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## Low frequency magnetic shielding: Nanocrystalline coating vs. ferromagnetic foils.

**Nanovate™-EM is an innovative direct coating technique proven to be a “value-add” alternative to conventional foils.**

Magnetic Shield Corporation, Bensenville, IL USA

Since 1941, Magnetic Shield Corporation has been a leading supplier of low frequency magnetic shielding and a leading source for technical solutions and rapid prototyping. For decades, engineers, designers, scientists, and researchers have relied upon Magnetic Shield Corporation's expertise, raw materials and fabrication methods to bring their products, systems, facilities and equipment into compliance.

Until recently, Magnetic Shield Corporation's proprietary ferromagnetic alloys MuMetal®, Co-Netic® and Netic® have proven to be the most effective materials. Now, Magnetic Shield Corporation, as exclusive representative, offers a new low frequency EMI coating, Nanovate™-EM.

### AVAILABLE MATERIALS:

With recent advancements in nano-technology, Nanovate™-EM has emerged into the market. An innovative nanocrystalline coating is now available to address today's challenges as parts and assemblies become more sophisticated. Nanovate™-EM can be directly applied to complex shaped polymers, composites and metals, and possesses the magnetic permeability desired for effective shielding of low frequency electromagnetic interference.

Many of today's electrically sensitive devices require protection from low frequency electromagnetic interference (EMI), thus require shielding from sources of electromagnetic radiation. Magnetic fields can be measured near components or circuits when electrical noise is emitted from alternating current (AC) or direct current (DC) sources such as switches, circuits, wiring, motors, batteries, power supplies, and transformers.

Shielding materials such as Nanovate™-EM, MuMetal® and Co-Netic® have high magnetic permeability and can protect sensitive devices from surrounding magnetic fields by redirecting the field through the shielding material and away from the critical device. Shielding at or around the critical device is common practice and usually less costly. However, in the same fashion, power sources that emit low frequency electromagnetic fields can play havoc on several devices at one time, or create an environment that is unstable for multiple devices. Isolation at the source may be desirable, but typically requires more shielding, at higher costs. While ferromagnetic alloys are cost effective in shielding either the source or critical device, Nanovate™-EM coating is most practical for shielding

the affected device since it will be smaller, more complex in shape, and contain existing components that are easily coated.

### MATERIAL SELECTION:

After measuring field strength at the source and the critical device, a desired resulting field must be determined, and a suitable shielding material selected. Selection of a shielding material is based on its magnetic permeability, or the ability of the shielding material to absorb the magnetic field. Additionally, each material has a magnetic saturation level, which determines the magnetic field strength that can be effectively shielded.

In strong fields, a magnetic shield can become “full” after which it will no longer provide effective shielding. Many materials chosen for high magnetic intensity applications have good saturation, but higher saturation often comes with a sacrifice in terms of the absolute permeability that can be achieved.

Determination of shielding material thickness becomes relevant as thickness correlates to performance. For evaluating shield thickness it is best to rapid-prototype with stock materials, which are generally available in thickness of .002”, .004”, .006” and .010”. For advanced prototyping

and validation, Nanovate™-EM can be applied at similar thicknesses, and will yield similar performance results. In cases where thicker shielding materials are required, ferromagnetic sheet and bar are available for fabrication or machining. For purposes of this article, we will compare the use of our traditional ferromagnetic foils (thin-gauge) and Nanovate™-EM coating.

**PROTOTYPING:**

For rapid prototyping and thickness determination, Magnetic Shield Corporation’s Lab-Kit is used to create hands-on samples. Wrapping existing parts is a cost effective way of determining thickness for a shield, even if Nanovate™-EM coating will be used in the final developmental samples. In cases where a physical shield needs to be created (no existence of useable surfaces for coating), a ferromagnetic foil shield can be made quickly. Where space is limited and geometries are complex, components can be quickly coated with Nanovate™-EM. Due to part complexity (holes, radii, and three-dimensional shape) Nanovate™-EM will encapsulate the part surface more exacting and may result in better performance. Typically, closed shapes are most efficient for magnetic shielding. Using our Lab-Kit is helpful to establish shape and thickness of shield design – even in cases where Nanovate™-EM is desired in the final product.

In many cases of product development, actual electromagnetic interference is unknown until prototypes are tested. Shield calculation formulas do exist, but they are

usually valid only for theoretical conditions of closed shield shapes and well defined interfering fields. Prototyping allows you to immediately see the effect of the shield. In some cases, the problem is not evident until later in the product development cycle; after components are selected, and tooling is complete. Nanovate™-EM coating has been successful in these instances. To add a metal shield requires physical space, more parts, and additional assembly steps. Nanovate™-EM can be directly applied to existing surfaces at minimal thickness. Of course, analyzing EMI early on in the design phase of a project or program will help save time and costs.

**COST CONSIDERATIONS:**

After developing the physical construction through prototyping, cost analysis is considered. While it’s true that ferromagnetic foils are reasonably priced, forming and/or welding are typically necessary which can cause changes in material grain structure; and annealing is usually required after

fabrication. Also, in creating a metal shield, assembly labor, part count and added weight are factors. With Nanovate™-EM, no secondary processing is necessary if applied directly to existing parts, and assembly and inventory costs may be reduced.

**FABRICATED SHIELDS:**

In ferromagnetic foils, the magnetic shielding properties rely on maintaining a large crystal-line grain size of around 100 μm or more in the material. Since the materials have an equilibrium state grain size of around 1–10 μm, the large grain structure must be achieved through annealing the metal at high temperatures, often in a tightly controlled atmosphere to control impurities.

Although specialty foils are very effective EMI shields, they are best suited to shielding simply shaped parts. There are currently a few methods for creating parts with relatively simple geometries, described in Table 1.

Since sheet metal or foils are manufactured flat, the materials

Existing Shielding Solutions			
	Foil Lay up	Formed Foils	Metal components
			
Advantages	<ul style="list-style-type: none"> <li>• Excellent shielding properties</li> <li>• Effective for low volume applications and simply shaped parts</li> </ul>	<ul style="list-style-type: none"> <li>• Excellent shielding properties</li> <li>• Suitable for handling modest geometries</li> </ul>	<ul style="list-style-type: none"> <li>• Can be cost effective where weight is not an issue</li> </ul>
Drawbacks	<ul style="list-style-type: none"> <li>• Labor intensive = high cost</li> <li>• Sensitive - performance degrades quickly with deformation</li> </ul>	<ul style="list-style-type: none"> <li>• Requires heat treatment after forming to achieve shielding performance</li> <li>• Sensitive - performance degrades quickly with deformation</li> <li>• Integration onto part surface requires manual labor = higher cost</li> </ul>	<ul style="list-style-type: none"> <li>• Steel parts are very heavy</li> <li>• Al and Mg often do not have sufficient low frequency shielding</li> </ul>

Table 1. Existing shielding solutions.

can be cut to size and laid in or around the effective area (foil lay-up) onto flat surfaces to achieve the necessary part shielding.

Although this approach provides excellent shielding performance, this lay-up approach is a cumbersome method for shielding parts with any contour.

Ferromagnetic shielding materials can also be cut and formed to the shape required. For example, a sensitive transducer measuring a faint analog current might require a “can” of material over the device that will be integrated into the enclosure or onto the circuit board. This shape would need to be cut and stamped, or formed and welded, from the original flat foil. Although this adds cost to the shielding process, it is not, in itself, a particularly complex operation.

Unfortunately, stamping, forming and welding operations reduce the effectiveness of the shield by introducing deformation into the material—destroying the key material characteristic that generates the high permeability properties.

To restore a defect-free structure, the material must be annealed once more in a high temperature controlled environment to restore shielding effectiveness. This necessity presents a unique process step for customers, as the forming operation now has to be coupled with a secondary annealing operation, adding an additional step in the supply chain.

Apart from shielding efficacy, the forming step also sets a practical size limit as complex or small geometries are difficult to produce. As electronic structures become smaller and more complex, formed

metal shields may not be a viable alternative. Lastly, once the shield is cut, formed, and annealed, it still needs to be integrated into the assembly of the shielded part. This integration requires labor and often relies on adhesives or fasteners, further adding to the assembly cost and complexity.

Ferromagnetic alloys and other materials are also available for thick gauge stamping, casting, or machining, and can be used for low frequency EMI shielding. Often, this can be a very cost-effective method, but the additional weight can be problematic in some applications. In most of today’s applications, weight is critical, and steel components are being replaced with other light-weight

materials, such as aluminum, polymers or composites, that have little or no low frequency EMI shielding capability. These materials are often combined with a foil shield in assembly. With Nanovate™-EM the aluminum, polymer or composite part can be directly coated.

#### DIRECT PART COATING:

An alternative solution to traditional methods is to apply Nanovate™-EM, a high magnetic permeability, nanocrystalline grain structured, metal coating directly to the surface of a part (Figure 1). This process is easily adapted to small and complex shield shapes and avoids many of the possible drawbacks of a foil shield, including the elimination of annealing steps. Coating parts with conductive surfaces is often used for high frequency EMI shielding in electronics applications using techniques such as physical vapor deposition (PVD), conductive paints, and electro-less and electrolytic plating. In these cases, the primary requirement is a thin conductive coating. With recent developments in nanocrystalline ferromagnetic coatings, the same concept can now be used for low frequency EMI shielding.

In contrast to conventional shielding foils that derive magnetic properties from their large, un-deformed grain structure, Nanovate™-EM coating, with a very small (nanometer, in fact) grain structure, can also achieve high permeability, and therefore, providing similar magnetic shielding performance. Figure 2 illustrates the relationship between coercivity and grain size in

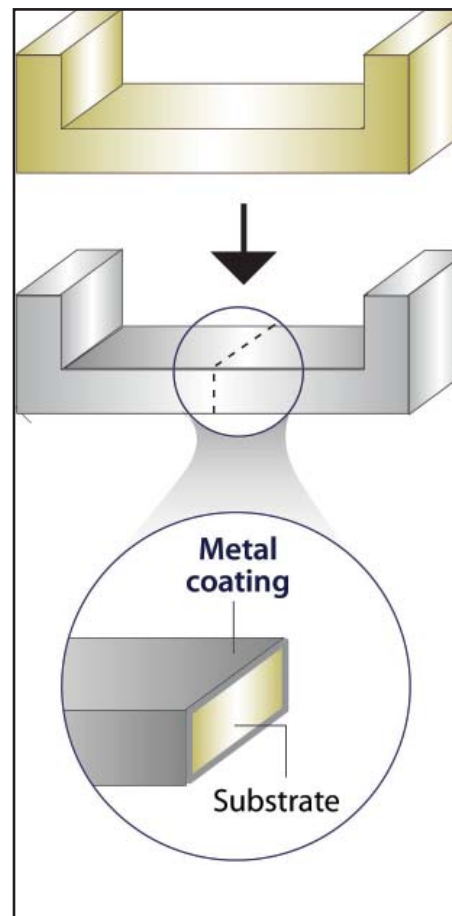


Figure 1. Direct application of Nanovate™-EM.

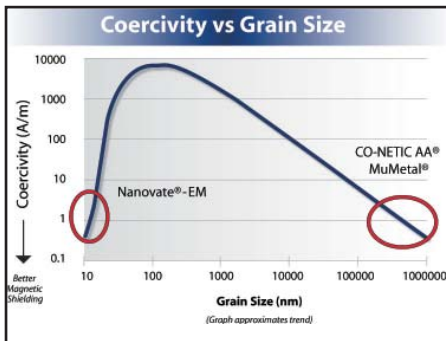


Figure 2. Coercivity vs grain size.

a ferromagnetic material. Typically magnetic shielding materials with low coercivity also possess high permeability. Therefore, as shown in the graph in Figure 2, when grain size of the material is reduced to the nanometer scale, coercivity is minimized and permeability is maximized. A similar effect also occurs with very large grain size as found in fully annealed ferromagnetic foils.

Although the magnetic shielding characteristics of Nanovate™-EM are qualitatively equal to Mu-Metal® and Co-Netic®, the real benefit lies in the processing and design flexibility that this material affords. This material is used most frequently as a coating deposited directly onto part substrates such as metals (e.g., aluminum enclosures), polymers (e.g., thermoplastic formed parts), and composites (e.g., carbon fiber epoxy structures).

Nanovate™-EM can be integrated directly into a part structure or assembly enclosure, a design option that reduces part count by eliminating a formed foil shield and related adhesives, hardware and labor. Selective coating is possible, allowing shielding performance that can be delivered where it is needed most and avoiding

unnecessary added weight. For injection-molded polymers in particular, monolithic part integration is now possible because the shielding function can be molded directly into the larger electronics enclosure or part cavity.

Secondary forming operations should not be necessary when using this coating, however, if Nanovate™-EM is exposed to forming or resizing, the grain size is unaltered, thus retaining shielding effectiveness and avoiding both a loss in performance and a re-annealing step. However, the long-term operating temperature of Nanovate™-EM must be kept under a threshold of approximately 400°F to avoid grain growth back to a larger crystalline equilibrium state.

As with any solution, this nano-coating approach has its own drawbacks. The coating process is a secondary operation that adds cost to the part. In addition, the thickness and distribution of nanocrystalline metal in a typical deposition process is influenced by part geometry, similar to painting or plating. Despite these factors, the application process is industrially scalable, and the metal coating approach is effective for applications in which metal shields are impractical at high volumes. An example of a finished part that benefits from direct part coating is shown in Figure 3, which depicts a complex aluminum machined housing that requires shielding. The application is weight sensitive and flatness is critical. Full surface bonding of foils to the flatness specification would be impractical due to uneven adhesion. Nanovate™-EM coating proved to be

the best alternative when applied at 50 microns thickness. Not only has the part performed well in EMI testing, the part also benefited from increased surface hardness and an aesthetically pleasing finish.

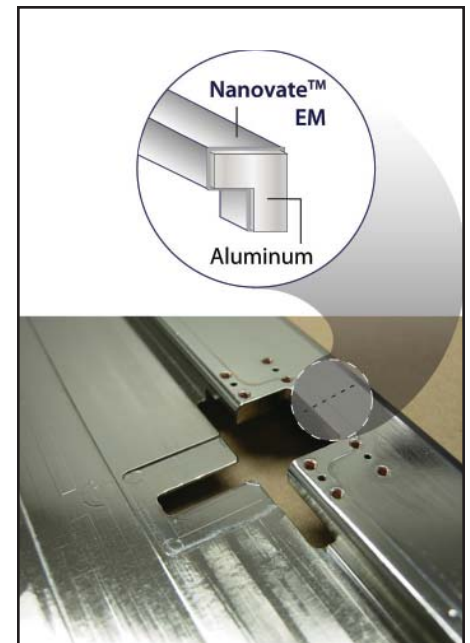


Figure 3. Machined aluminum housing.

Polymer parts can also benefit greatly from direct coating solutions (Figures 4 and 5). Figure 4 shows a polymer housing with the coating applied selectively to the critical and specific area. This selective application delivers shielding performance where it is required and eliminates unnecessary weight. Complex and integrated moldings may be coated as in Figure 5, a step that also provides additional stiffness, strength, and surface hardness to create multifunctional parts that may be lighter and thinner than die-cast parts. Coating a complex polymer housing with Nanovate™-EM will add stiffness and strength to the polymer part.

When part integrity is critical,

Nanovate™-EM acts structurally, as it has higher strength and hardness than coarse-grained equivalent materials such as MuMetal® and Co-Netic® (Table 2). While

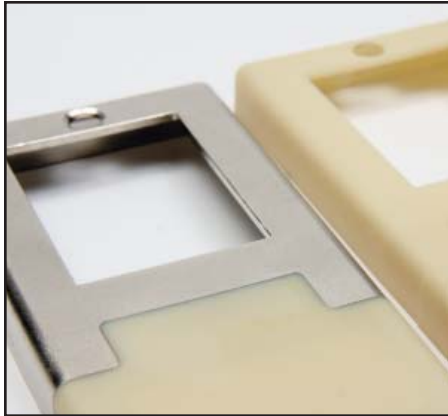


Figure 4. Direct application of Nanovate™-EM to complex shaped polymer.

all these materials are effective shields, Nanovate™-EM can be directly applied to polymer substrates, dramatically increasing strength and stiffness of the hybrid part. A relatively thin, lightweight, weak and flexible polymer enclosure can now become a rigid, durable structural part. The high yield strength and good ductil-

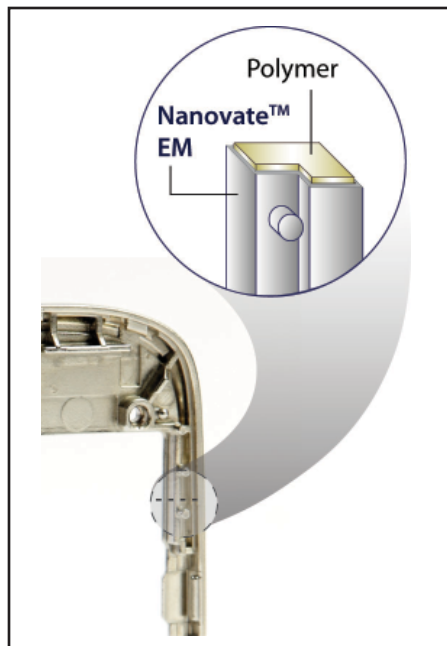


Figure 5. Complex and integrated moldings.

ity also make Nanovate™-EM particularly well suited for parts that often undergo a lot of flexing. Traditionally, high strength coatings are normally brittle, a situation that typically leads to failure at low loads.

Nanovate™-EM is considered fully dense due to its nano-structure—i.e., has no voids or porosity. Having a highly impermeable,

dense coating could be beneficial either for keeping liquids or gases from penetrating the surface of a part, as would be the case for protecting a polymer case from chemical attack, or for keeping the part from out-gassing into the environment—often a secondary consideration in semiconductor or space applications.

#### CONCLUSION:

While Co-Netic® and Mu-Metal® ferromagnetic foils are widely used materials for creating relatively simple geometries of effective electromagnetic shields, they are not amenable to certain complex geometries of today's part designs. Nanovate™-EM nanocrystalline coating offers an alternative solution for shielding, and provides other value-add benefits. Direct coating of metal, polymer, or composite parts can reduce assembly and part cost by simplifying the supply chain and assembly process. Nanovate™-EM now offers the possibility of creating small or complex shields that were previously impractical with foil shielding methods. Additional benefits are also realized in the nanocrystalline grain structure to strengthen, stiffen, render impermeable, or add durability to a polymeric part.

#### CONTACT INFORMATION:

For further information about Nanovate™-EM technology and its use, or guidance in shielding material selection, contact Mark D. Wickler, Chief Operating Officer of Magnetic Shield Corporation (630) 336-4100. Further information is available at [www.magnetic-shield.com](http://www.magnetic-shield.com).



	 Nanovate™-EM	 CO-NETIC AA® MuMetal®
<b>Material Application</b>	<ul style="list-style-type: none"> <li>• Foils (thick and thin)</li> <li>• Coating of polymers</li> <li>• Coating of composites</li> <li>• Coating of metals</li> </ul>	<ul style="list-style-type: none"> <li>• Foils</li> <li>• Stampings</li> </ul>
<b>Yield Strength</b>	• > 900 MPa	• ~340 MPa
<b>Hardness</b>	• > 500 VHN	• ~140 VHN
<b>Post Processing</b>	• None, as deposited	• Annealing needed after any deformation
<b>Effect of Deformation</b>	• Difficult to deform because of high Yield Strength	• Significant drop in magnetic properties when deformed

Table 2. Comparison of nanocrystalline coating vs. polycrystalline foil.