**ECE4871 – Culminating Design Project**

# Technical Review Paper Evaluation Form

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/ 30 Technical Content

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- Underlying technology
- Implementation of the technology
- Overall quality of the technical summary

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Magnetic Field Shielding

**Introduction:**

As technological advances in fabrication drive device footprints to shrink, attention has turned to a key limiting factor: preventing the propagation of rogue magnetic fields. Smaller devices and higher power levels can produce waves with adverse effects to product function, environmental safety, and human health. Traditionally, large sheets of iron or other alloys with high permeabilities have been proven effective in channeling the magnetic fields produced by high power applications, such as transformers, yet size and weight constraints can make this approach prohibitively cumbersome. This technical review presents both commercially available and state of the art means for blocking magnetic radiation, and explores potential methods of implementation with associated benefits of these diverse techniques.

**Commercial Means of Magnetic Shielding:**

To the best of human expectation, there is no material that can block magnetic fields; such behavior requires the presence of magnetic monopoles, which humanity's current body of science predicts to be impossible [1]. However, all materials possess an intrinsic property known as permeability that determines how easily a magnetic field propagates in the given space. Applications that produce large magnetic fields, such as motors, transformers, and power lines, commonly use large sheets of high permeability alloys to channel magnetic fields and limit outward propagation [2].

One company with a large market share in this industry is Magnetic Shield Corp, whose products include Co-NETIC-AA, NETIC S3-6, and MuMetal [2]. Co-NETIC-AA is one of their best performing alloys, with a base relative permeability of 30,000 that can rise to 450,000 depending on how it is treated during fabrication [3]. This compares favorably to iron, which has a relative permeability of 200,000, and popular iron alloys such as stainless steel, which is ~1000. For context, air has a permeability of roughly one.

On the other hand, Magnetic Shield Corp's most popular product is MuMetal [3]. MuMetal is estimated to be made up of Nickel, Iron, Copper, and Chromium/Molybdenum and has a permeability of only 100,000, but is sold cheaply at $1-10 for a small sheet of a couple inches [4]. Although this alloy is somewhat less permeable than iron, these seemingly exotic alloys enjoy better performance in physical properties, such as susceptibility to rust, flexibility, strength and more [3]. Although other companies



share this market space with Magnetic Shield Corp, each with a diverse array of products, this is as far as this paper is going to delve into shielding via use of alloys.

## Shielding via Induction of Eddy Current

Magnetic fields each propagate from a North Pole to a South Pole, a naming convention that persists from the original study of bar magnets. From introductory electromagnetics, the curl of the magnetic field is directly related to the current density enclosed in a loop of magnetism [5] (note, this paper only considers the original Ampere's Law and ignores Maxwell's addition to this law of the displacement current for the purpose of simplicity). In the case of a solenoid, the associated magnetic field runs through the ferrite core of the magnet and encloses many loops of wire, allowing for the generation of a larger magnetic field that is directly proportional to the number of wires enclosed in a loop of magnetic flux.

It is similarly known that a magnetic field is capable of inducing a loop of current around every line of magnetic flux [5]. These induced currents are referred to as eddy currents, and are induced by time changing magnetic fields. These sorts of eddy currents can be generated by allowing a magnetic field to propagate through a small loop of a highly conductive, low permeability material, such as aluminum [6]. When this happens, the eddy currents induce a new magnetic field around the loop of current that opposes the existing field in direction. This new magnetic field effectively blocks fields passing through the shielding material, and instead directs them around the shield [6], allowing for a different form of shielding. This sheet can be a mesh material with holes in the material to reduce weight, at the cost of shielding performance [6]. As the width of the holes increases from 0.5mm to 3mm, the induced magnetic field decreases most strongly around the center of the material, from 70μT to 10μT, while only experiencing a drop from 50μT to 35μT around the edge of the material [6]. Placing a mesh 2mm from a wire coil can still attenuate the field measured 2mm from the mesh from 250μT to 50μT.

It is important to note that this is a fundamentally different process to the idea of using a ferrous material to guide the field lines. In the practice of using a high permeability material for shielding, a piece of magnetic material directs the field through the shield and prevents further propagation, allowing for shielding of both time-invariant and time-variant fields [1]. In the technique of opposite field induction via eddy currents, a low permeability, high conductivity material is placed perpendicular to the magnetic field, inducing a new magnetic field to oppose the existing time-variant field [6].

## Active Shielding Techniques

The two previous techniques are described as passive shielding techniques, where no additional power is required to shield from rogue magnetic fields [7]. However, there is another shielding technique,



called active shielding, where compensatory coils and a control system induce opposite polarity magnetic fields to cancel the field strength at different points [7]. This technique can be challenging to implement, due to the need for extra power, controls systems, and additional hardware, and is also limited to lower/moderate frequency by the quality of the control system [8]. Despite these drawbacks, active shielding allows for some unique shielding methods and improved performance [8]. For example, active shielding is increasing in popularity in high power transmission lines, and has been demonstrated to attenuate the magnetic field produced by the lines to a level that is safe for the population [8]. In the Ukraine, these active shields have been demonstrated to have two to five times higher shielding efficiency than existing passive solutions [8].

**State-of-the-Art Passive Shielding**

The best performance, however, has been discovered in the study of a seemingly unrelated field: superconductors [7]. As their name implies, superconductors have very, very high conductivity, but are incredibly cost prohibitive due to their rarity and difficult operation environment at near 0K temperatures. Moreover, superconductors have a remarkable property known as the Meissner Effect, which states that as semiconductors reach a supercooled state, they produce their own magnetic field [7].

One type of superconductor shielding uses REBCO coils, or Rare-Earth-Ba-Cu-O, to shield the center of the coil from magnetic fields [7]. Research has demonstrated that such a technique can be incredibly effective, measuring 40dB of attenuation at the center of the coil from an incident low frequency, 10μT magnetic field [3]. These coils are not publicly available, and are currently cutting-edge technology, but have some very promising results and offer remarkable protection from magnetic fields.

**Implementation of Shielding Techniques**

The best way to shield depends on the application. For containing magnetic fields, the best way to shield is likely to use high permeability materials to guide the field and prevent further outward propagation. For blocking magnetic fields, the best option is likely to use highly conductive materials for the generation of eddy currents, and thus opposing magnetic fields, but this can only be used for time-variant fields. Superconductor coils, on the other hand, are currently an exciting area under study for how they can shield external magnetic fields at very low frequencies and with very high effectiveness.

If currently available passive shielding techniques are not precise enough for the user, it is possible to use active shielding technologies. These techniques can offer excellent attenuation, but can be difficult to design and resource intensive.



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