A COMPARISON OF ACTIVE COMPENSATION SYSTEMS: STEFAN MAYER INSTRUMENTS FAST MR-3 VS. COMPETITOR

J. P. Heindel
Vitatech Electromagnetics LLC
115 Juliad Court, Suite 105
Fredericksburg, VA 22406

ABSTRACT

This paper examines the effectiveness of the Stefan Mayer Instruments (SMI) active compensation systems (ACS) FAST MR-3 to mitigate external source of magnetic interference in an urbanized environment. The main source of magnetic interference is a DC powered traction system for an underground commuter train network.

INTRODUCTION

There is a multitude of active compensation systems (ACS) currently offered by a handful of manufactures. These ACS attempt to mitigate magnetic interference by measuring the local magnetic field via sensor(s), processing the information, and driving/powering sets of Helmholtz coils. The methods, in which the magnetic interference is measured and the counter field is generated, differ by manufacturer and model of ACS. These differences include the use of fluxgate magnetometers, coil magnetometers, or a combination of both types of magnetometers. Certain manufacturers will utilize a current amplifier rather than a voltage amplifier for additional performance. When installing the ACS Helmholtz coils, coils can be placed: around the perimeter of the room, in a hatch or pound sign configuration, or inside a tool cabinet. Two different manufacturers' units were demonstrated at a university in New York City. The purpose of the demonstration was to compare the effectiveness of the Stefan Mayer Instruments (SMI) FAST MR-3 active compensation system (ACS) to a leading competitor's ACS. The ACS are demonstrated in a cleanroom environment to mitigate the magnetic interference for an E-beam. Sources of magnetic interference include, but are not limited to, building AC 60-Hertz power, DC-traction systems for underground commuter train system, elevators, vehicle traffic on local roads, and adjacent equipment. Four 3-axis fluxgate magnetometers (3 Sensys FGM3D 4k Special Low Noise and 1 Bartington Mag-03MCT100) provided the 12 magnetic flux density data channels. Each channel was simultaneously recorded with an OROS OR36 16-channel signal analyzer at a sample rate of 10,240 samples per second.

SITE CONDITIONS: EMI

Electromagnetic interference (EMI) can consist of various frequencies and is comprised of a magnetic and an electrostatic field component. This comparison focuses on magnetic interference and is limited to frequencies between 0.01 to 4,000 Hertz. The predominant source of magnetic interference for this site is a third-rail DC-traction system for an underground commuter system (i.e. New York City subway). Each fluxgate magnetometer samples the local magnetic environment in three (3) orthogonal component axes, B_X, B_Y, and B_Z. The resultant value B_R is calculated using Equation 1:

$$B_R = \sqrt{{B_X}^2 + {B_Y}^2 + {B_Z}^2}$$

Using the resultant B_R, accounts for the overall electromagnetic interference measured and limits data differences between sensors by reducing the impact of sensor position or misalignment. Figure

1 presents the resultant B_R magnetic interference recorded:

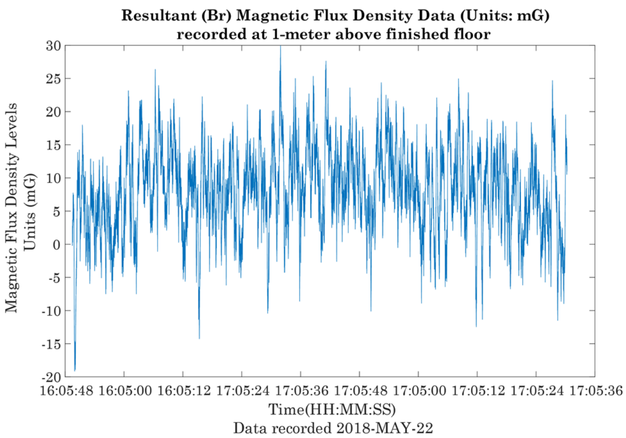

Figure 1: Resultant BR for Reference sensor #1, magnetic flux density levels recorded outside the active compensated volume at an elevation of 1-meter in units of mG

The magnetic flux density data was recorded during the afternoon of May 22nd, 2018 from 16:05 and 17:05 when the underground DC powered commuter train system reached increased levels of demand. The peak to peak (i.e. max – min) value was calculated for 350 9.77-second windows to facilitate the comparison between the reference data collected outside the compensated volume (i.e. reference sensor #1). Figure 2 presents the recorded magnetic flux density levels in peak-to-peak format.

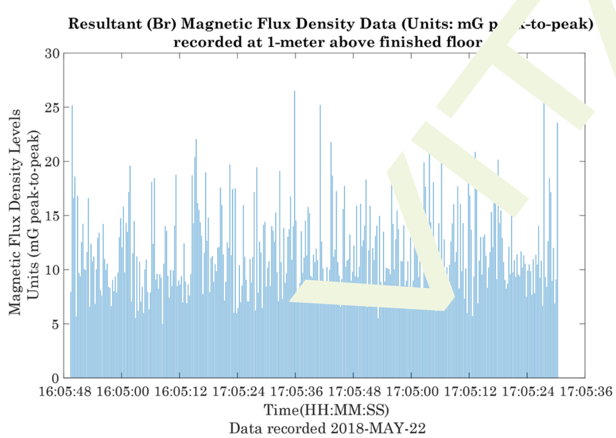

Figure 2: Resultant B_R, for Reference Sensor #1, magnetic flux density data recorded outside compensated volume at an elevation of 1-meter above the floor in units of mG peak-to-peak

This plot illustrates that the maximum change in any 9.77 second window is 26.52 mG $_{P\text{-}P}$. It was noted that some events lasted for longer than 9.77 seconds and had a maximum change of more than 40 mG $_{P\text{-}P}$.

ACTIVE COMPENSATION SYSTEMS

SMI FAST MR-3

The Stefan Mayer Instruments (SMI) FAST MR-3 is an active compensation system (ACS) with an overall bandwidth of 0.01 to 10,000 Hertz sampled by two (2) sensors, one (1) fluxgate magnetometer and one (1) coil-magnetometer. The control unit captures magnetic information via the two (2) sensors, adjusts the phase of the interference signal, and drives the Helmholtz coils with the compensation signal. The current driven through the Helmholtz coils creates an opposing magnetic field to offset the magnetic interference. The SMI FAST MR-3's dual sensors provide the ability to place each sensor in its ideal position to limit the interaction between the ACS and the tool's equipment. This in combination with the three (3) operational compensation modes (DC Only, AC + DC, and AC – Only) gives the SMI FAST MR-3 a distinct advantage.

For this demonstration, the Helmholtz coils driven by the SMI FAST MR-3 were mounted inside a hollow-carbon-fiber-tube frame. The Helmholtz-coils are pairs of multiturn wire cables arranged in three (3) component axes. The X coil pair is aligned in a North/South orientation, the Y coil pair is aligned in an East/West orientation, and the Z coil pair are in a vertical orientation. The fluxgate, coil, and external reference magnetometers were placed in the isocenter of the compensated volume. The X and Y axis Helmholtz pairs are comprised of two (2) three (3) conductor loops with a width of four (4) feet, a height of eight (8) feet, and separated by four (4) feet. The Z axis Helmholtz pair is comprised of two (2) six (6) conductor loops with a width of four (4) feet, and length of four (4) feet and a separation of four (4) feet. Image 1 illustrates the Helmholtz coil configuration.

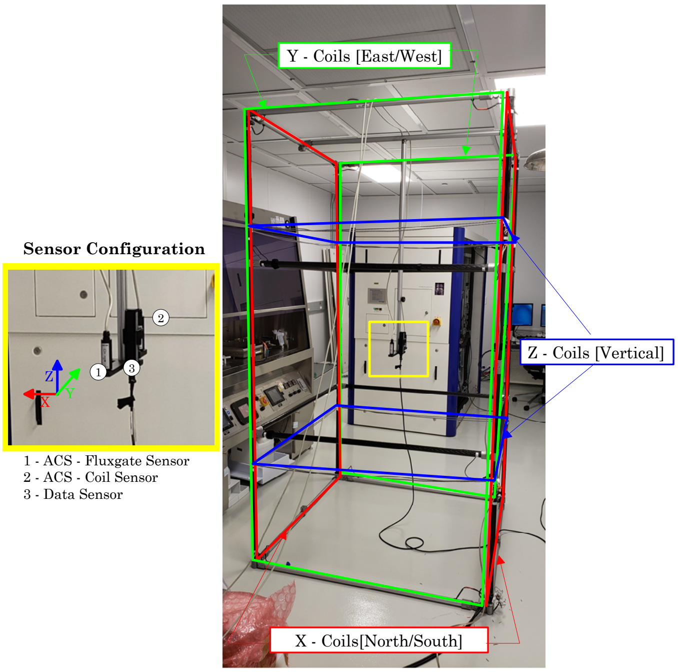

Image 1: Stefan Mayer Instruments FAST MR-3 Helmholtz coil configuration and sensor placement

Magnetic flux density data was recorded inside the ACS Helmholtz coil volume with the SMI FAST MR-3 cycled ON and OFF to verify performance of the system. Figure 3 presents the magnetic flux density data recorded inside the SMI FAST MR-3 compensated volume.

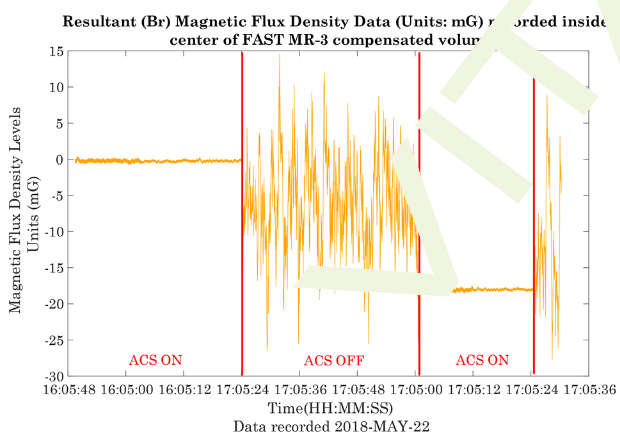

Figure 3 : Magnetic flux density levels recorded at the iso-center of SMI Helmholtz compensated volume in units of mG

With the SMI FAST MR-3 operational, the resultant magnetic flux density levels were reduced to 0.6 mG $_{P-P}$ for interference with 0.01 to 4,000 Hertz. The SMI FAST MR-3 was cycled ON and OFF to verify performance of the ACS and to verify that the electromagnetic interference is consistent between the reference sensor and sensor inside the SMI compensated volume. Peak-to-Peak values for the SMI FAST MR-3 magnetic flux density data were also calculated for comparison to the reference levels. Figure 4 presents the magnetic flux density data inside the SMI FAST MR-3 compensated volume.

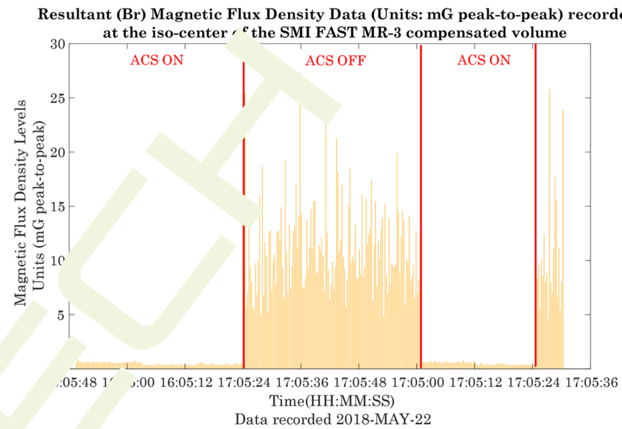

Figure 4 : Magnetic density levels recorded at the iso-center of SMI Helmholtz compensated volume in units of mG peak-to-peak

This plot illustrates the maximum change in any 9.77 second window with the ACS ON or OFF. With the SMI FAST MR-3 mitigating the magnetic fields, the maximum magnetic flux density level is 0.6 mG $_{P-P}$ and, comparable to the reference sensor, the maximum magnetic flux density level without the ACS is 27.28 mG $_{P-P}$. The attenuation of the magnetic interference is represented in units of decibels (dB). Decibels are on a base ten logarithmic scale and a calculated by multiplying 20 by the base 10 log of the magnetic flux density levels inside the compensated volume ($B_{R\text{-}smi}$) by the magnetic flux density levels outside the compensated volume ($B_{R\text{-}ref}$) shown in Equation 2:

$$dB = 20\log_{10}\left(\frac{B_{R-smi}}{B_{R-ref}}\right)$$

Figure 5 presents the attenuation of the magnetic interference in dB:

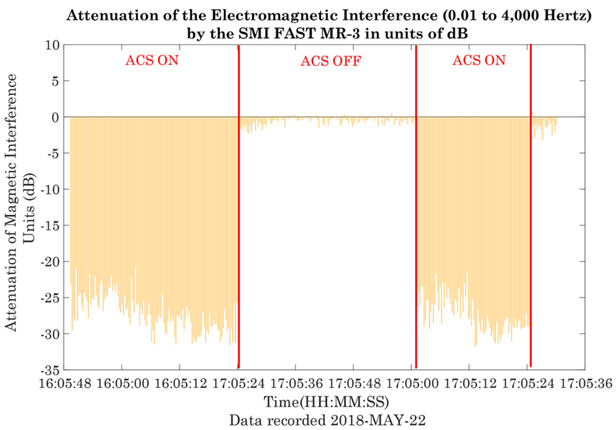

Figure 5 : Calculated attenuation of electromagnetic interference (0.01 to 4,000 Hertz) when mitigated with a SMI FAST MR-3 ACS

The SMI FAST MR-3 provides a maximum resultant attenuation of magnetic interference from 0.01 to 4,000 Hertz of -31.5 dB, or a reduction of the electromagnetic interference by 37.58 times. The performance is less than expected due local (i.e. within 10 to 15 feet) high gradient alternating current (AC) sources.

The full bandwidth (0 to 4,000 Hertz) magnetic flux density data was filtered into quasi-static DC (0 to 10 Hertz) and AC ELF (10 to 4,000 Hertz) to determine if the AC sources were in fact reducing the maximum calculated attenuation of the SMI FAST MR-3. The quasi-static DC and AC ELF data was processed in a similar way as the full bandwidth magnetic flux density data. Figure 6 presents the quasi-static DC attenuation provided by the SMI FAST MR-3 ACS.

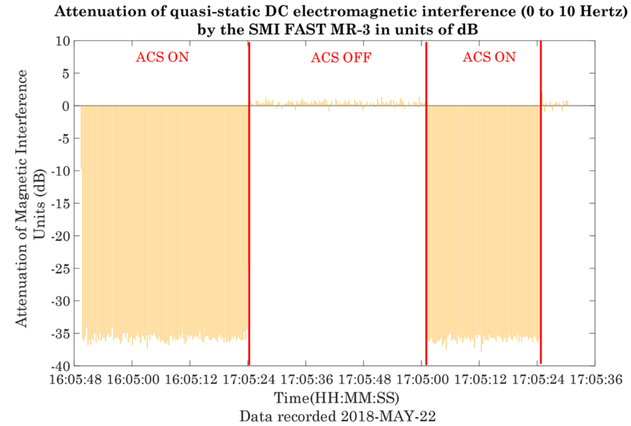

Figure 6 : Calculated attenuation of quasi-static electromagnetic interference (0 to 10 Hertz) when mitigated with a SMI FAST MR-3 ACS

The maximum attenuation provided by the SMI FAST MR-3 for quasi-static DC magnetic interference is -37.86 dB, or a reduction of the magnetic interference by 78.16 times. This is less than the maximum theoretical attenuation listed in the manufacture's literature of -55 dB or a magnetic field reduction of 562.34 times. Additionally Figure 7 presents the AC ELF attenuation of the SMI FAST MR-3 ACS.

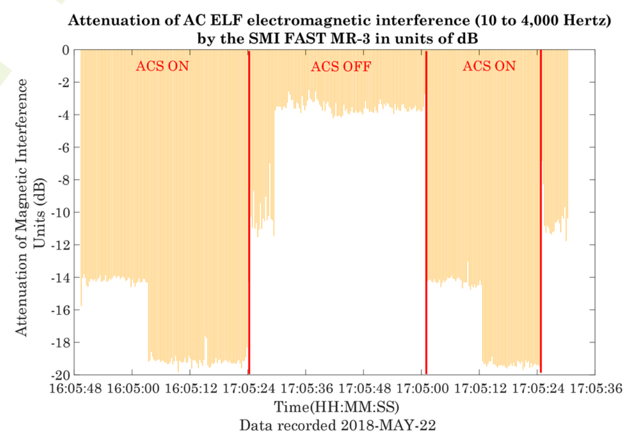

Figure 7 : Calculated attenuation of AC ELF electromagnetic interference (10 to 4,000 Hertz) when mitigated with a SMI FAST MR-3 ACS

The maximum attenuation provided by the SMI FAST MR-3 for AC ELF magnetic interference is -9.86 dB or a magnetic field reduction of 3.11 times. This is due to the high gradient nature and close proximity of the AC ELF sources to the SMI FAST MR-3 ACS.

COMPETITOR'S ACS

The competitor's active compensation system (ACS) was previously installed inside the E-Beam's equipment enclosure. The Helmholtz coils were comparable to that of the SMI but had more conductor turns (approximately six to twelve) for the coil windings. These additional turns increase the effective power of the Helmholtz coils but it can also increase AC noise feedback and result in uncontrolled oscillations of the system. Image 2 illustrates the competitors ACS coil configuration and sensor placement.

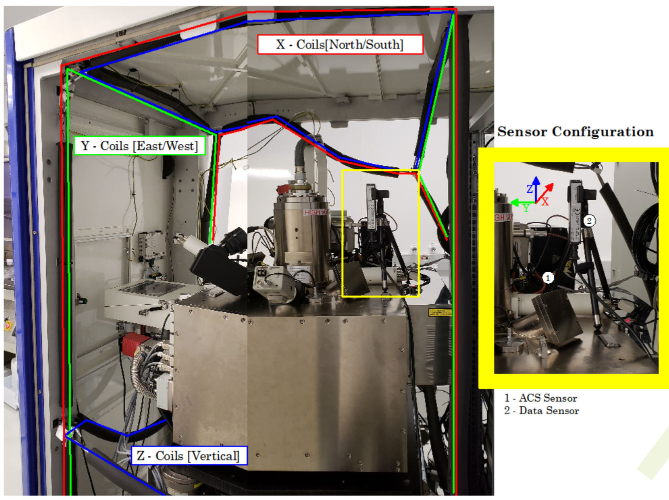

Image 2 : ACS competitor's Helmholtz coil configuration and sensor placement inside the E-beam enclosure

A Sensys FGM3D 4k Special Low Noise fluxgate magnetometer was placed inside the E-beam enclosure to recorded magnetic flux density data simultaneously with the reference sensor location. The competitor's ACS generated a significant level of AC ELF noise and increased the AC ELF (10 to 4,000 Hertz) magnetic flux density levels by 80 dB, or by 10,000 times. This could be due to the competitor's ACS attempting to compensate for local sources inside the E-beam's enclosure, an inadequately damped feedback loop inducing oscillations magnetic field output of the Helmholtz coils, or poor ACS sensor placement. Figure 8 presents the full bandwidth (0 to 4,000 Hertz) magnetic flux density levels inside the competitors ACS volume.

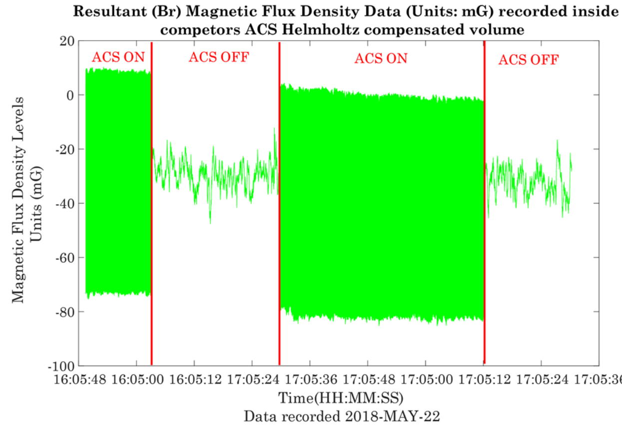

Figure 8 : Magnetic flux density levels recorded inside the competitor's AC Helmholtz coil volume in units of mG

The additional AC ELF noise seen when the ACS is operational prevents accurate full bandwidth (0.01 to 4,000 Hertz) attenuation values to be calculated. The AC ELF (10 to 4,000 Hertz) noise was filtered from the data to facilitate analysis of the quasi-static DC (0 to 10 Hertz) portion. Figure 9 presents the quasi-static DC (0 to 10 Hertz) portion of the competitor's data.

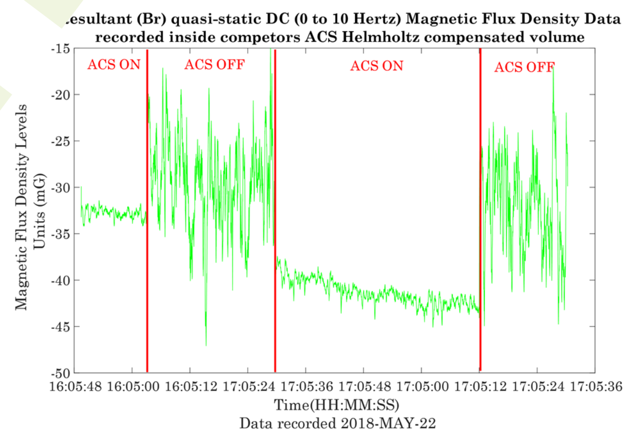

Figure 9 : Quasi-static DC (0 to 10 Hertz) magnetic flux density levels recorded inside the competitor's AC Helmholtz coil volume in units of mG

With the AC ELF (10 to 4,000 Hertz) portion of the magnetic flux density data removed, one can see the performance of the competitor's ACS. The source of the AC ELF noise is unknown. Additionally, the peak-to-peak values for a 9.77 second window were calculated. Figure 10 presents the calculated peak-to-peak values of magnetic flux density levels recorded inside the competitor's ACS Helmholtz coils.

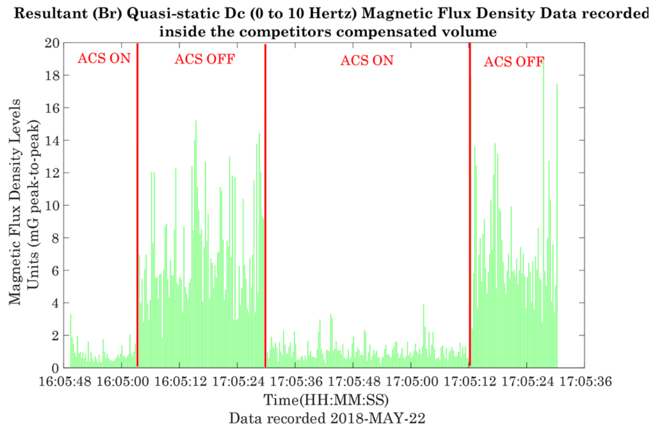

Figure 10 : Quasi-static DC (0 to 10 Hertz) Magnetic density levels recorded inside the competitors compensated volume in units of mG peak-to-peak

This plot illustrates the maximum change in any 9.77 second window with the ACS ON or OFF. With the competitor's ACS mitigating the magnetic fields (ACS ON and operational), the maximum magnetic flux density level recorded was 3.904 mG $_{P\text{-}P}$. Figure 11 presents the attenuation of the magnetic interference in units of dB.

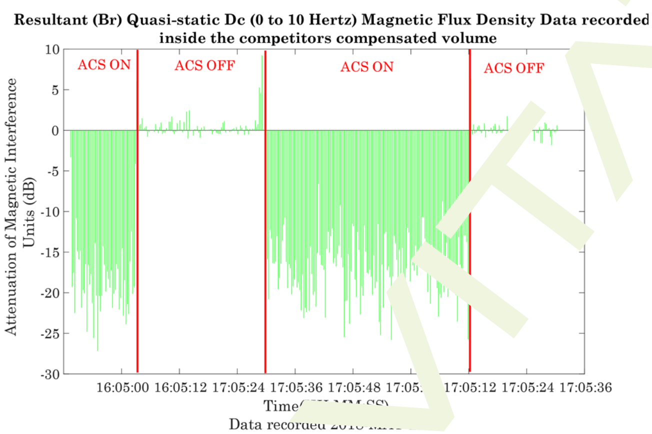

Figure 11 : Calculated attenuation of quasi-static electromagnetic interference (0 to 10 Hertz) when mitigated with a competitor's ACS

Note the overall magnetic flux density levels with the ACS OFF are lower inside the competitor's Helmholtz-coils due to the placement of Reference Sensor #1 and its separation from the sensor inside the competitor's compensated volume. The maximum attenuation provided by the competitor's ACS for quasi-static DC magnetic interference is -27.17 dB or a reduction of 22.83 times. This is far below the manufacture's listed typical attenuation of quasi-static DC (0 to 10 Hertz) magnetic fields of 40 to 50 dB or a field reduction of 100 to 300 times.

CONCLUSION

The Stefan Mayer Instruments (SMI) active compensation system (ACS) FAST MR-3 adequately attenuates the AC ELF and Quasi-static DC electromagnetic interference (EMI) to a greater degree than a leading competitor. The SMI FAST MR-3 attenuated quasi-static DC (0 to 10 Hertz) by -37.86 dB or a field reduction of 79.16 times. A leading competitor's ACS could only provide 2[illegible].21 % of the quasi-static DC (0 to 10 Hertz) EMI attenuation as the SMI FAST MR-3 ACS. The competitor's ACS increased the AC ELF (10 to 4,000 Hertz) magnetic flux density levels by 8[illegible] dB due to it measuring the EMI created by the E-Beam's support system. The SMI FAST MR-3 with its dual sensor configuration and three (3) operational modes can band limit the compensation signal and reduce this type of issue.