VOICE COIL
THE PERIODICAL FOR THE LOUDSPEAKER INDUSTRY

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# *STEALLUS*, Part 1

*By Steve Mowry*

There seem to be so many claims regarding large displacement woofers and subwoofers. Some of these appear in magazine ads, on websites, at trade events, and at the US Patent and Trademark Office. While researching and compiling this two-part article, I termed this situation the War of the Gaps. These claims are numerous and can be confusing; however, that may have been the objective. . . to some degree, anyway. The following discussion is intended to focus on meaningful but simplified criteria for the evaluation of moving coil transducers and to present a novel but minimalist approach to transduction that finally addresses the root sources of nonlinearity.

## MOTOR TOPOLOGIES

This article illustrates and briefly discusses the most commonly used motor topologies beginning with the most common topology, the over-hung voice coil motor assembly (***Fig. 1***). The voice coil height is greater than the gap height, and thus as the coil is displaced in the gap, the flux linkage will remain fairly constant until the overhang limit is reached. This topology trades efficiency for linearity. The taller the voice coil wind, the higher the displacement-related linearity, but the lower the efficiency of the motor.

The first six examples are clearly geometrically asymmetrical. Examples 7, 8, and 9 illustrate symmetrical topologies. After almost 100 years of development, why is this?

The under-hung voice coil topology in ***Fig. 2*** has the physical limitation of the top-plate thickness with respect to the voice coil wind height and with regard to displacement. It tends to be linear with respect to displacement of the coil within the respective height. The short coil tends to run hot, and the steel core and outside diameter result in high inductance and flux modulation. Douglas Button and Jerry Moro went "all out" with the JBL 1500AL under-hung professional low-frequency transducer with 4″ voice coil (www.audioheritage.org/html/projectmay/technology/1500al.htm).

However, the solution is a high-cost transducer that still has some inductance and flux modulation and displacement limitations. STEALLUS has similar design objectives to the 1500AL but is a much simpler solution, a minimalist approach versus a "cost is no object" approach. However, clearly the 1500AL is one of the finest low-frequency transducers on the planet.

The mechanical peak-peak (P-P) limit of displacement for a moving coil transducer with well-designed suspension is typically the voice coil wind height plus the magnetic gap height. The well-hung topology in ***Fig. 3*** exploits this and can have very high displacement and very high $\beta(x = 0)$ at the cost of distortion relating to reduced amplitude linearity, self-inductance, and flux modulation.

In ***Figs. 1-3*** the voice coil is wound in a linear manner in even numbered layers 2, 4, 6, or 8; however, the voice coil can be wound with a nonlinear distribution of the windings with partial layers on top of some base layers. In

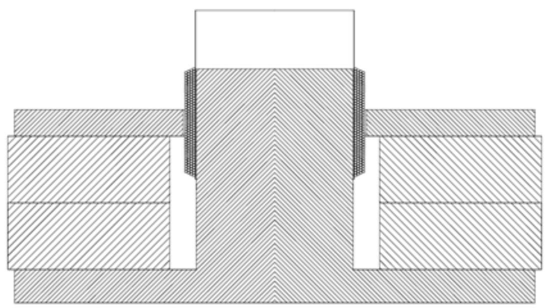

FIGURE 1: Typical overhung topology.

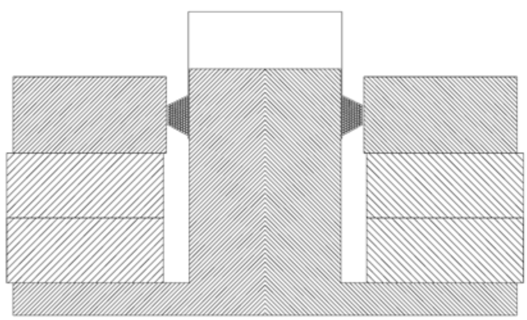

FIGURE 2: Underhung topology.

this way, the peak value of $\beta$ and some additional mass can be traded for an increase in **Xmax** (***Fig. 4***).

TC Sounds Inc. refers to the topology in ***Fig. 4*** as Linear Motor System (LMS) at www.tcsounds.com/lms.htm and claims Patent Pending. I was able to identify TC Sounds Inc.'s published US Patent Application # 20030219142, Speaker driver with detachable motor and basket, which in April 2006 became a US Patent. 7,031,490, www.freepatentsonline.com/7031490.pdf.

TC Sounds also has two US Patents on Speaker driver frame designs: D455,733 www.freepatentsonline.com/D455733.pdf, D451,499 www.freepatentsonline.com/D451499.pdf.

After an extensive patent search including the trademark **Linear Motor System** and **LMS**, I could not find anything concerning the nonlinear wound voice coil from any inventor.

Adire Audio (www.adireaudio.com) has the **XBl$^2$** trademark and US Patent. 7039213. **XBl$^2$** implements a nonlinear distribution of flux within the gap by using creative motor geometry that is essentially the dual of the nonlinear distributed voice coil windings (***Fig. 5***). These are two examples of woofer motor assemblies that implement nonlinear physical topologies that result in very high **Xmax** and thus **Vmax**. The peak value of $\beta$ will be less than for a woofer with the typical over-hung topology in ***Fig. 1***. However, $\beta$ can be adjusted to some degree by the magnet size and grade. Motors with high $\beta$ and high **Xmax** are typically large to say the least.

The **XBl$^2$** is a clever way to linearize **Bl**(x) & $\beta$(x) (***Fig. 5***). Adire operates on the B field with the undercut pole and/or top-plate to distribute the flux density in what effectively implements two gaps with the flux in the same direction (**Push-Push**). One challenge with the **XBl$^2$** and the Push-Push topology is the sensitivity to variations in the voice coil wind height. Try an FEA model of Push-Push or the **XBl$^2$** topology motor assembly and perturb the voice coil wind height about the rest position. Then take the derivatives of the Bl(x) curve sweeps and plot!

These two patented topologies (***Figs. 5*** and ***6***) are similar and the objectives of a twin distribution of flux relative to the voice coil are the same. However, the 2× gap push-push in ***Fig. 6*** clearly utilizes much simpler part geometries than the topology in ***Fig. 5***, but how can I get the flux density to be distributed symmetrically with regard to the middle of that top secondary magnet in ***Fig. 6***? I cannot.

Both the **XBl$^2$** and the **Push-Push** Patents make reference to simple symmetrical drive topologies. Two of these are illustrated in ***Figs. 7*** and ***8***.

***Figure 7*** illustrates two disk magnets that are magnetized in opposite but axial directions with a non-ferromagnetic spacer between them, no steel, and no ferromagnetic material.

In his patent, House discusses the "limitations" of this topology and essentially references his invention to this simplest of all motor assemblies, the return-less or infinite gap motor assembly.

Before 1970, the strongest magnets were of the type known as AlNiCo, an alloy of Aluminum, Nickel, Cobalt, and Iron. The **BHmax** of the best AlNiCo magnets, AlNiCo5, reached about 10 MGOe in 1970. By 1980, commercial Samarium Cobalt magnets had achieved a **BHmax** of about 30 MGOe, three times greater than Alnico. In 1984, researchers at the General Motors Research Laboratory and in Japan discovered an even stronger type of rare earth magnet using an alloy of Neodymium, Iron, and Boron. NdFeB magnets can now

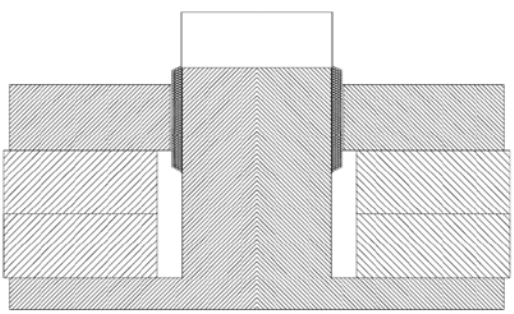

**FIGURE 3: Well-hung topology.**

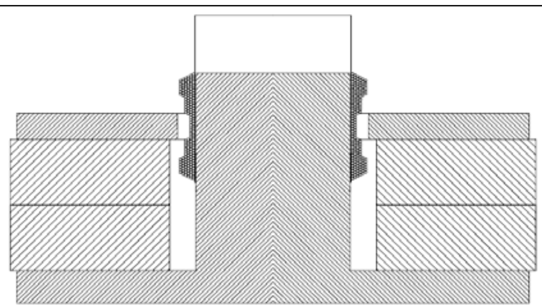

**FIGURE 4: Nonlinear distributed voice coil winding topology.**

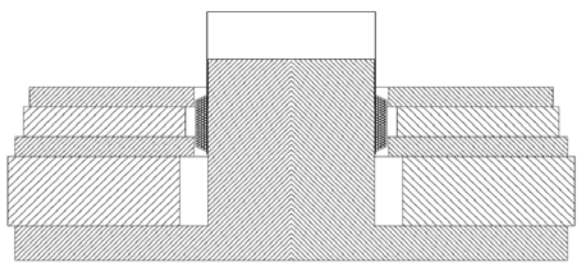

**FIGURE 6: Step Technologies' patented push-push dual gap and magnet topology (*www.freepatentsonline.com/6940992.pdf*).**

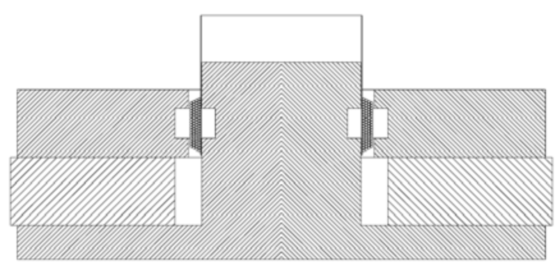

**FIGURE 5: Adire Audio's patented XB1$^2$ quasi push-push topology (*www.freepatentsonline.com/7039213.pdf*).**

achieve a **BHmax** of about 50 MGOe, five times greater than any magnet existing before 1970.

The origin of the topology illustrated in ***Fig. 7*** dates back to when sintered rare earth, Samarium Cobalt, and NdFeB magnets became commercially available in 1980 and 1984, respectively. Two magnets, a piece of plywood, a little adhesive, and about 50-100 lbs of force were all that was needed to assemble this simplest of all motor assemblies, three parts with two the same part. Ceramic/ferrite magnets just did not have a **Br = B**(H = 0.0) maximum flux density inside the magnet itself (remnance) that was high enough (0.3-0.4T). Nor was the **BHmax** of about 3 to 4 MGOe high enough for the return-less motor topology.

AlNiCo, Sm2Co17, and NdFeB sintered magnets have **Br** ≥ 1.0T; however, only Sm2Co17 and NdFeB sintered magnets are suitable for the STEALLUS topology. The **Hc = H**(B = 0) (A/m) coercivity within AlNiCo5 is very low—problematic for a return-less motor. Frankly, that's problematic for any motor topology; however, AlNiCo has the lowest reversible temperature coefficients of any permanent magnet material.

***Figure 8*** illustrates Yoshio Sakamoto's US Patent for Kenwood (5,550,332, www.freepatentsonline.com/5550332.pdf). This was considered another improvement on the topology in ***Fig. 7***. A ferromagnetic (steel) spacer/yoke and gap-plate washer were added to implement a finite air gap but still return-less. Focusing and/or concentrating the flux to a gap increased motor efficiency, as well as inductance and flux modulation, along with cost and complexity of assembly, not to mention the improved thermal conductivity of the steel coin separating the magnets relative to the nonferrous spacer.

Finally, there is the twin coil/anti-coil push-pull topology. Velodyne, JBL, and P.Audio utilize this topology in their "best" subwoofer applications. ***Figure 9*** illustrates the push-pull topology.

The push-pull topology in ***Fig. 9*** has inherently lower distortion and is designed for AC operation with full complementary symmetry and with inductance canceling coil and anti-coil configuration. However, the nonlinearity related to the steel and flux modulation is still there. The real limitation to this topology is the size and complexity of the voice coil(s) and the motor assembly. There are essentially two hard-part assemblies in addition to the soft-part assembly, the outside magnet(s)/gap-plates assembly and the inside pole piece. Assembly is more difficult than typical topologies.

The stack-up height is also the largest of all topologies; the coils must be spaced such that they do not enter their respective anti-B fields, but if correctly designed, DC-offset that is typical in most moving coil transducers is gone! Douglas Button implements the push-pull topology in several of his subwoofer designs and has several patents for JBL concerning specific features claiming to enhance/improve the performance of this topology: 7,072,481, www.freepatentsonline.com/7072481.pdf; 7,012,345, www.freepatentsonline.com/7012345.pdf; 6,847,726, www.freepatentsonline.com/6847726.pdf; 6,774,510, www.freepatentsonline.com/6774510.pdf; 6,768,806, www.freepatentsonline.com/6768806.pdf; 5,828,767, www.freepatentsonline.com/5828767.pdf; 5,748,760, www.freepatentsonline.com/5748760.pdf.

Although these inventions improve performance, most if not all of them also tend to add complexity, cost, and/or size and weight to the transducer(s). The push-pull topology is also referred to as prior art in Stiles US 6940992 in figure 1D on sheet 4 of 23. Previously, the push-pull topology was a favorite of mine with transducer designs from 50mm to 400mm.

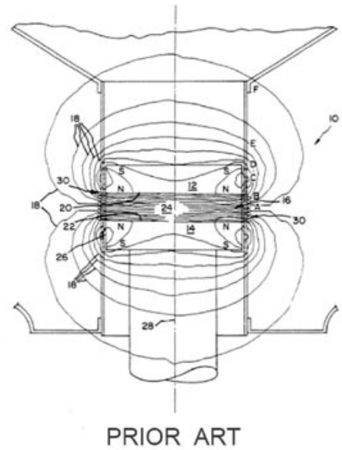


**FIGURE 7: From William N. House, Bloomington, Ind., Transducer Motor Assembly Patent for Harman International Industries, Northridge, Calif. (*www.freepatentsonline.com/5142260.pdf*).**

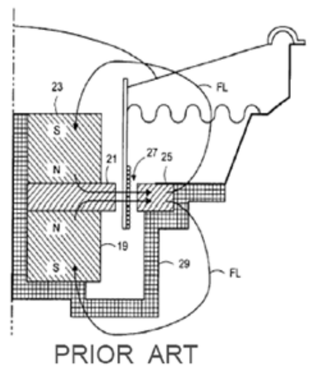


**FIGURE 8: From Enrique M. Stiles, Imperial Beach, Calif., Push-push Multiple Magnetic Air Gap Transducer Patent for Step Technologies Inc., Minneapolis, Minn. (w*ww.freepatentsonline.com/6940992.pdf*).**

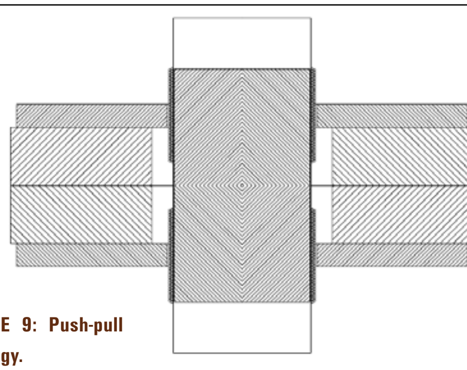

**FIGURE 9: Push-pull topology.**

## THE STEALLUS TOPOLOGY

STEALLUS is a new transducer topology from S. M. Audio Engineering that has the following features:

1. Simplified bottom-up gauged assembly.
2. Lowest self-inductance and flux modulation of any moving coil transducer.
3. High mechanical stability with symmetrical mid-engine drive.
4. Hybrid voice coil.
5. Compact package.
6. Improved mechanical coupling of the voice coil to cone.
7. High Vmax and Xmax.
8. High β and Bl (magnet cost driven).
9. Ultra-light weight.
10. Designed for manufacture and assembly with several of the typical failure modes designed-out.

Some of the advantages of the STEALLUS minimalist topology are:

1. Complementary symmetry class-A drive analogy.
2. Very close to air core coil AC behavior.
3. Short bobbin with friendly stack-up.
4. Voice coil OD variability and clearance are don't care (not critical).
5. Optimized lead-out geometry.
6. Elegantly simple.
7. Versatile and flexible in application and implementation.
8. Low distortion.
9. Designed to high cost/performance ratio.
10. Quality is designed-in with a truly minimalist approach to transduction.

Next month in Part 2 we'll look at the STEALLUS topology in more detail.

**Steve Mowry**, president of SM Audio Engineering, has a BS, Business Administration, from Bryant College, and a BS and MS, Electrical Engineering, from URI with highest distinction. Steve has worked in R&D at BOSE, TC Sounds, EASTTECH, and P.Audio. Steve is currently an independent consultant/lecturer in project management/transducer and system design. His website is www.s-m-audio.com. *VC*

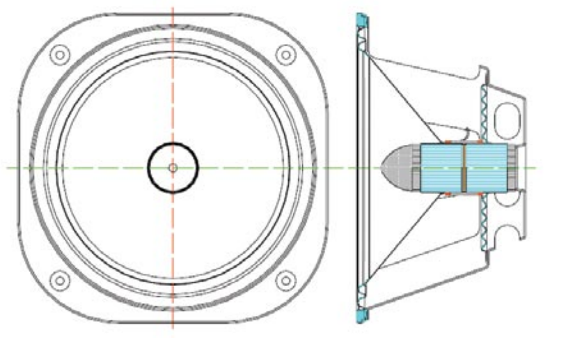

FIGURE 10: The STEALLUS minimalist topology (S-7).