An Introduction to AuraSound's Neo-Radial Technology…
…a revolutionay way to magnetically drive loudspeakers.

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I. An introduction to AuraSound

Aura Sound s is an advanced technology company made up of magnetics scientists, engineers and designers. Founded as the audio group of Aura Systems and in 1999 AuraSound became affiliated to Regaltronics, a large international electronics company. Aura Systems, as a company, has specialized in the development and applications of applied magnetics since 1987. Aura Systems's innovative, proprietary and patented technology has been used in a wide range of products from military uses, the design of advanced loudspeakers for a wide range of applications.

Aura Systems produces electromagnetic, high-force linear actuators or HFA'S. AURA's technology has been proven in such demanding applications as nuclear submarines and satellites. AURA's applied science of magnetic actuators is emerging in a wide range of peacetime industries, including compressors, motor-generators, valves, power tools, revolutionary designs for automotive use such as the AuraGen, and high-definition optical controls.

AURA produces magnetic actuators which can move tons many feet . . . with the precision of a servo motor. This same technology has been scaled to produce advanced loudspeaker designs for a wide range of OEM, automotive, hi-fi and professional audio applications.

The results of this new NRT® technology not only changes the way designers and engineers think about loudspeaker system design, but significantly improves the quality of music reproduction by reproducing sound with less distortion. AuraSound's NRT® technology offers improvements for the entire range of loudspeakers on the market today. NRT® magnetic systems offer high voice-coil excursion, superior linearity (equivalent to servo speakers), higher sensitivity, much lower flux leakage than conventional shielded speakers, and superior thermal power capacity.

This AuraSound NRT® Cookbook is a introduction to the theory and application of neo-radial high-force linear actuator technology, as it has been adapted to create an essentially new type of magnetic structure for permanent magnet loudspeakers. The unique, elegant and compact NRT® magnet geometry has several substantial benefits: loudspeakers utilizing this new magnetic system can play louder and reach lower frequencies, while generating audibly lower distortion than conventional ferrite-magnet loudspeakers.

Unlike existing loudspeaker motor systems, Aura's HFA technology is an exact position actuator, responding with precision in a direct mechanical analogue of the audio signal from the amplifier. AuraSound's magnetic system is inherently free of the nonlinearities in voice coil position of conventional loudspeaker magnetic systems, such as harmonic distortion and changes in critical Thiele-Small box tuning parameters with excursion (Qes, BL. etc.). And to top it all off, neo-radial magnetic structures are lighter, more compact and inherently shielded than conventional technologies.

II. Loudspeaker Magnetics

A Review of the Basics

The motor that powers the overwhelming majority of dynamic loudspeakers is the voice coil and permanent magnet svstem. Signal current flowing through the voice coil within a loudspeaker's magnetic gap generates a force which moves the speaker cone. According to Lorentz's Law, this force is equal to the product of the magnetic field strength times the length of wire in the gap times the current flowing: F=BLi.

In loudspeaker voice coils, electrons travel (or oscillate) in a common cylindrical path at a constant speed, generating an alternating magnetic field, known as a Biot-Savart field. Loudspeakers are "transducers," in that they convert electrical energy (current flow) to mechanical (acoustical) energy. Without the interaction of the stationary magnetic field and the field created by the constantly varying electric charges, no acoustical output would result, and all of the power amplifier's current would be dissipated simply as heat in the voice coil.

A variety of magnet materials and topologies have come and gone. ln the early days when the loudspeaker was first invented (the 1920's), powered electro-magnets with direct current field coils were used. These were soon replaced by magnetized low-carbon steel magnet structures, which in the early 1940's gave way to Alnico magnets (aluminum, nickel and cobalt alloys). Supplies of an essential Alnico ingredients have been unreliable since the 1960's. By the 1970's, much of the loudspeaker industry was forced to convert to ferrite (ceramic) magnets. These magnets were formed from ferrous metal dust baked with aluminum oxides. Although ceramic magnets are inexpensive and plentiful, the resulting magnetic assemblies are heavy and the baked ceramic ferrites are easily damaged.

Magnetic Parameters

A magnetic material's energy product (Bd x Hd) is the energy it can supply to a magnetic circuit, when operating at any point on its demagnetization curve. Energy product is measured in MegaGauss-Oersteds (MGO). Higher energy products means higher performance magnets. Alnico-5's energy product is 5.5 MGO, Ceramic 5 (ferrite) is significantly lower at 3.4 MGO. During the last ten years prices of Alnico and ceramic (ferrite) magnets have continued to rise, but the energy product has not improved.

Neodymium offers dramatically higher energy than ferrites and Alnico, or even Samarium Cobalt rare earth magnets. Neodymium is still a fairly new technology, with significant commercial production only in the last few years. The energy product of ceramic magnets seem very meager when compared to even the lowest performance grades of sintered Neodymium which are above 25 MGO.

Today, the common grades of Neodymium are over 30 MGO, almost ten times that of Ferrite 5. Grades of 45 MGO and higher are commercially available. Only a few years ago 50 MGO was believed to be the theoretical maximum, yet 55 MGO Neodymium are being produced under laboratory conditions. With ever increasing performance and an improving "cost / energy" product, use of Neodymium magnets continues to become more attractive.

Loudspeaker design engineers care about energy products because, all other things being equal, driver output is proportional to gap flux density squared, $(Bg)^2$. $(Bg)^2$ is directly proportional to the volume of magnet material used and to its available magnetic energy, BH. As the magnets' energy product increases, less material is needed to supply the same amount of magnetic flux to the voice coil.

Loudspeaker Magnet Geometries

First, a quick look at the basic loudspeaker magnet design geometries. Loudspeakers are made with both axial and radial magnetic structures using a variety of magetic materials. The terms axial and radial refer to the phenomena that the magnetic lines of force can be increased in a preferred direction by applying a magnetic field during heat treatment. This will affect the orientation and polarity of the completed structure after magnetization.

Loudspeaker designers have utilized ferrite, Alnico, Sumarian cobalt and Neodymium axial polarized designs. AuraSound's Neo-Radial Technology introduces Neodymium radial magnetic structures. The axial Alnico and axial Neodymium structures are identical except that the Neodymium magnetic slug is shallow, because it has a higher product.

Except for the ferrite, all these magnetic structures are inherently shielded, with both the axial and radial Neodymium structures offering more compact construction than the ferrite and Alnico magnetic systems.

Aside from their different magnetic orientation, there are beneficial characteristics of the radial over axial orientation for loudspeakers. This is especially true in the case of low distortion underhung voice coil woofers, subwoofers which require high excursion. The original Alnico or Neodymium axial slug configuration, which still requires a top plate, is efficent for tweeters and compression drivers with short gaps. But as the gap depth increases (top plate becomes thicker), the flux density proportionally decreases.

When the top plate of a loudspeaker is doubled, the flux density is halved. With the radial Neodymium configuration, the gap depth may be doubled by doubling the length of the magnet, and with only a nominal penalty in loss of flux density. Since an axial Neodymium geometry woofer would have the same intrinsic top plate limitations as any other magnetic material, it easy to see why there have been few (axial geometry) Neodymium woofers over the last ten years, but many popular Neodymium tweeters.

Magnet Form Factors

1. Alnico is used in deep and narrow slugs with high flux density through the magnet. Note that designs utilizing Alnico in this fashion require a large and heavy flux return structures. There is very little stray flux when the magnet is enclosed within the steel "pot" return structure which is typical of both Alnico and Neodymium magnetic systems. This is why Alnico and Neodymium magnetic systems are described as "inherently shielded." No external shield or "bucking" magnet with its additional steel shell, extra weight, extra cost, and increased size is needed to provide magnetic shielding.

2. Ferrites (ceramic magnets) have low induction and moderate coercive force, so they are used in shallow, wide rings with low flux density through the magnet. Large surface areas are required between the magnet and steel top and bottom plates to collect the necessary flux and conduct it through a 90 degree bend into the center pole.

3. Neodymium has very high coercivity, so the form factor (magnet shapes) employed can be short with large areas and moderate flux densities through the magnets. Coercivity, or coercive force, Hc, is the magnetizing force required to bring the induction to zero in a magnetic material which is in a cyclically magnetized condition.

III. Neo-Radial Technology

Introduction

A dynamic loudspeaker can be separated into three integrated sub-svstems:

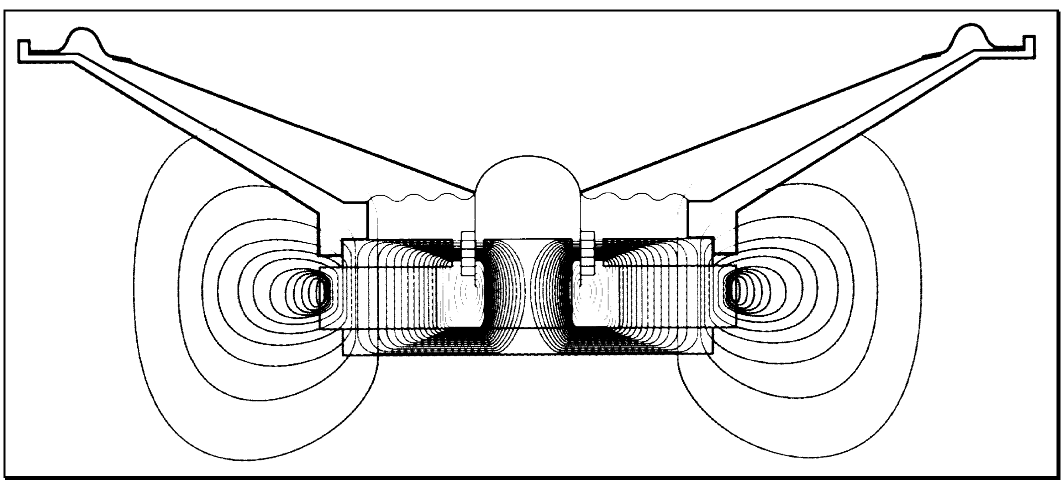
1. The Motor System: which is composed of the magnetic material, the magnetic return structure, and the voice coil.
2. The moving Diaphragm: cone and dust cap.
3. The diaphragm's Suspension: spider and surround

To fully realize the potential benefits of AuraSound's new NRT® magnetic system, improved diaphragms (cones), long excursion spiders and improved voice coils have been employed.

Design Considerations: The Loudspeaker Motor

Axial Magnetic Field

In today's marketplace, nearly all loudspeakers use ferrite magnet systems. These traditional ferrite magnet systems collect flux from a ring magnet with an axially oriented magnetic field parallel to cone motion. The top plate then conducts or bends the flux 90 degrees to focus it in the gap, in a radial direction. In the process. there is considerable energy waste, typically as much as 60-65%. As can be seen from the accompanying illustration, fully half the total magnetic energy is wasted outside of the loudspeaker. To achieve effective shielding from this stray magnetic energy, ordinary ferrite speakers require an additional bucking magnet and an additional exterior steel pot structure (magnetic return).



Conventional Ferrite Magnet

50% of the magnet's energy is wasted outside the loudspeaker. Random flux losses can account for an much as another 15% loss of the total energy of the magnet.

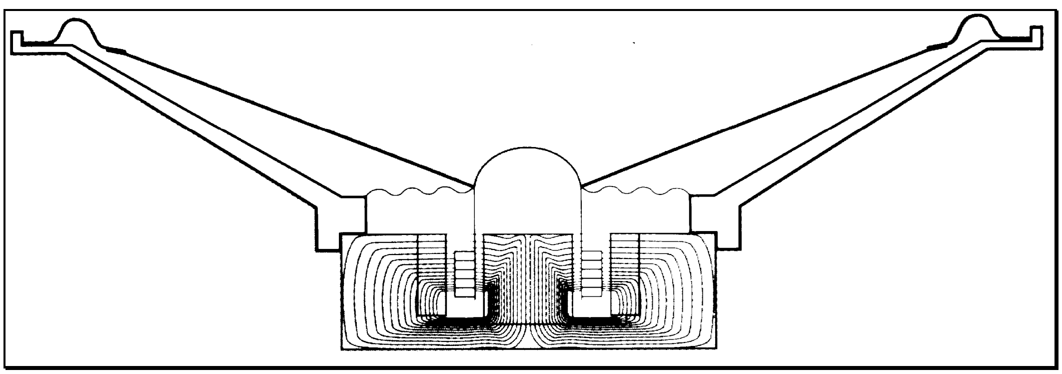
Radial Magnetic Field.

AuraSound's unique magnetic geometry uses a radially oriented magnetic field. This radial magnetization provides a uniform magnetic field for the voice coil as it moves in the gap between the surrounding Neodymium cylindrical magnet and the return structure (a combined pot and pole piece, which forms an "E" in cross section). There is no conventional top plate-ring magnet-backplate sandwich. The result is a magnetic system which offers very high excursion, superior linearity (equivalent to that of a servo speakers), higher sensitivity, less flux leakage than a conventional shielded speaker, and superior thermal power handling.

In this unique geometry, the flux return path is closed. There is no wasted magnetic field strength in stray flux, and thus inherent magnetic sheilding. No additional shielding is required for use near TV monitors or computer disk drives. Since greater flux (over 90%) remains to do useful work in the gap, the result is higher sensitivity.

AuraSound's NRT® geometry is therefore ideal for TV speakers, multi-media computer sound systems, as well as compact home theatre loudspeakers and subwoofers which must operate near the CRT in a TV / video monitor. The inherently shielded NRT® magnetic structure allows placement of loudspeakers anywhere near, or even up against a CRT.

This new freedom of placement, along with their very small magnetic pot structure, has lead to incorporation of AuraSound's OEM loudspeakers into multi-media computer monitors with 2 x 3 inch models located directly adjacent to the viewing screen.



AURA Neo-Radial Technology Magnet

Over 95% of the magnet's energy is used by the loudspeaker. The NRT® design requires NO external shielding can—as there is no stray flux leakage

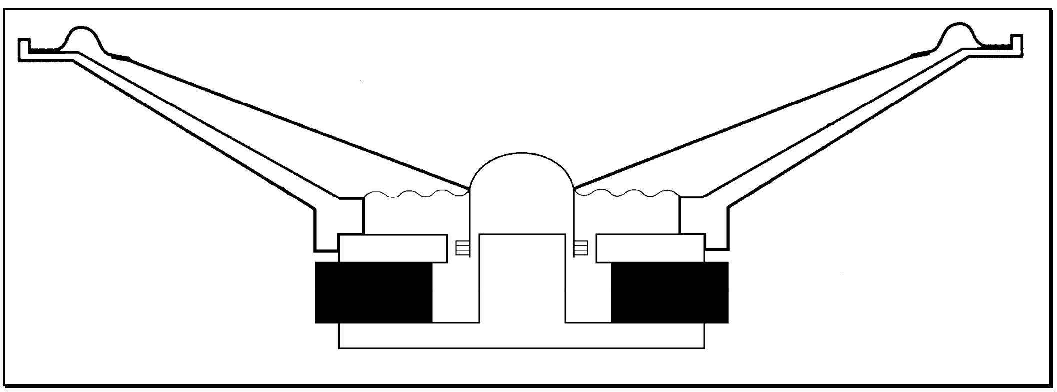
Design Considerations: The AuraSound Magnetic Gap

Deep Gaps with Underhung Voice Coils

AuraSound's NRT® employs a radially-polarized Neodymium magnet geometry. The key element of this approach is a combination of an underhung voice coil within a radially polarized magnetic structure. However, before delving into the specific details, it will be useful to review the basic loudspeaker designs now in use. There are three basic voice coil gap geometries in use today: the underhung coil, the equal-hung coil and the overhung coil.

By definition, a loudspeaker with an underhung design uses a voice coil winding height that is shorter than the depth of the magnetic gap. Loudspeaker designs which utilize underhung voice coils tend to be more linear than conventional designs because the voice coil remains entirely within the uniform magnetic field. This underhung arrangement is rarely seen however, except in a few specialty hi-fi designs, because of the very high loss of sensitivity with axially polarized magnetic systems.

Even in the rare instances when Neodymium magnets have been tried in woofers in the original "Alnico style" axial slug configuration, the sensitivity of underhung coil woofers is usually lower than comparable conventional ferrite overhung woofers.

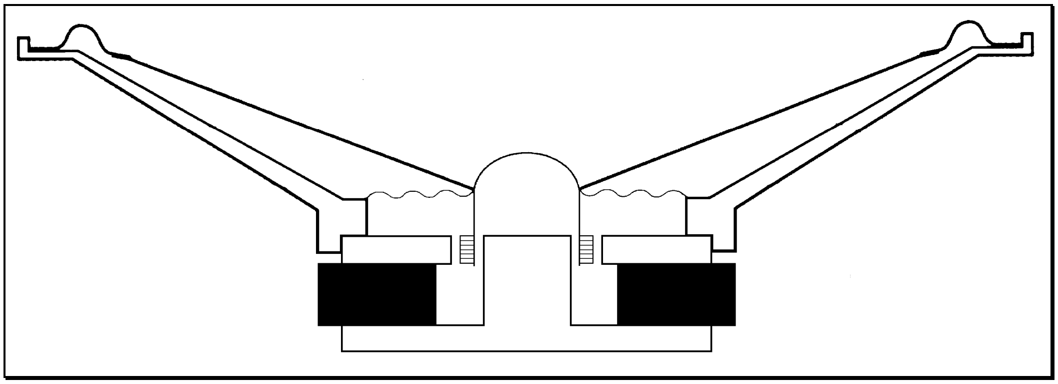


UnderHung Voice Coil Design

This design, while theoretically high in linearity, is rarely used because it is inefficient. Loudspeakers with this design are often 4 - 5 dB lower in output.

Equal Hung Designs

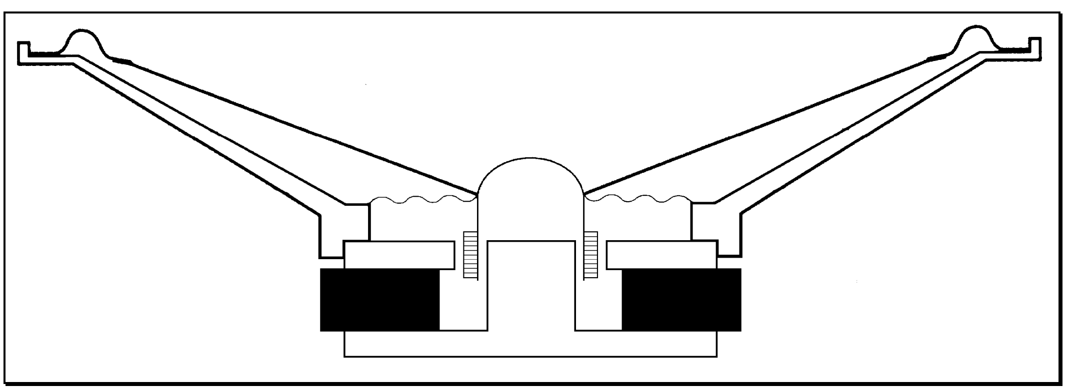
Many manufacturers of high efficiency woofers commonly used in PA systems and the ‘lead’ speakers used in musical instrument loudspeaker systems, use designs whose voice coils are almost the same height as the magnetic gap. The attendent gain in output sensitivity is paid for by reduced excursion, reduced low frequency output, and poor linearity**.**



Equal-Hung Voice Coil Design

OverHung Designs

Woofers and sub-woofers have traditionally used overhung coils, or coils whose height was greater than the shallow gap height formed by the top plate. These overhung coils are utilized in order to achieve increased excursion, while still keeping the Gauss high in a small gap. In addition to providing very limited linear excursion, overhung coil designs suffer from having to move extra mass: often 50% of the voice coil is not within the magnetic gap, and generates no motive force. Overhung coils not only increase moving mass, but also increase DC resistance and inductance, and reduce the loudspeaker sensitivity and degrade its Qes.

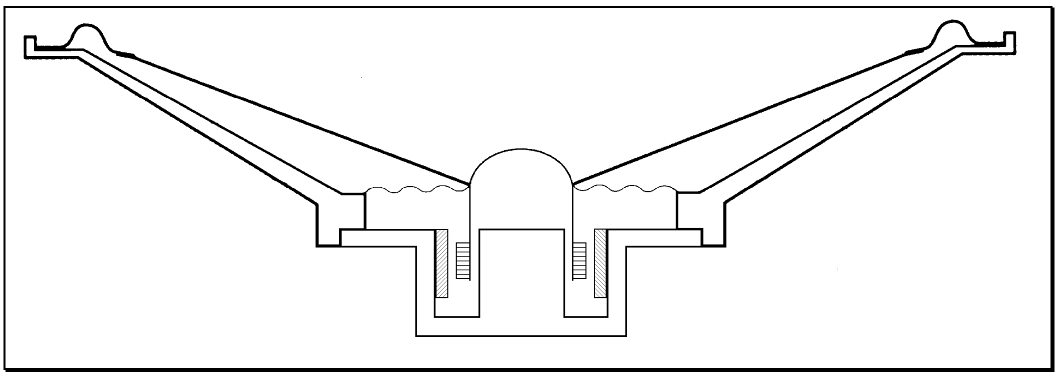


OverHung Woofer Design

Neo-Radial Technology

With AuraSound's NRT® geometry, the gap height simply becomes the total height of the magnet. Thus, gap height (linear excursion) can be extended by simply lengthening the magnet. In traditional gap geometries, the height of the magnetic gap is limited to the top plate thickness. In a conventional design, when the thickness of the top plate (or gap depth) is increased, the magnetic flux density proportionally decreases: doubling the top plate thickness halves flux density and greatly reduces output. With Neo-Radial Technology, increased woofer gap depths may be achieved by simply increasing the length of the magnet.

Most AuraSound NRT® voice coils are designed as underhung, filling only a portion of their deep gaps. Since force (F) = BLi, high forces are available, providing high sensitivties and deep bass (from very long excursions). This is the optimum application of the radial magnetic configuration, and provides the big advantage of nearly absolute linearity: the linearity is only possible from the constant flux seen by an underhung voice coil. T-S parameters remain stable during all voice coil excursions.



AURA NRT® Design

The elegantly simple structure of the Neo-Radial Technology design belies its many benefits. The Neodymium magnetic material is shown as shaded. Its very small size outperforms designs with much larger magnetic systems.

Excellent Magnetic Linearity when Underhung

In traditional loudspeakers, the Thiele-Small parameters dynamically change with the position of the coil in the magnetic gap, particularly as cone excursion rises. As the voice coil moves in and out of the gap, the flux density seen by the voice coil varies, so the magnetomotive force, F = (BL)i, delivered by the magnet to the voice coil /cone becomes non-linear.

As the coil responds to the audio signal and its position changes, the number of turns of the coil that are in the flux field change, thus dynamically modulating the Thiele-Small parameters (such as BL and Qes). A loudspeaker's low-frequency performance in an enclosure is designed around its Thiele-Small parameters. When these T/S parameters change dynamically with increasing cone excursion, so does the low frequency performance (or enclosure tuning) of the loudspeaker system.

Mid-band non-linearities and harmonic distortion are additional problems which degrade clarity and definition. These tend to be very common characteristics with full range loudspeakers that must also reproduce deep bass. These problems are neatly by-passed by the NRT® design.

AuraSound NRT® loudspeakers with underhung geometry are free from this problem as their entire voice coil is constantly immersed in a uniform magnetic field. The BL and Thiele-Small parameters do not change dynamically with cone (coil) excursion. When a short coil is used in conventional magnetic structures to achieve underhung geometry, it comes at a high price: low BL, poor sensitivity, and linear excursion limited by the top plate thickness. With NRT® this is no longer a problem.

AuraSound's radially polarized magnet permits higher linear excursion and higher BL than overhung coils in conventional magnetic systems; higher sensitivity than conventional designs, and eliminates flux gradients along the length of the coil. The resulting linearity (and performance) is equivalent to a servo loudspeakers.

ILLUSTRATION

Bl vs. Excursion plot: conventional underhung vs. conventional overhung vs. Neo-Radial underhung performance

In order for a loudspeaker to have low distortion. the voice coil must move linearly (in response to the AC input current) through the gap, both forwards and backwards. Linearity of cone motion depends on the linearity of the magnetic motor as well as the mechanical suspension. Further, linearity of the voice coil requires linearity in the magnetic field — a feat which is not easy to obtain in practice.

A non-constant Bl generates intermodulation (IM) and harmonic distortion. In conventional loudspeaker motor structures, some of the flux diverges or spills out of the gap at the pole tips, creating “stray flux,” “leakage” or “fringe” fields above and below the gap. When the upper or lower edge of the voice coil begins to pass through the gap, the force acting on the coil changes (for a given input current). This is because the number of turns in the magnetic field varies. This nonlinearity in electromotive force by definition causes distortion. At high excursions, when the voice coil begins to be driven out of the gap, the magnetic flux changes non-linearly.

More turns of wire in the gap yield greater mechanical force available to move the speaker diaphragm (perpendicular to the directions of the current and field) since F = (Bl)i. F is the force (Newtons or dynes/100,000), B is the flux density or magnetic field strength (in Tesla or Gauss/10,000), l in the length of conductor in the B field (in meters, or centimeters/100), and i is the current flowing through the wire (in Amperes).

Note that in overhung coils, as used in the typical subwoofer, there is a lot of wire above and below the gap, but useful work is done only by the portion of the voice coil wire actually in the gap. The wire outside the gap adds only resistance and inductance.

The Many Benefits of Wide Gaps

With AuraSound's NRT® designs and their deep gaps, increasing the gap width has a smaller penalty in flux loss. Widening the magnetic gap permits space for: larger production tolerances, heavier gauge voice coil wire, multi-layer (4 or even 8 layers) voice coils, higher aspect ratio flat wire, or a “shorted turn” copper cap on the pole piece.

Flux, Wire Turns, Neodymium. MGO, and the Future

The typical flux density, in a woofer using a neo-radial magnetic structure may range from 5000 to 9000 Gauss (0.5 to 0.9T or Tesla). This flux density, is slightly lower than what speaker design engineers would typically expect from high energy magnetic systems. But . . . flux density does not tell the whole story. The NRT® gap width can be greater than conventional magnetic systems without the steep drop in magnetic flux density·

Design optimization techniques, such as increasing the number of winding layers, flat wire, aluminum conductor wire and other techniques, are used to achieve optimum Bl, without excessive mass or inductance. To attain the full potential of this new technology, design engineers can optimize their design decisions to work with these attributes.

As Neodymium energy density continues to rise, even greater design flexibility for the design engineer become available. For example, a woofer or midrange speaker using 25 MGO Neodymium of the 1980s, would have a 5,000 Gauss gap density. Using the latest 45 MGO Neodymium, would have over 9,000 Gauss gap density (assuming the pot structure was not saturated) and at a much lower price!

IV. AuraSound Loudspeakers - Applications By Market

For customers, greater cone excursion and higher thermal capacity means that a smaller diameter loudspeaker can be used for the same low frequency response. Alternatively, an equal size driver can play louder and deeper. The benefits of dramatically increased excursion provided by NRT® are critically important since doubling acoustic power output (+6 dB) requires 4 times the excursion.

Subwoofers and Professional Sound Reinforcement

Since the human ear is relatively insensitive to very low frequency information, so higher SPLs are required to achieve good bass response. Just as pro sound users are very focused on a loudspeaker system's wideband maximum output level, subwoofer enthusiasts also have to pay attention to their speaker system's maximum output.

The constraints placed on normal subwoofers: displacement, thermal, distortion — all these are strengths of the AuraSound NRT® motor structure. Pro-audio system designers will be able to reduce the number of bulky sub-woofer enclosures that their PA systems require, while providing their clients with lower distortion, better sounding systems.

Automotive / Car Speakers

Since loudspeaker driver size is often selected based on "What will fit in the left-over space . . . ." Many users will be able to keep the same size loudspeakers, while playing them louder, and with increased bass output. Aftermarket car-audio installers will be able to reduce the number and size of bulky enclosures subwoofers currently require, as well as to provide their clients with a cleaner, better sounding, higher power capacity system. NRT® advantages are compelling to the car-audio aftermarket and to the OEM automotive market: louder, cleaner, 'punchier,' lower distortion sound in smaller, lighter packages.

Hi-Fi Loudspeakers

Compact satellites / subwoofer systems can now deliver comparable performance using only satellite loudspeakers with very high excursion neo-radial drivers. High performance monitor-style loudspeaker systems can finally deliver adequate bass, and reap the further benefit of lower distortion across the frequency band. Monitor-style consumer loudspeakers are typically unable to deliver their truly high quality sound at elevated listening levels because distortion in their components begins to rise dramatically at high power levels.

TV / Monitor Speakers and Multimedia

When applied to TV / Multimedia sound, AuraSound OEM loudspeakers offer built-in shielding and high performance. AuraSound drivers lend themselves to compact, extended range, high-output speakers. In one specific product, a five-speaker stereo television (single 4 inch subwoofer, stereo woofers and tweeters) was upgraded using only two 4 inch AuraSound extended range speakers.

NRT OEM speakers' small size and inherent shielding eliminates the need for complex, bulky and expensive plumbing schemes to direct sound from speakers at the rear or sides of the TV monitor to the front. Simple mounting on the front of TV monitor baffles is now a reality. Speakers can be closer to the picture tube, saving precious space.

V. Major Benefits of Neo-Radial Technology

AuraSound's NRT® magnetic structures offers speaker design engineers a host of benefits:

I) NRT magnetic structures are generally much smaller and lighter than conventional ferrite designs. This permits a greater freedom for designers utilizing NRT OEM products. Loudspeakers can be incorporated into swept-back enclosure designs because of the smaller magnet, and because no bulky shield can and extra magnet are required for use in close proximity to video displays and TV screens, these designs and be place directly adjacent to CRT displays. The smaller magnet also permits front drop-in mounting, greatly simplifying product tooling design and system assembly.

2) An AuraSound loudspeaker's gap is typically deep, thus accommodating very high linear excursion. In an NRT® design, excursion is limited by the height of the magnet which can be increased arbitrarily, while a standard loudspeaker's linear excursion is limited by its top plate thickness.

A transducer's magnetic motor system is operating linearly only if the number of turns of voice coil wire in the gap remains constant. Conversely, a loudspeaker becomes non-linear when the number of turns in the gap changes (due to the voice coil being driven partly out of the gap).

3) AuraSound woofers, and especially subwoofers, may be configured to yield both large BL product (strength or force factor) and high efficiency. This same patented NRT® topology also yields improved linearity, excursion and increased thermal power handling. This is the result of a large amount of voice coil wire (and heavier gages), which can be packed into the relatively wider, deeper gaps.

4) NRT voice coil geometry, is often underhung, and voice coils which are shorter than the top plate benefit from a large increase in thermal power handling. The radiated heat from the voice coil has a direct path, and uniform thermal resistance, from the entire voice coil to the steel magnetic return structure.

In order to achieve adequate excursion, most conventional woofers utilize an overhung configuration (the voice coil is taller than the top plate). As mentioned earlier, there are several drawbacks to this approach. Since voice coils can only readily radiate heat within the gap area, the ends of the coil which remain outside the gap are left to overheat and fail at sustained high power levels.

5) Underhung voice coils using NRT® have high linearity (constant flux through the range of voice coil motion) and without the sensitivity loss of underhung voice coils in conventional designs.

For More Information

We hope this technical review on AuraSound's Neo-Radial Technology has been helpful, and that it provides you with greater insight into new aspects of loudspeaker design. Please feel free to contact us if you need to discuss any aspect of this paper or would like to hear more about the AuraSound NRT® OEM magnetic structure program.

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