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Navigating the Selection of Magnetic Resonance Imaging Shielding Systems

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***Abstract*— All shielding technologies are not equal and consideration of a host of factors should be given when selecting shielding, including performance requirements (E-Field, H-Field, Plane Wave, etc.), the application, quality of products, long-term performance, materials used, and construction methods. This paper explores shielding systems utilized for magnetic resonance imaging (MRI). Construction methods, quality of product, performance implications with associated data, as well as the impact to project costs and future operating costs are discussed. When evaluating the RF shielding effectiveness for MRIs, the primary concern is the potential risk of deleterious impact to the performance of the MRI rather than human exposure. The scope of this paper addresses the evaluation of the RF shielding's impact on the performance of the MRI magnet.**

***Index Terms*—Electromagnetic Shielding, Magnetic Resonance, MRI Shielding, Radio Frequency Shielding, Shielding Effectiveness**

I. INTRODUCTION

Magnetic Resonance Imaging (MRI) continues to play a significant role in the treatment and diagnosis of patients as well as contributing to better patient outcomes. However, when designing and constructing a MRI room, the significance of Radio Frequency (RF) shielding can be overlooked or diminished in terms of its importance to the long-term operation and performance of the MRI magnet. RF shielding is often viewed as a necessary construction nuisance when procuring a MRI system despite shielding performance playing a critical role in the image quality produced by the magnet. The RF shielding should be viewed as an extension of the MRI system rather than simply a construction component. While some facilities do view the shielding as equipment, not all realize the potential impact to image quality, schedules, patient flow, patient treatment, and a host of other negative outcomes that could result from a shielding system that is not performing to specification. As a result, greater emphasis should be placed on the selection of the RF shielding system as it is critical to the functionality of a MRI magnet. The primary objective of this paper is to share application experiences regarding different shielding products and construction methodologies with the EMC community

There are several shielding systems available in the market place, all with advantages and disadvantages. The most common shielding systems utilized for MRI applications include modular shielding systems comprised of copper, galvanized or aluminum panels, and layup shielding or wallpaper shielding, which involves effectively wallpapering a wall and ceiling with copper or a material such as Flectron®, manufactured by Laird.

"Wallpaper" shielding system (left) vs. modular panel shielding system (right).

Some of the factors that should be considered when selecting a shielding system include:

- How robust is the shielding system?
- How well is performance maintained over time?
- What type of maintenance is required?
- If I plan to upgrade my MRI, will the shielding system upgrade with my magnet?
- What will shielding cost?
- What other costs are associated with accommodating or preparing for a specific shielding system?

These questions should be considered with the objective of:

- Maximizing the return on investment by maximizing long-term performance within the MRI OEM's frequency requirements of the MRI, which is typically 64 MHz to 150 MHz for 1.5T and 3.0T MRI, but are OEM and model

Take-Home Messages:

- While this article analyzes shielding systems for MRI applications, the concepts and considerations discussed apply to most RF shielding applications.
- Consider performance requirements, application, and construction method to maximize return on project investment.
- Construction method and material selection impact shielding durability and long-term performance.
- Performance in some shielding systems can degrade significantly over a short period of time.
- Shielding selection can have a significant impact on initial project and long-term operation costs.

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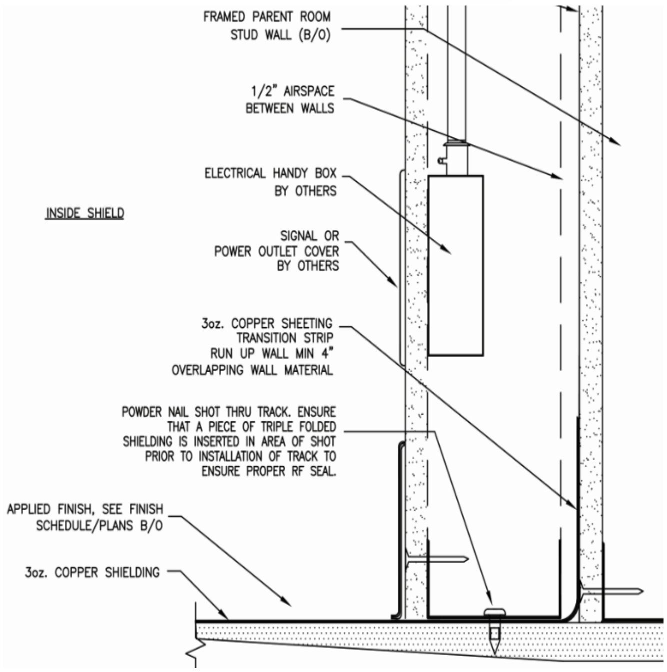

Fig. 1 Typical Wallpaper Type Shielding Floor and Wall Detail.

specific.

- Minimizing the potential for costly maintenance and repairs.
- Minimizing the potential that the shielding could be the cause of any MRI downtime and related costs.

II. Construction Methodologies and Considerations

Wallpaper style shielding systems are commonly mounted to the parent stud wall on a plywood or drywall substrate as noted in the accompanying detail, Figure 1. The shielding relies on the plywood or drywall to act as a dielectric barrier to electrically isolate the shielding, a common requirement of MRI shielding vendors and standard practice to ensure the quality and performance of the shielding. The shielding could experience multiple ground points if the substrate mounting screws are not sufficiently recessed into the mounting substrate or covered with an additional dielectric material to prevent multiple point grounding of the shielding. In addition to the effort required to avoid multiple ground points in the shield application itself, care must be taken when installing utilities and finishes on the walls, ceiling, and floor. It is imperative when mounting items on the interior and parent walls as well as the ceiling to avoid creating multiple ground points or penetrating the RF shielding which will lead to the potential for RF interference during imaging. Further, wallpaper type systems allow the mechanical attachment of studs and other items for interior finishes, plumbing, electrical, etc. directly to the shielding material. Initially, shielding integrity is maintained, but over time those connections degrade the integrity and attenuation of the shielding system.

When considering modular and wallpaper type shielding, there are several attributes of these different shielding systems that could impact the long-term quality of the image produced by the MRI magnet. Reviewing the typical construction of a copper panel system as noted in Figure 2, differences in shielding panel systems methodology provide additional assurances to maintaining image quality. Where wallpaper type shielding is mounted directly to the parent room, modular panel systems are offset from the parent room by a recommended 2" to maintain electrical or ground isolation. This provides an extra layer of security from accidentally creating multiple grounds or puncturing the room from the parent room side as any item penetrating the parent room will need to travel an additional 2" before coming in contact with the shielding. Similarly, on the interior room side, the shielded portion of a modular copper panel is set back 1-3/4", again, providing some additional distance between the interior wall face and the shielding. This limits the potential of inadvertently damaging the shielding when mounting items in the interior room. Modular systems allow the installation of mechanical utilities and interior finishes without puncturing the shield surface. This ensures long-term performance with stable shielding attenuation that will not degrade over time due to the installation of mechanicals and interior finishes.

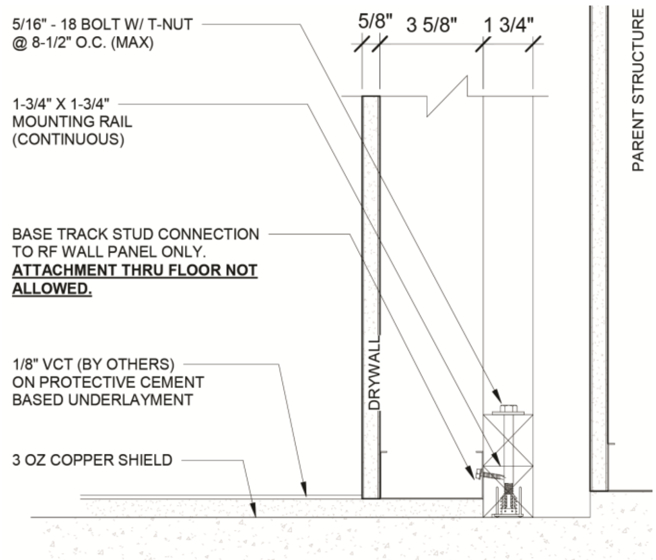

Fig. 2 Typical Copper Shielding Panel Floor and Wall Detail.

Another consideration are the costs of shielding systems. Shielding costs alone should not be the only consideration when selecting a shielding system, but rather the overall cost impact of a shielding system to the project and the long-term shielding performance. A wallpaper type shielding system requires a substrate shell be built to support the shielding, which includes walls and ceiling. The expense for installing the substrate is typically picked up by the general contractor, but is part of the overall construction cost. Modular systems are self-contained and installed within the parent room and do not require a subcontractor to provide ancillary construction elements similar to wallpaper type shielding systems. While a wallpaper type shielding system may initially appear to be less expensive than modular shielding, once the total project costs for supporting the shielding systems are considered, the overall cost of using a wallpaper type system is similar to or more costly than using a modular shielding system.

III. RF Shielding Performance

In addition to considering construction methodology, cost, and risk associated with these methodologies, long-term performance should be considered. All RF shielded rooms should be serviced periodically to help maintain performance. Specifically, doors need to be serviced as

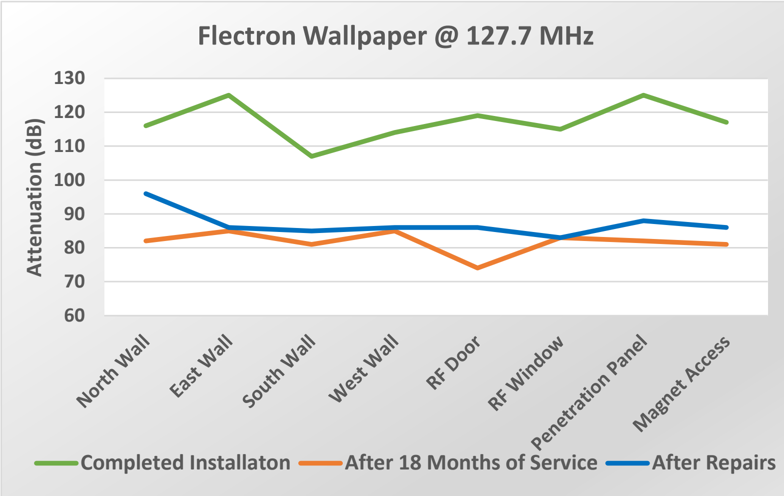

Fig. 3 Wallpaper Shielding System Tested per IEEE-299 Standard [1] at 127.7 MHz. [2], [3], [6]

one of the few moving parts on a RF shielded room. Doors are prone to degradation in performance over time due to wear and tear on the sealing mechanisms and buildup of substances on the door jamb that can reduce performance. However, the general shielding construction methodology plays a significant role in long-term performance. For example, wallpaper type systems that are mounted on a substrate utilizing glue and staples appear to degrade faster and more significantly than other systems utilizing mechanically fastened locking hardware. As an example, the graphs in Figures 3 and 4 display the measured performance at completion of installation and after 18-months of service of a wallpaper type MRI shielding system and a panelized mechanically fastened system located at a MRI OEM's southeastern United States manufacturing facility. The rooms both house MRI systems and are subject to the same environmental treatment, including the addition of interior finishes, elevated static magnetic fields due to the MRI, and air conditioning. Data was collected for both rooms in accordance with the IEEE-299[1] test method and utilizing the OEM's specified test frequency of 127.7 MHz.

As evident in Figure 3, the wallpaper type shielding experienced a dramatic reduction in performance greater than 45 dB in attenuation from the original commissioning measurements [2] over an 18-month period [3]. This results in the room performing well below the OEM's requirement of 100 dB placing the MRI magnet at risk of experiencing RF interference. Consider that the average life expectancy of an MRI magnet is five to 10 years and a wallpaper type shielding system has degraded by over 45 dB in 18-months. This would put the existing MRI system at risk of generating low quality images that could result in missed diagnoses, poor patient outcomes, and added costs for repeat imaging. From a MRI facility management perspective, the costs incurred from reduced patient throughput present additional financial concerns. This would also make it highly probable that the shielding will need to be replaced if the MRI system were upgraded or repaired sooner than forecasted to resolve existing imaging problems.

Alternatively, data is presented in Figure 4 of a copper panel shielding system utilizing mechanical fastening installed around the same time as the wallpaper type shielding system, in the same MRI OEM facility discussed above.

The copper panel shielding data indicates a modest decrease of 13 dB or less of attenuation over an 18-month period [4] from the original commissioning measurements [5]. Further, the copper panel shielded room performance remains above the minimum performance requirements of the MRI magnet OEM. The copper panels were fastened with t-nut assemblies limiting the potential for separation at the panel seams. Therefore, the decrease in performance largely appeared to be due to degradation at door seals, window seals, and other penetration seals.

As the performance of the wallpaper shielding was well below the performance requirements of the MRI magnet, attempts were made to repair the shielding to improve the performance. The repairs were limited to servicing the door, replacing RF gasket, and repairing a floor anchor [6]. The results of those repairs are presented in Figure 3.

While the repairs improved the performance of the shielding system slightly, it is apparent that the shielding performance has degraded overall, leaving the MRI magnet at risk of potential RF interference even after repairs and service. Some of the degradation was due to decreased performance at door seals and penetration seals, but this did not account for the entire reduction in performance. Further investigation indicated that the shielding degradation was likely also due to the fasteners through the shielding that were securing the interior finish studs. The fasteners were becoming loose over time due to minor movement of the interiors, leading to RF "leakage". To bring the room back to specification in order to ensure the MRI magnet would continue to operate properly would require the removal of interior finishes to repair or replace the shielding. This would result in significant downtime for the MRI facility, impacting revenue and would drastically increase the costs associated with repair.

It should be noted that MRI systems are sensitive receivers and highly susceptible to external Radio Frequency Interference (RFI), specifically RFI that falls within the passband of the magnet. The radio frequency (RF) transmit coils do not produce high levels of RF that represent an exposure risk to individuals outside of the MRI suite. Therefore, when

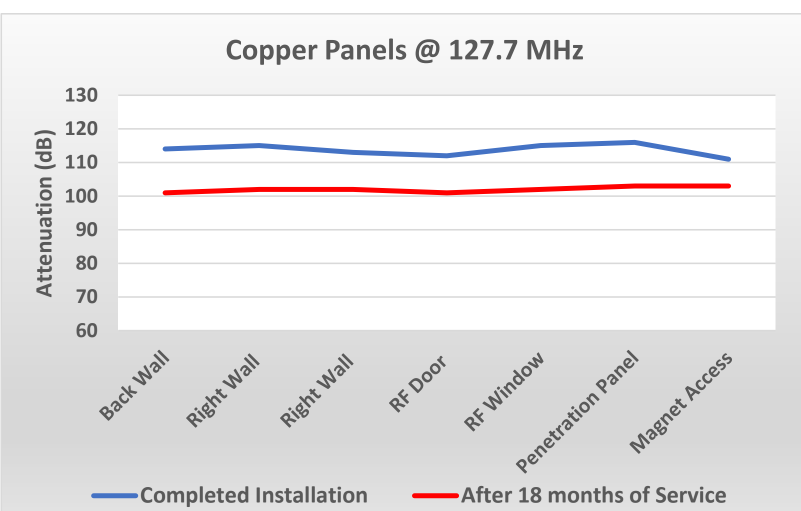

Fig. 4 Copper Panel Shielding System Tested per IEEE-299 Standard at 127.7 M [4], [5]

evaluating shielding effectiveness for MRIs, the primary concern is the potential risk of deleterious impact to the MRI rather than to limiting exposure risks to individuals outside the MRI as addressed in standards such as International Commission on Non-Ionizing Radiation Protection (ICNIRP)[7] or FCC[8] guidelines.

IV. Conclusion

Shielding systems are critical to MRI equipment performance, image quality, and patient outcomes. As noted, some shielding systems may be more prone to damage due to facility activities that would require the penetration of facility walls or ceiling. Further, data indicates that some shielding systems may provide better long-term performance that offer other benefits. For example, a shielding system that has better long-term performance could reduce MRI maintenance and upgrade costs as the shielding can be reused, reducing construction cost. Alternatively, a shielding system that degrades significantly over the long-term can significantly increase construction costs if the shielding needs to be replaced, resulting in additional construction costs including the replacement of finishes. Further, a shielding system that degrades quickly puts the equipment at risk of RFI, which impacts the equipment's performance. Given the role that RF shielding plays in MRI image quality, patient throughput, patient outcomes, and facility revenue, careful consideration should be given to the type of shielding deployed to maximize long-term performance, minimize downtime, and minimize future upgrade costs.

Acknowledgment

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[8] FCC OET Bulletin 65 - Evaluating Compliance with FCC Guidelines for Human Exposure to Radiofrequency Electromagnetic Fields

All reports are available upon request by contacting the author.

Biography:

Joel Kellogg
Joel is the Director of Business Development for Healthcare, Industry, and Government at ETS-Lindgren with over 20 years of design, production, and management experience for healthcare, government and industrial projects. Joel's experience includes the development of electromagnetic interference (EMI) active cancellation systems for the reduction of EMI to MRIs and electron microscopy systems, the development of data acquisition systems for the measurement of EMI, vibrations, and acoustics, and the development of shielding products. Joel is also knowledgeable in many areas of site planning and design for radiology, laboratory, and industrial equipment including EMI, radio frequency (RF), and radiation shielding along with other environmental aspects including vibration and acoustic requirements. Throughout his career, Joel has completed design and construction documents for numerous facilities including the radiology department expansions for the VA Palo Alto Hospital, OSU Cancer Center, the New Stanford Hospital, NNSA, Johns Hopkins Material Characterization Facility, and NASA Communications Facility. Currently, Joel's focus is advancing the shielding technology of products and services for Healthcare, Industrial, and Government customers along with driving shielding product roadmaps for ETS-Lindgren. Joel received his Master's in Business Administration (MBA) from the Keller Graduate School of Management in 2007 and his Bachelor of Science, Electrical Engineering (BSEE) from the University of Wisconsin – Madison in 1998.