The State of Loudspeaker Magnetics (Introduction of Nitride-Iron magnets)

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Focus

The State of Loudspeaker Magnetics

By Mike Klasco (Menlo Scientific, Ltd.) and Salvador Magdaleno-Adame (Salvador Consultant)

The loudspeaker magnetics industry has enjoyed long stable runs interspersed every couple of decades by a tsunami. Before World War II, loudspeakers tapped the radio's power supply for their electromagnets. Aluminum-Nickel-Cobalt (AlNiCo) alloy permanent magnets were first used extensively for military applications during the war and became readily available after the war. While there are a couple of important magnet specifications for speakers, assuming you have these key parameters in the ballpark, then the key factor is the magnetic strength of the raw magnetic material measured in Mega Gauss Oersted (MGOe). AlNiCo magnets, at about 8 MGOe, dominated the loudspeaker market for decades, but then the cobalt supply chain needed for the alloy became unstable in the early 1970s, precipitating a shift to the widespread compromise of using ferrite magnets (known as ceramic ferrite magnets). Specifically, supply was affected by the political and military conflict at the cobalt mines, which were in the control of the "insurgent forces" in central Africa in the Congo (known as Zaire during that period), driving prices up and supply stability down.

Magnet Types

Ferrite magnets, often deprecatingly called "mud magnets," required huge magnetic structures just to come close to the sound that was more elegantly achieved by AlNiCo magnets. Woofers, compression drivers, and everything else got bulkier, heavier, and lost sensitivity. Ferrite magnets started at about 3 MGOe, and in 50 years have barely improved with the premium Y35 around 4.5 MGOe. DMEGC in China is by far the world's largest supplier of ferrite loudspeaker rings (having acquired the Indiana General magnet fabrication equipment and moved it to China), and Alliance is still the only magnet company stocking ferrite loudspeaker rings in the US.

In the mid-1980s, GM (Magnequench) and Sumitomo independently but simultaneously both began commercial production of NdFeB magnets (known as neodymium or neo magnets), a stupendous alloy of Neodymium (Nd), Iron (Fe), and Boron (B). With an initial energy of 25 MGOe, as impurities were reduced, both energy and corrosion resistance continued to improve for NdFeB magnets. Today, further refinements in formulation and mitigation of the losses incurred from trimming to net shape yield mid 30 MGOe as the commodity-grade, 42 MGOe as often used, and N55 MGOe as awesome for limited temperature applications. If ferrite is "mud," then neo is like caviar. It was first introduced in flagship compression drivers from JBL and EV (also EV's N/DYM dynamic mics). Neodymium (neo) created a whole new game, and in the 1990s, most speaker manufacturers started seriously evaluating the potential benefits of using neodymium magnets in loudspeakers.

Neodymium magnets have enabled lighter headphones, more compact compression drivers that can be more tightly arrayed, and make portable DJ speakers that do not cause hernias. Neodymium was a "gift from God" for ribbon speakers with much needed higher magnetic flux density in the air gap along with thinner bar magnets in front of the diaphragm resulting in better Qes, sensitivity, and extended and smoother top-end. Neodymium became even more enticing when pricing dropped as many Chinese vendors entered the supply chain.

In **Figure 1**, ferrite and neo loudspeakers produce the same magnetic field in the air gap and we can see the difference in the size of the magnets in both designs using different magnet materials. The magnet volume is small for the neo loudspeaker compared with the magnet volume for the ferrite loudspeaker.

China's Magnet Market

The $14 billion-a-year rare earth magnet market is more than 60% controlled by China. Under their "Made in China

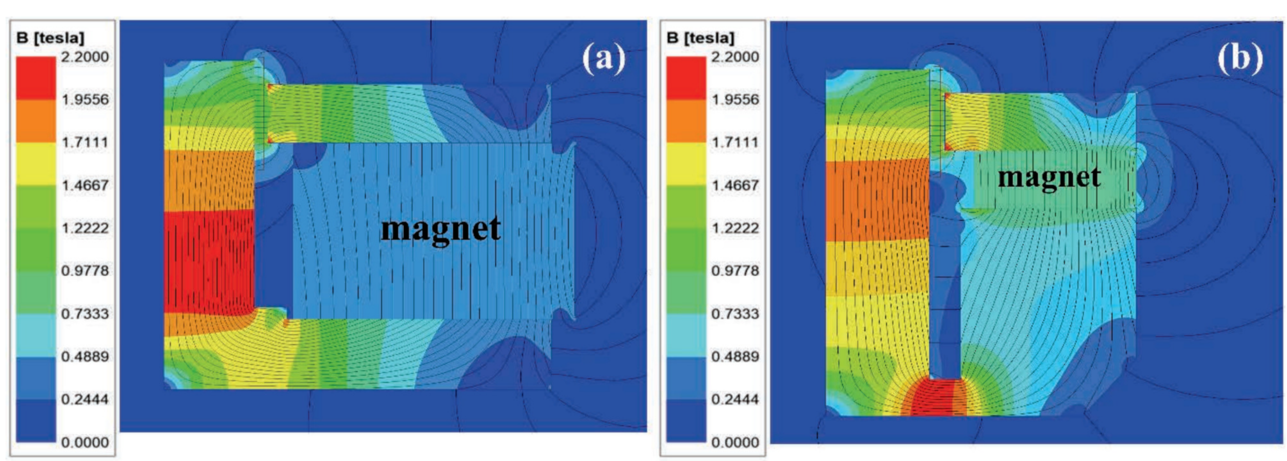

Figure 1: Magnetic field distribution for: a) a ferrite loudspeaker and b) a neodymium loudspeaker

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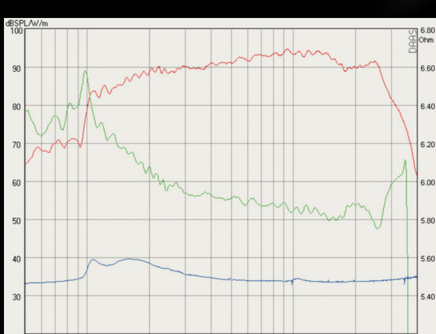
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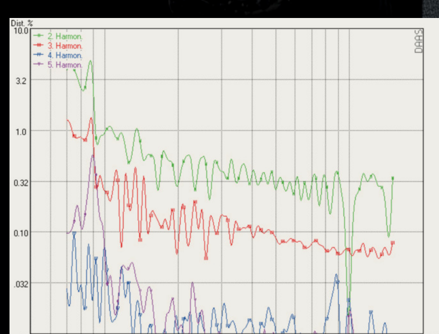
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2025" initiative, manufacturers are increasingly using rare earth magnets in finished and semi-finished products, as opposed to exporting the magnets. Permanent magnet motors for EVs dominate the Chinese market and industry sources estimate the global rare earth magnet market will nearly double by 2027.

Yet today's transducer designers think long and hard before going with a neodymium design because, back in 2011, price-fixing resulted in skyrocketing magnet costs. The dynamics were more complex than just "price-fixing," rather it was some combination of differing forces ranging from a decision by the World Trade Organization against China on neodymium exports, health and environmental concerns on rare earth mining, and conservation of resources. The bottom line was that the Chinese government decided to limit and control pricing on neodymium magnet exports (while keeping neodymium pricing down for domestic consumption). Specifically, neodymium export quantities had quotas.

The fallout from the price hike was that many speaker brands brought back their clumsy ferrite designs. In 2012, neodymium pricing fell dramatically, keeping pricing reasonable—until 2018. Since then the price has slowly been creeping back up, and neodymium prices surged in Q3 2019, reaching $76/kg USD in September, an increase of more than 100% since the beginning of the year. Recently, the pricing has been oscillating up but not settling down much. But don't worry, things could always get worse—current prices are still well below the $500 high after China held back shipments in 2010.

The US Magnet Market

However, China is not the only source of rare earth metals. Back in 2000, the US was still a leading producer of magnets from giants Arnold, Crucible, Indiana General, GE (Hitachi U.S.), GM/Magnequech. But in the following years, most of these long-established suppliers shifted production overseas.

While today the bulk of magnet fabrication is in China, there is some production in Malaysia, Vietnam, and soon the US. The tide appears to be coming back to US shores with Alliance expanding from a magnet distributor to a manufacturer. Urban Mining Co. in Texas is uniquely inputting the last stages of its manufacturing facility's neo magnets from its neo recycling feedstock. Let's look at the neodymium geopolitical supply chain, as whoever owns the rare earth mines controls the "supply."

The desert area along the border of California and Nevada is full of rare earth metals. Rare earth metals are not so rare with reserves of about 20 million tons in the vicinity of Mountain Pass, CA. You would think there would be a mine... and there is. I drive by it on every trip I take from the Bay area (Northern California) on my way to the CES trade show in Las Vegas, NV. If you take Highway 15 on the way to Las Vegas and turn onto Bailey Road (just before the Nevada border), you are at the mine. Prior to the pandemic, Mike Klasco, Nora Wong, J. Martins visited at the Mountain Pass facility on their way to CES (**Photos 1-3**).

The story is that the Mountain Pass deposit was discovered by a uranium prospector in 1949, who measured the high radioactivity. Rare earth metals and uranium tend to be found together. The Molybdenum Corp. of America bought the mining claims, and small-scale production began in 1952. Production expanded greatly in the 1960s to supply demand for europium, used as a phosphor in color television picture tubes. The deposit was mined on a larger scale between 1965 and 1995 supplying most of the worldwide rare earth metals' consumption. In 1998, the mine's separation plant ceased production of refined rare earth compounds. The mine closed in 2002, in response to

Photo 1: Mike Klasco is in the control room during a visit to the Mountain Pass Mine facility.

Photo 2: Mike Klasco navigates the ladder work inside the Mountain Pass facility.

Photo 3: The *audioXpress* site inspection team (Nora Wong, J. Martins, and Mike Klasco) visit the Mountain Pass neodymium mine ore processing facility

both environmental restrictions and China's lower prices for rare earth metals.

In 2017, MP Materials acquired Mountain Pass out of bankruptcy and more recently achieved run-rate production of >30,000 metric tons of rare earth concentrate, or ~15% of the global market, and downstream processing and separations facilities are restarting. Now MP Materials is going public in a $1.47 billion deal by merging with a private-equity-backed company with magnet production on the road map.

Another ambitious soup-to-nuts neo initiative tied to non-Chinese mining groups is USA Rare Earth, the funding and development partner of the Round Top Heavy Rare Earth and Critical Minerals Project.

Let's start this tale back in late 2011, when Hitachi announced the phased construction of a state-of-the-art sintered rare earth magnet manufacturing facility, planning to spend up to $60 million over four years. However, following the settlement of the rare earth trade dispute between China and Japan, Hitachi closed the plant in 2015 after less than two years of operation.

USA Rare Earth's recent acquisition of the Hitachi Metals' shuttered North Carolina facility should provide most of what is needed to re-establish rare earth magnet production in the US. The target is to produce at least 2,000 tons annually of rare earth magnets, approximately 17% of the current US market. This would be the first NdFeB permanent magnet manufacturing plant in the Americas.

This acquisition is complementary to the Company's Round Top Project in West Texas, which it is developing with Texas Mineral Resources Corp., and its pilot processing facility located in Wheat Ridge, CO. Round Top is rich in heavy rare earth elements, including dysprosium and terbium, which are required for NdFeB magnets. USA Rare Earth plans to produce high-purity separated rare earth powders at Round Top that could support its newly-acquired magnet manufacturing capacity and create a secure, reliable domestic supply chain. So we have some bits and pieces of the neo-supply chain solution and some "coming soon" alternatives.

The Current Market

Today, the only producer on the scale of separated Rare Earths outside of China is Lynas Rare Earth, Ltd. Its deposit in Mt Weld, Western Australia is mined and the rare earth oxides are then initially processed at Mt Weld Concentration Plant. Lynas operates the world's largest single Rare Earths processing plant where the concentrate is separated and processed to produce high-quality Rare Earth materials at the Gebeng, Malaysia operation.

Designed and built in two phases, the full Phase 2 capacity will be capable of producing up to 22,000 tons per annum of separated products. Commissioning of Lynas Malaysia started in late 2012. Currently, the most valuable product produced at the plant is Neodymium-Praseodymium (NdPr). Lynas produced its first Rare Earths products for customers in February 2013. As part of Lynas' 2025 growth strategy, it is also planning a Rare Earths Processing Facility in Kalgoorlie, Western Australia.

So is there another almost unlimited source of neodymium? Next year, we anticipate neodymium "mined" from recycling electric motors, wind turbines, alternators, hard drives, cellphones...and even loudspeakers. Very little is currently recycled from neodymium magnets. From an environmental, geopolitical, and market perspective, there is a need to develop new, efficient solutions to this problem. Five years ago, a couple of entrepreneurs and a Slovenian magnetics scientist banded together under the company name of Urban Mining Co. (UMC) and attended the Association of Loudspeaker Manufacturing & Acoustics (ALMA) International Symposium & Expo 2018, (ALMA International is now called Audio Loudspeaker & Technologies International or ALTI).

The plan was to recycle neodymium for speaker magnets. At the time, this venture was premature as there were many challenges, but this tenacious team eventually was granted patents. In 2016, they raised $25 million to put together a neodymium magnet recycling facility near Austin, TX. As you read this, there is already a pilot operation in beta operation and a purpose-built "refinery" on schedule for completion. Initially capable of producing 250 tons of recycled magnets annually, a future expansion is planned within two years to recycle 1,000 tons per year.

UMC sees its future as a magnet producer employing this unique approach to recover, reprocess, and reuse rare earth magnets otherwise discarded into landfills and junk yards. UMC estimates about 1000 tons to 2000 tons of NdFeB will be available per year from waste hard disk drives derived from US data centers alone. As the recycling infrastructure shifts toward aligning itself with the circular economy, industrial technology and manufacturing companies (e.g., UMC) play an instrumental role in shaping it.

Recycling Material

Urban Mining is not alone. Many private, government, and academic research facilities have invested significant effort in developing somewhat different recycling processes. The operational and financial feasibility of optimizing any bench-top scale extraction process to a large manufacturing scale has yet to be proven. Currently, no neodymium magnet suppliers can economically collect used magnets and re-process them. For post-consumer magnets harvested from equipment at the end of their life cycles, the material composition is unknown and may be different from unit to unit, which creates significant problems in achieving good quality from the recycled product.

I read through a few studies and the recovering procedure starts with collecting neodymium magnets from used electronics or equipment, demagnetize them, and render the raw material. Obstacles to the process are many. The early neodymium recycling resulted in a product that could not be re-magnetized! While this has been long resolved—due to its iron content—exposed neodymium magnets can be easily degraded, oxidized, and corroded, especially the stuff that was produced a while back, which is exactly what is likely to be recycled. Purification needs to be put in place to remove excess oxides and refurbishing the material back to its original magnetic properties can be difficult.

The idea of recycling neodymium may be "Politically Correct" along with the strategic implications of having a domestic back-up supply. Yet if not done efficiently, it can be an energy-intensive process that causes more problems than it solves. Conversely, mining rare earth is nasty, as the mining process may expose workers to radioactive fumes and particulates both in the extraction and the separation of ores. Since recycling only involves re-processing magnets that only contain neodymium, boron, and iron, the scary stuff was separated out long ago during the first round. Compared to the mining process, recycled magnets potentially have a less environmental impact, consuming an order of magnitude of energy with fewer pollutants. Recycling rare earth minerals may have the wind behind its back if neodymium is in the cross hairs of trade conflicts, along with the success of UMC's Texas operation.

What about developments with magnetic materials for magnetic structures? Low carbon (soft) steel is the default loudspeaker magnetic structure back plate and top plate material, typically cold-forged to shape. But for 100 years, there have been high-performance alloys used for mission-critical applications—and now with neodymium, these can offer real performance benefits from compression drivers to headphones and balanced armature earphones and hearing aid transducers.

Permendur, invented in 1929 at Bell Telephone Labs, is a cobalt-iron soft ferromagnetic alloy with equal parts of cobalt and iron, notable for its high magnetic saturation level. Coupled with its low coercivity and core losses, its high saturation and permeability, higher flux in the

About the Authors

Mike Klasco is the president of Menlo Scientific, a consulting firm for the loudspeaker industry, located in Richmond, CA. He is a graduate from New York University, with post graduate work in signal processing, and he holds multiple patents licensed or assigned. For the past 35 years, Mike has worked on countless R&D projects for large and small companies. Mike specializes in materials and fabrication techniques to enhance audio performance.

Salvador Magdaleno-Adame received a B.Sc. degree in electrical engineering from the Universidad Michoacana de San Nicolas de Hidalgo, Morelia, Mexico, in 2008, and a M.Sc. degree in electrical engineering from the Instituto Tecnologico de Morelia, Morelia, in 2013. He has occupied several magnetic engineering positions in companies in the US working in different magnetic technologies, including transformers, permanent magnet motors, magnetic actuators, loudspeakers, permanent magnet technologies, and more. He has authored more than 60 papers and has a consultancy business called "Salvador Consultant" to support the magnetic and electromagnetic industry in the US. His current research interests include the numerical calculation of electromagnetic fields in magnetic and electromagnetic devices using the finite-element method, application of different magnetic materials in magnetic devices, design of magnetizing fixtures utilized in the magnetization process of permanent magnets, and the development of new magnetic technologies for different applications and industries.

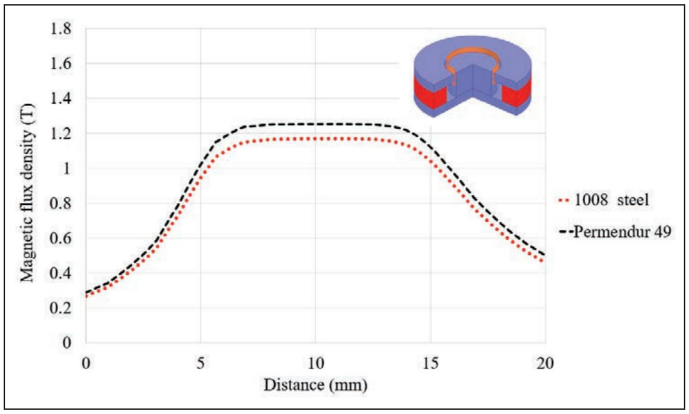

Figure 2: Magnetic flux density comparison in voice coil gap with 1008 low carbon steel and Permendur 49 in magnetic structure of neodymium loudspeaker.

voice coil gap can be reached beyond 2T (or 20kG). The advantage of high saturation in a magnetic core is that it can function at higher magnetic field strengths, so more compact and lighter for a given magnetic flux and power level.

Supermendur, which some of us know as "Hiperco 50," was invented in 1957. It has a similar composition to Permendur 49 but is grain oriented. Hiperco can be found in balanced armature earphones and hearing aid drivers. **Figure 2** shows the voice coil gap magnetic flux density distribution for a neo loudspeaker with Permandur 49 and 1008 low carbon steel.

And now for something completely new...Niron. Niron Magnetics clean earth magnet technology enables permanent magnets fabricated from Iron-Nitride (FeN) and does not utilize any rare earth elements. Niron Magnetics and its niron magnets promises several major advantages over traditional magnets, including higher magnetic field strength, enhanced temperature stability, and lower cost input materials and manufacturing.

The costs of nitride and iron are low and stable compared to rare earth magnets. Unlike neodymium or cobalt, niron is composed of commodity ingredients and is readily available from many sources throughout the world and is not sensitive to geopolitical factors. Niron magnets can be manufactured to get high energy levels compared with neodymium magnets (around two times more).

Using a patented, scalable process, Niron is developing the first commercial mass production process for iron-nitride permanent magnets. With a higher magnetic density than conventional ferrite and potentially even NdFeB magnets, Niron will enable size and weight reduction in electro-dynamic transducers. Specific applications include microspeakers, dynamic, earphones, and headphones, without compromising sensitivity or power handling. ***VC***

Author's Note: Special thanks to Salvador Magdaleno-Adame for preparation of the simulation graphics and technical review. Next month we will provide a full report on Niron's application to speakers.