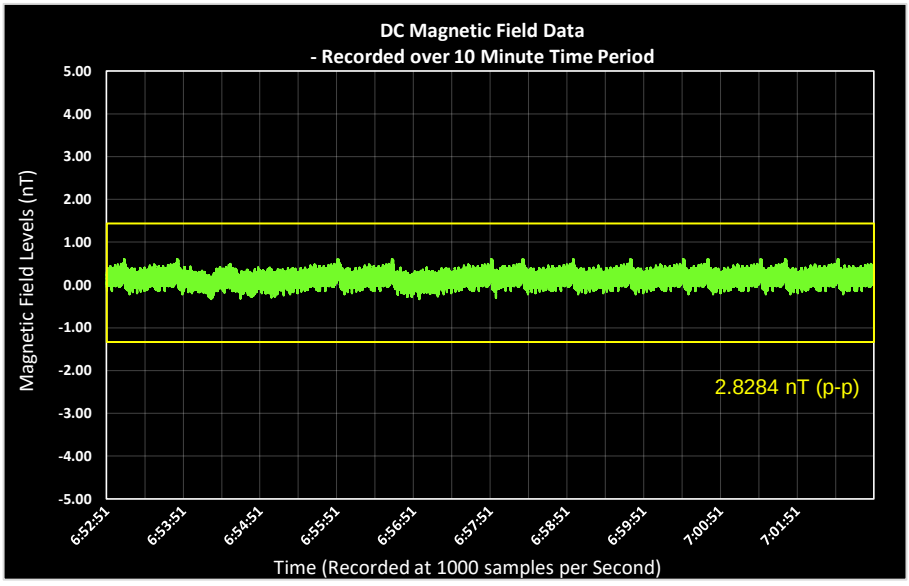
Probe 1
Active Compensation System: **On**
Ambient Background w/Elevators Running

Figure 3B



X-Axis (Horizontal)

Magnetic Field Levels	
Minimum	-0.33
Maximum	0.58
Total Delta (P-P)	0.91

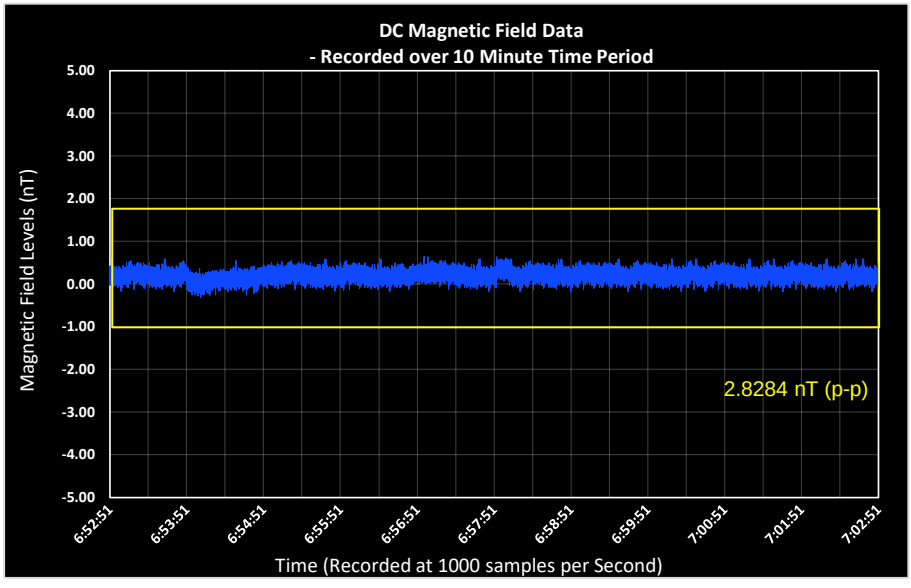


Y-Axis (Horizontal)

Magnetic Field Levels	
Minimum	-0.33
Maximum	0.60
Total Delta (P-P)	0.93

Unit Conversion

10 nT = 0.1 mG



Z-Axis (Vertical)

Magnetic Field Levels	
Minimum	-0.32
Maximum	0.64
Total Delta (P-P)	0.96

FMS
Field Management Services Corp.
New York - Los Angeles