XBL: A Primer

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Table Of Contents

Table of Figures

1 Introduction

XBL is a patented[i] loudspeaker driver technology that yields increased output, lower distortion, smaller physical packages, and typically lower cost. It is easily implemented, can be produced by any driver factory, and requires no special tools, jigs, or processes.

This document is intended for the casual-to-intermediate loudspeaker enthusiast or designer. We'll cover the fundamentals of what a loudspeaker driver is, how the magnetic circuit works, and what are the most common designs in use today. Then we'll compare and contrast XBL versus other designs, and provide some real-world examples of just how XBL benefits a variety of clients.

2 Magnetics in 30 seconds

The easiest way to understand magnetic flux[ii] flowing in steel is to think of water. Water likes to flow where it is easy – downhill, over smooth surfaces. Likewise magnetic flux likes to flow through steel, not through air. So it will follow the steel in the speaker, and avoid the air if it can.

And like water flowing in a stream, a small obstruction (like a rock in the middle of the stream) in the flux path will cause the flux to go around it. It will not stop the flow of flux! But what it will do is slow the average speed of water; this means the strength of the water flow – or the strength of the flux flow – may be reduced.

So when looking at a diagram of a loudspeaker driver (or driver), look at the magnet as the source of water, and look at the steel as the stream bed through which the flux flows. Constrictions, blockages, long paths may affect the total flow of flux, but it can affect it in good and bad ways.

3 Driver Fundamentals

3.1 Overview

A driver is quite a simple device. Fundamentally, it is two magnets pushing and pulling against each other. Remember when you first played with magnets as a child? In one direction, the two magnets wanted to stick together. Turn one magnet over, and the two tried to jump apart from each other! You could push one magnet with the other, without physically touching.

A driver is functionally two magnets; one is typically a fixed permanent magnet (like you played with as a child), made from ferrite[iii], AlNiCo[iv], or neodymium[v]. This is typically secured within steel parts within the magnet structure (also call the motor). The steel parts channel and focus the flux from the magnet into a circular opening, called the gap; this is where the magnetic flux is highest, and what we try to optimize with all the steel and magnet parts.

Within this gap resides the voice coil[vi]. The voice coil is a coil of wire that is connected to the amplifier and has a current running through it – forms an electromagnet[vii]. This is the other magnet. The electromagnet effectively pushes or pulls against the permanent magnet, based upon the current flowing through the voice coil. This means it moves up and down. A cone is attached to the electromagnet, so that it creates pressure waves based upon the motion, which we hear as sound.

There are more complex descriptions of what a driver is[viii] beyond the scope of this document; for purposes of what we're discussing, you've learned all you need to learn!

3.2 BL – The Motor Force

3.2.1 Definition

The quantity BL refers to the magnetic force it the gap – B – and the length of wire experiencing that force – L. The magnetic flux, B, is measured in units called Teslas[ix]. The length of wire is measured in units called meters[x]. Not surprisingly, BL is measured in units of Tesla-meters, Tm. This unit is equivalent to Newtons[xi] per Ampere[xii], or N/A. A Newton is a unit of force, and an Ampere is a measure of current in the voice coil; thus BL tells us just how much force we get from the motor for every unit of current (which, when run through the impedance[xiii] of the voice coil gives us electrical power) we run through the system.

3.2.2 BL Impact on Loudspeakers

The BL parameter is a key parameter for loudspeaker performance. First and foremost, BL is a key driver of efficiency. All else being equal, a driver with a higher BL will generate more acoustic output (be louder) for a given amount of power applied. And in fact, efficiency is proportional to BL; if we double the BL, we double the acoustic output for a given power input.

BL also affects the Q of the driver; Q is a complex concept, but a quick summary can be made as follows: Q dictates the shape of the low end response of the driver. All else being equal, a higher BL will mean a shallower "knee" in the way the low end frequency response drops off. It also means the driver is better suited to bass reflex[xiv] cabinet, which enhances the low frequency output of the system.

The Q also affects the alignment of the driver/cabinet combination, which means the low frequency response will also change with the different BL. This graph shows the result of changing the Q of the driver for a given box design:

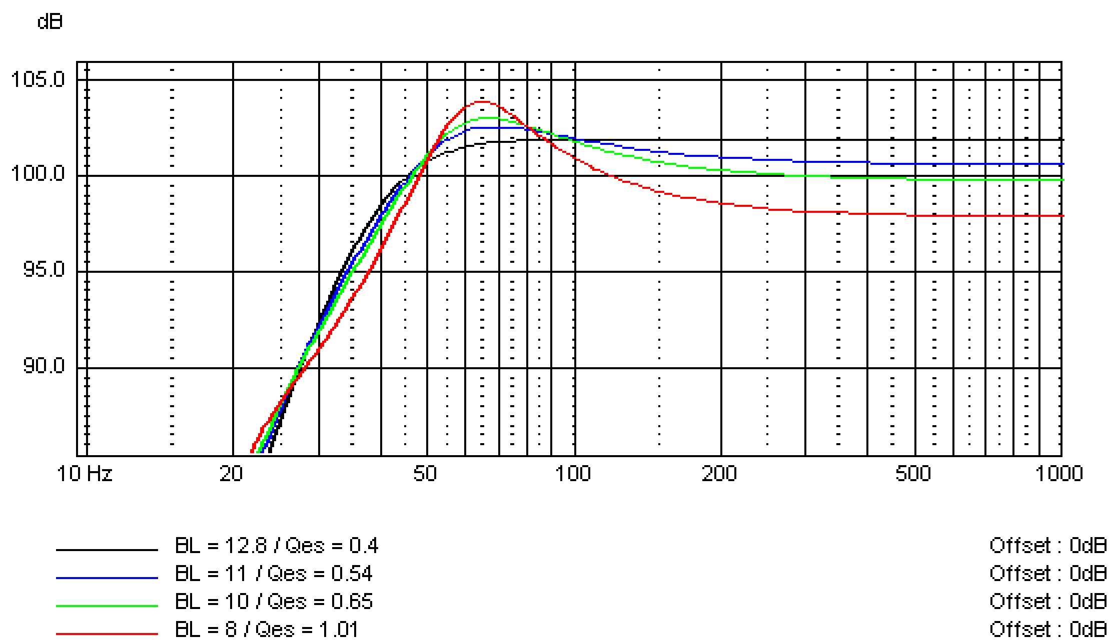

Figure 1 - Change in frequency response with change in BL

As is shown, the changes in Q affect the shape of the corner of the response, and these changes in Q correspond directly to changes in BL.

3.2.3 BL Curve

Now that we have defined BL and what it means to a loudspeaker, we can discuss what a BL curve is. Take the voice coil at its centered position, and measure the BL. This will give you the nominal BL of the driver. Now move the voice coil forward a little, and measure the BL. The change in the integrated flux will yield a new BL point for that position. Repeat this process over multiple locations and plot the values; you end up with a BL curve. A typical BL curve would be:

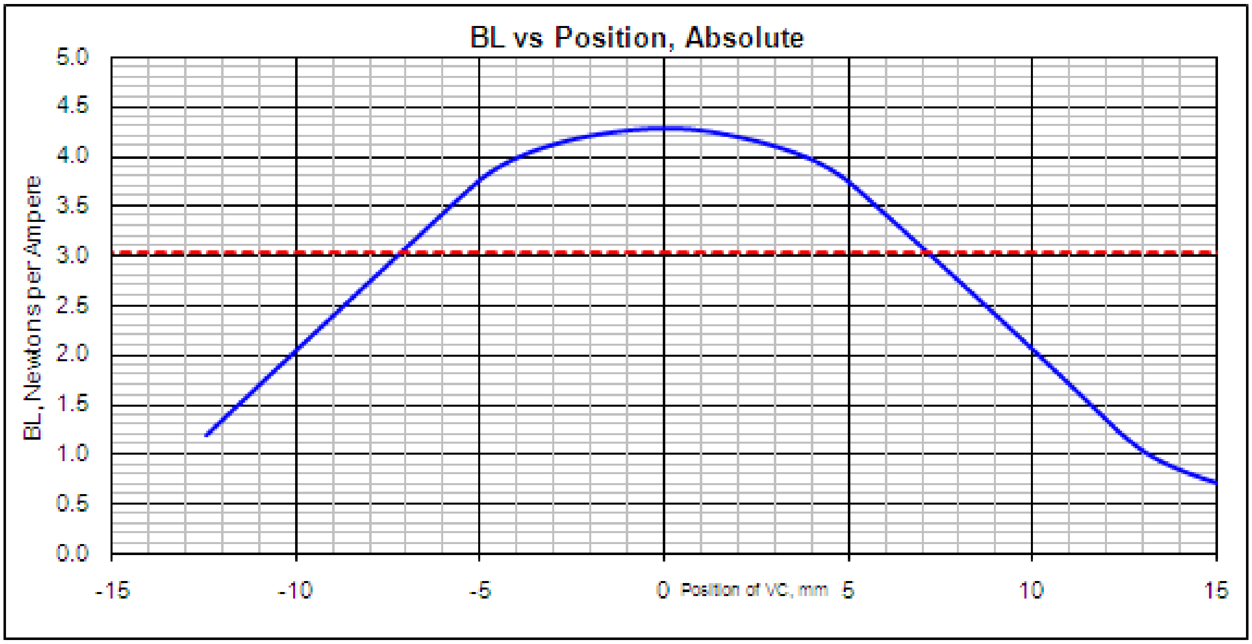

Figure 2 - A typical BL curve

3.2.4 Impact of Nonlinear BL Curve

Ideally, the BL should be constant over all range of motion; however, that is rarely the case (as we will see below). What happens when the BL changes? Typically the BL will drop as the driver moves; this implies that the efficiency of the driver also drops as the driver moves. This effect becomes a type of compression[xv] where the output of the driver does not scale linearly with applied power. Note this is not "power compression" from excessive heat in the speaker; this is a purely excursion and position-based effect, and will happen regardless of the other effects on the driver.

A nonlinear BL curve will also affect the way the driver and box interact; as we saw in Figure 1, as the BL of the driver changes the low frequency response changes. Imagine that the box low end response changes as shown in that graph as the driver moves more and more.

These two effects are just two of the more obvious changes; the biggest effect is distortion[xvi], or THD. As documented by Dr. Wolfgang Klippel[xvii] a nonlinear BL curve will generate THD. And the greater the nonlinearity, the greater the THD. THD has a negative impact on sound quality and accuracy of the signal, leading to a less than pleasant audio experience.

4 Existing Motor Topologies

There are three common designs or topologies for motors; these are the classic topologies used in 99.999% of all loudspeakers today. These are referred to as overhung, evenhung, or underhung. The "hungness" of the motor refers to the length of the voice coil relative to the magnetic gap. The different designs each integrate a different amount of flux over the length of the voice coil wire, and will result in different BL values versus excursion (BL curve).

4.1 General notes

For all examples we'll show, we are using a 38.5mm diameter voice coil, targeting a DC resistance in the 6.1 to 6.5 Ohm range, a voice coil mass of no more than 8 grams, a ceramic magnet that is 45mm ID by 90mm OD, a 16mm diameter pole vent, and typical clearances from the pole and top plate to the voice coil.

The mechanical clearance will be at least 30% more than the linear stroke (to protect from bottoming), and we will keep motor height less than 35mm and under 1300 grams.

This motor would be commonly found in a typical midwoofer/small subwoofer design.

The general driver parameters we'll use will be a cone/dustcap mass of 8 grams, 126 cm^2 cone area, a soft compliance of 0.7 mm/N, and an Rms of 1 kg/second.

4.2 Overhung

This design is the oldest and most used design today. Because the voice coil is long, it can dissipate a lot of power (the current flowing through the voice coil will dissipate a lot of power as heat). It also has a fairly low cost because the steel used to create the gap is very thin, and is often created by a stamping process.

For the overhung example, we have selected to do a short gap, long voice coil configuration because this configuration yields the lowest distortion of all overhung designs. The voice coil is 19mm long, the gap is 6mm tall, and the magnet is increased to 18mm thick to allow for the required mechanical clearance.

The actual motor part dimensions are:

Top plate: 41.5mm ID, 85mm OD, 6mm thick
Magnet: 45mm ID, 90mm OD, 18mm thick Y30 grade ceramic
Back plate: 16mm ID, 85mm OD, 6mm thick
Pole piece: 16mm ID, 37.8mm OD, 27mm high (3mm extension)
Voice coil: 38.5mm ID, 0.1mm thick former, 0.25mm diameter copper wire, 2 layers, 19mm long

With this design, we end up with the following Thiele Small parameters[xviii]:

Fs	48.6 Hz	Re	6.1Ω	Sd	126 cm²
Qms	4.68	Le	0.994 mH	Xmax	7.78mm
Qes	1.557	BL	4.3 N/A	SPL	82.4 dB
Qts	1.168	Mms	15.34 g	Xmech	11.5 mm
Vas	15.47 L	Cms	0.7 mm/N	Driver Mass	1.64 kg

For this overhung motor, the flux pattern is:

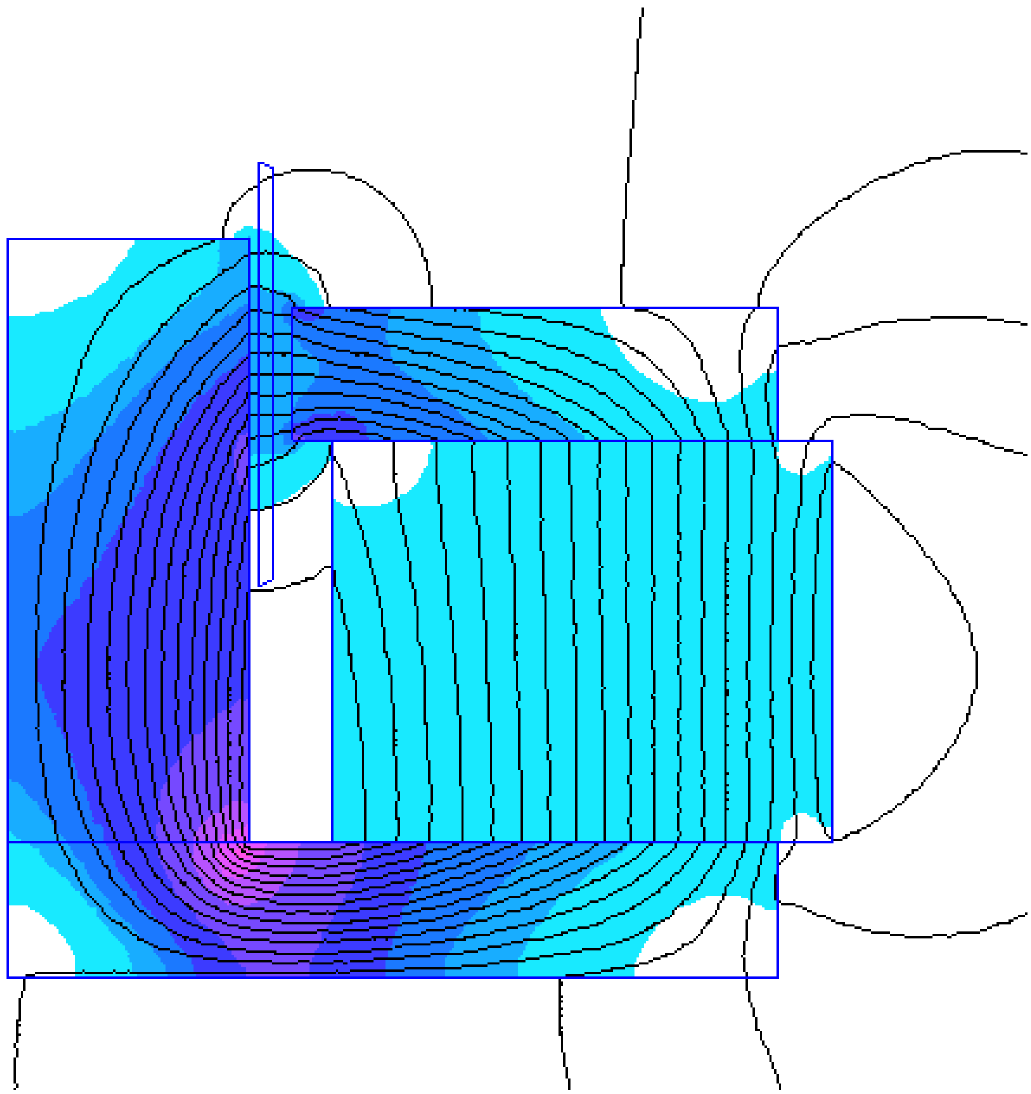

Figure 3 - Overhung Flux Diagram

And it also has the advantage of using all the magnetic flux in the gap, as well as a lot of the flux outside the gap (called the fringe field). We see that the field outside the gap is quite strong and extended, so that the voice coil hanging outside the gap integrates a significant amount of additional flux. The flux in the gap, and in the fringe field around the gap, would have a magnitude of:

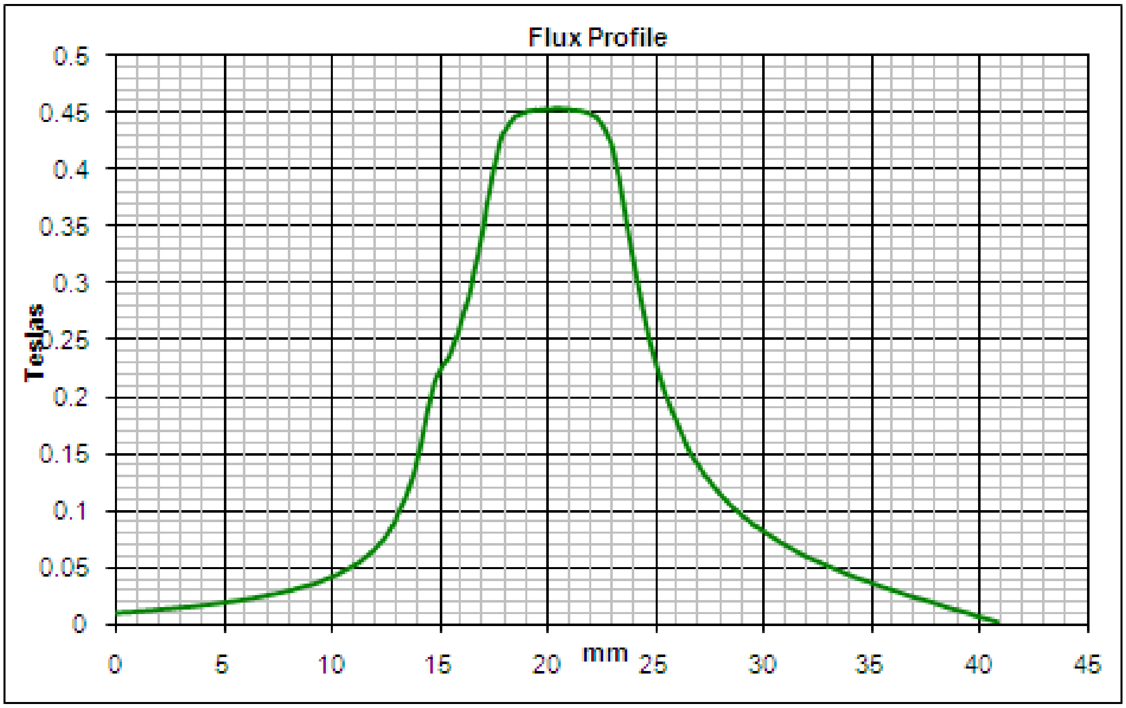

Figure 4 - Flux Profile for an Overhung Motor

The BL curve generated by this overhung motor has a typical shape like this:

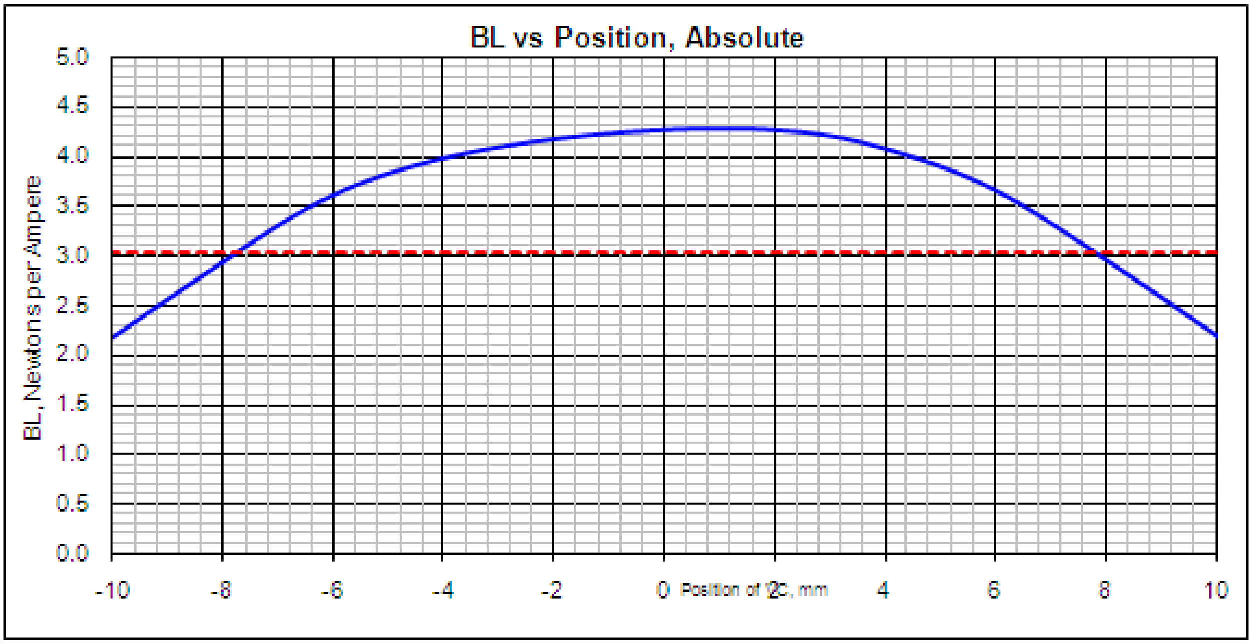

Figure 5 - Typical Overhung BL Curve

The curve has a generally parabolic, bell-curve like shape, and while the overhang is 6.5mm, we see the actual linear excursion limits are 7.78mm one way (where the blue BL curve intercepts the red linear limit).

For the above BL curve – which is quite symmetric for an overhung speaker design – we have a THD curve like this:

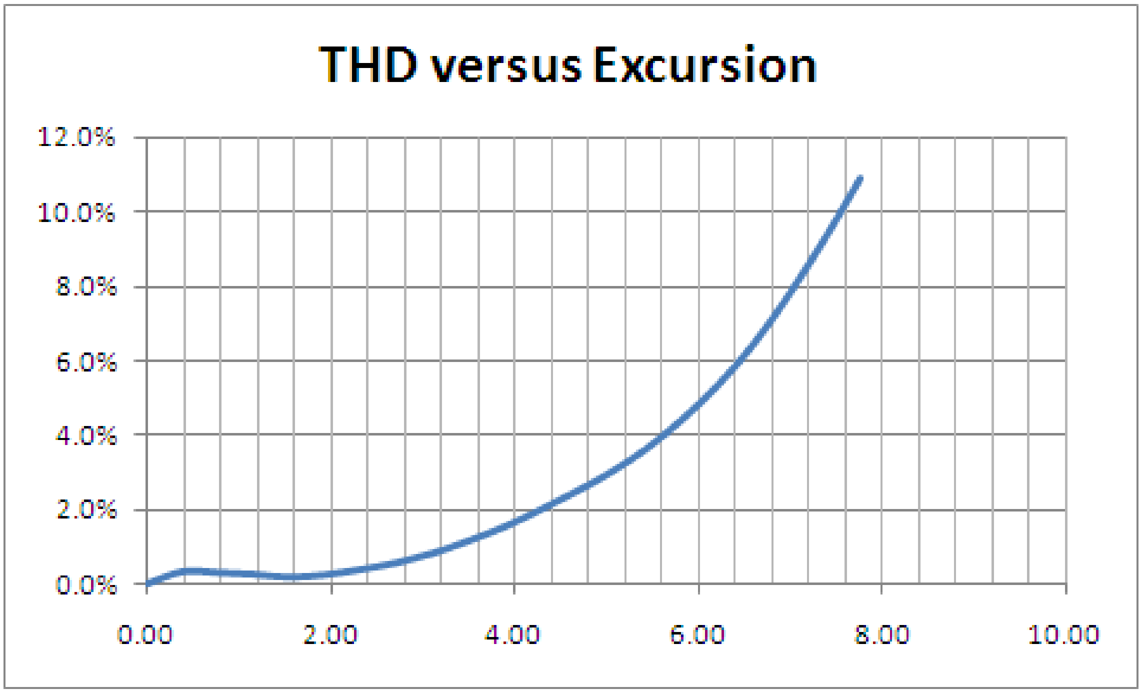

Figure 6 - THD of example overhung motor

There are several drawbacks to this design, however. To gain more stroke, we have to make the voice coil longer. But as the voice coil length increases the inductance[xix] of the voice coil increases, meaning that high frequency output is limited.

The longer length also means more wire, so it becomes a heavier assembly. More weight means lower sensitivity of the speaker – less acoustic output.

And a longer voice coil also means that you need more clearance behind the gap; if the voice coil hangs out 5mm below the gap, and it moves rearward 12mm, you need at least 17mm of clearance between the steel parts. And the longer voice coil means that – if the voice coil tilts – it will scrape the motor parts easier, so you often have to make the gap and clearance distances within the motor larger.

4.3 Evenhung

Evenhung refers to a situation where the voice coil length is exactly the same length as the magnetic gap. It is rarely used today, typically found only in extremely limited excursion devices such as micro speakers used in laptops, headphones, or tweeters.

For the evenhung example, the voice coil is 9.5mm long, the gap is 9.5mm tall, and the magnet is reduced to 12mm thick since we do not need the extra height for clearance. A shorter magnet will start to lose flux, so we chose 12mm as the lower limit.

The actual motor part dimensions are:

Top plate: 41.5mm ID, 85mm OD, 9.5mm thick
Magnet: 45mm ID, 90mm OD, 12mm thick Y30 grade ceramic
Back plate: 16mm ID, 85mm OD, 6mm thick
Pole piece: 16mm ID, 37.8mm OD, 24.8mm high (3mm extension)
Voice coil: 38.5mm ID, 0.1mm thick former, 0.25mm diameter copper wire, 4 layers, 9.5mm long

With this design, we end up with the following Thiele Small parameters[xx]:

Fs	48.7 Hz	Re	6.02Ω	Sd	126 cm^2
Qms	4.67	Le	1.286 mH	Xmax	5.13mm
Qes	0.675	BL	6.48 N/A	SPL	86.1 dB
Qts	0.59	Mms	15.26 g	Xmech	12.15 mm
Vas	15.47 L	Cms	0.7 mm/N	Driver Mass	1.54 kg

For this example the flux pattern is:

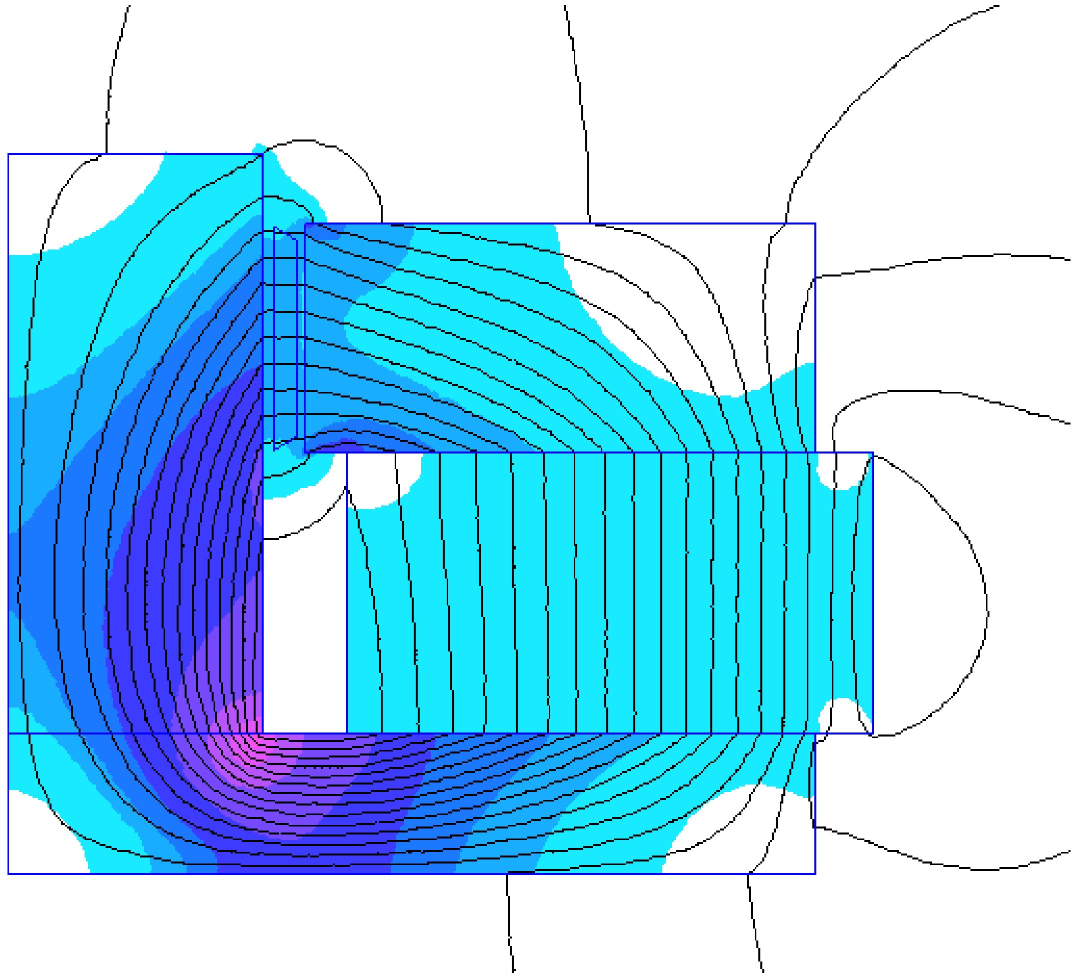

Figure 7 – Evenhung flux diagram

The voice coil integrates all the flux in the gap at the zero position, but as the voice coil starts to move it trades off integrating the stronger gap flux for the weaker fringe field. The flux in the gap, and in the fringe field around the gap, would have a magnitude of:

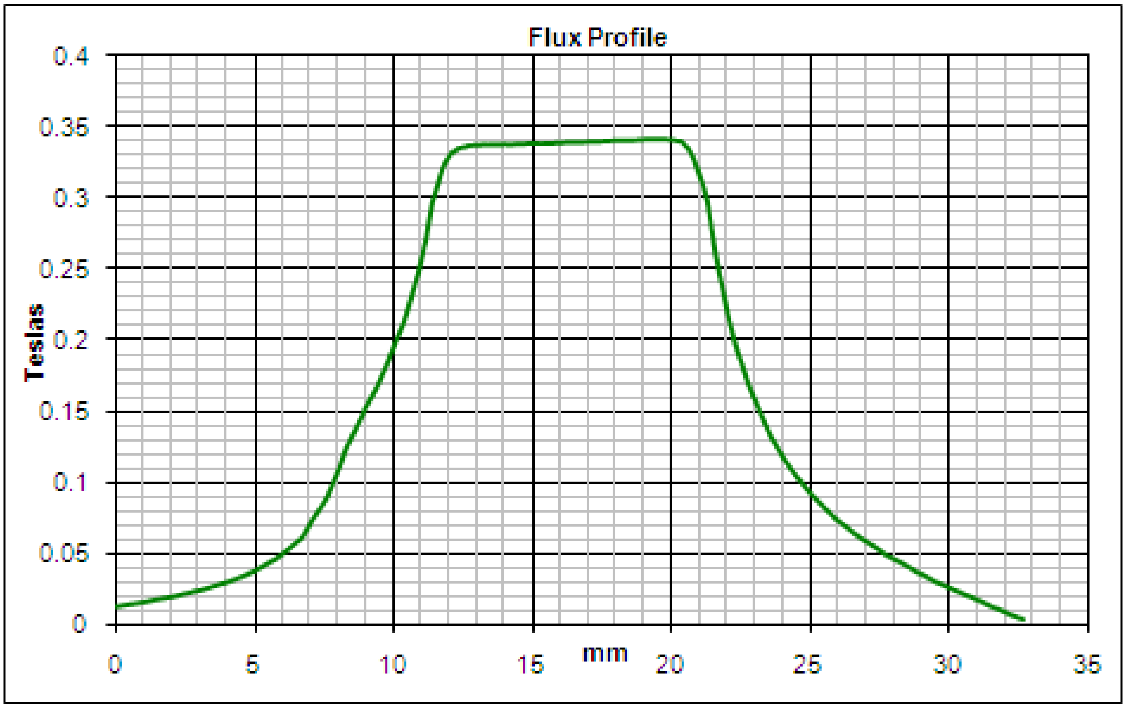

Figure 8 – Flux profile for an evenhung motor

The BL curve generated by an evenhung motor has a typical shape like this:

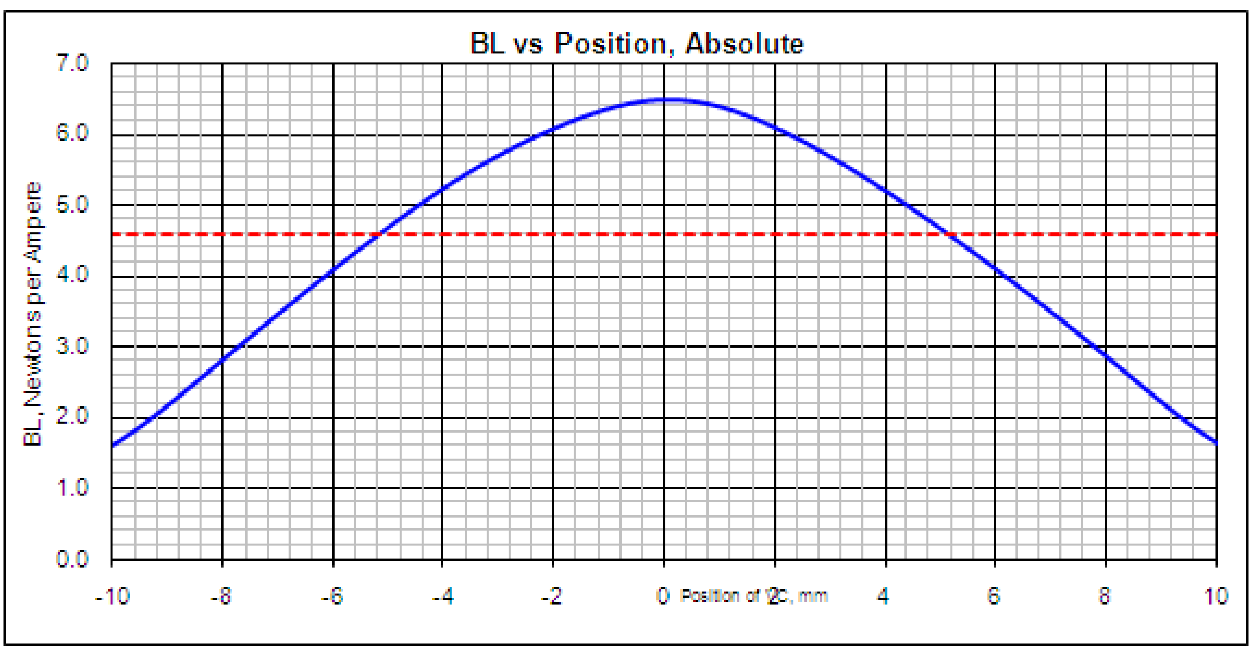

Figure 9 - Typical evenhung BL curve

The curve has a very parabolic shape, and while the driver has no overhang we see the actual linear excursion limits are 5.13mm one way (where the blue BL curve intercepts the red linear limit).

For the above BL curve – which is quite symmetric for an evenhung speaker design – we have a THD curve like this:

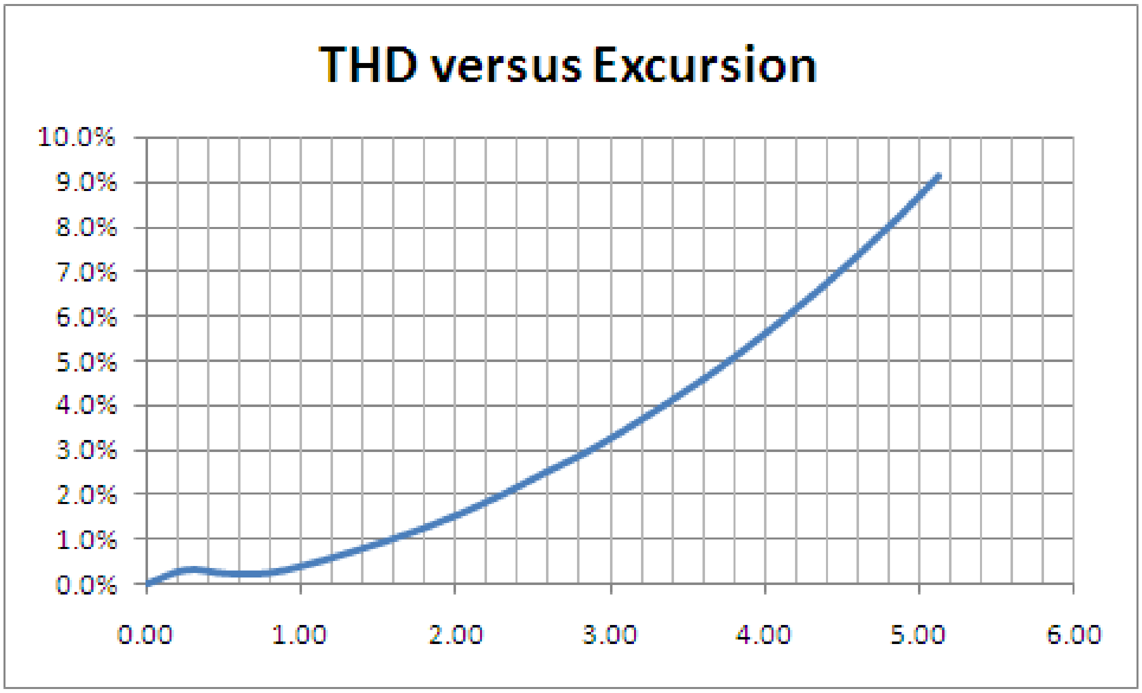

Figure 10 - THD of example evenhung motor

We see the THD is higher than the overhung design; even though the BL curve has generally the same shape, the smaller linear excursion limit causes the THD to rise faster than the overhung design.

4.4 Underhung

Underhung refers to a situation where the voice coil length is less than the length of the magnetic gap. This is the typical approach used to linearize the performance of a speaker, but it has several drawbacks that we will discuss in a minute.

For the underhung example, the voice coil is 6.6mm long, the gap is 12mm tall, and the magnet is reduced to 12mm thick since we do not need the extra height for clearance. A shorter magnet will start to lose flux, so we chose 12mm as the lower limit.

The actual motor part dimensions are:

Top plate: 41.5mm ID, 85mm OD, 12mm thick
Magnet: 45mm ID, 90mm OD, 12mm thick Y30 grade ceramic
Back plate: 16mm ID, 85mm OD, 6mm thick
Pole piece: 16mm ID, 37.8mm OD, 24.8mm high (3mm extension)
Voice coil: 38.5mm ID, 0.1mm thick former, 0.22mm diameter copper wire, 4 layers, 6.6mm long

With this design, we end up with the following Thiele Small parameters[xxi]:

Fs	54.1 Hz	Re	6.04Ω	Sd	126 cm^2
Qms	4.2	Le	0.867 mH	Xmax	6.5mm
Qes	1.66	BL	3.93 N/A	SPL	83.5 dB
Qts	1.19	Mms	12.37 g	Xmech	14.7 mm
Vas	15.47 L	Cms	0.7 mm/N	Driver Mass	1.63 kg

For this example the flux pattern is:

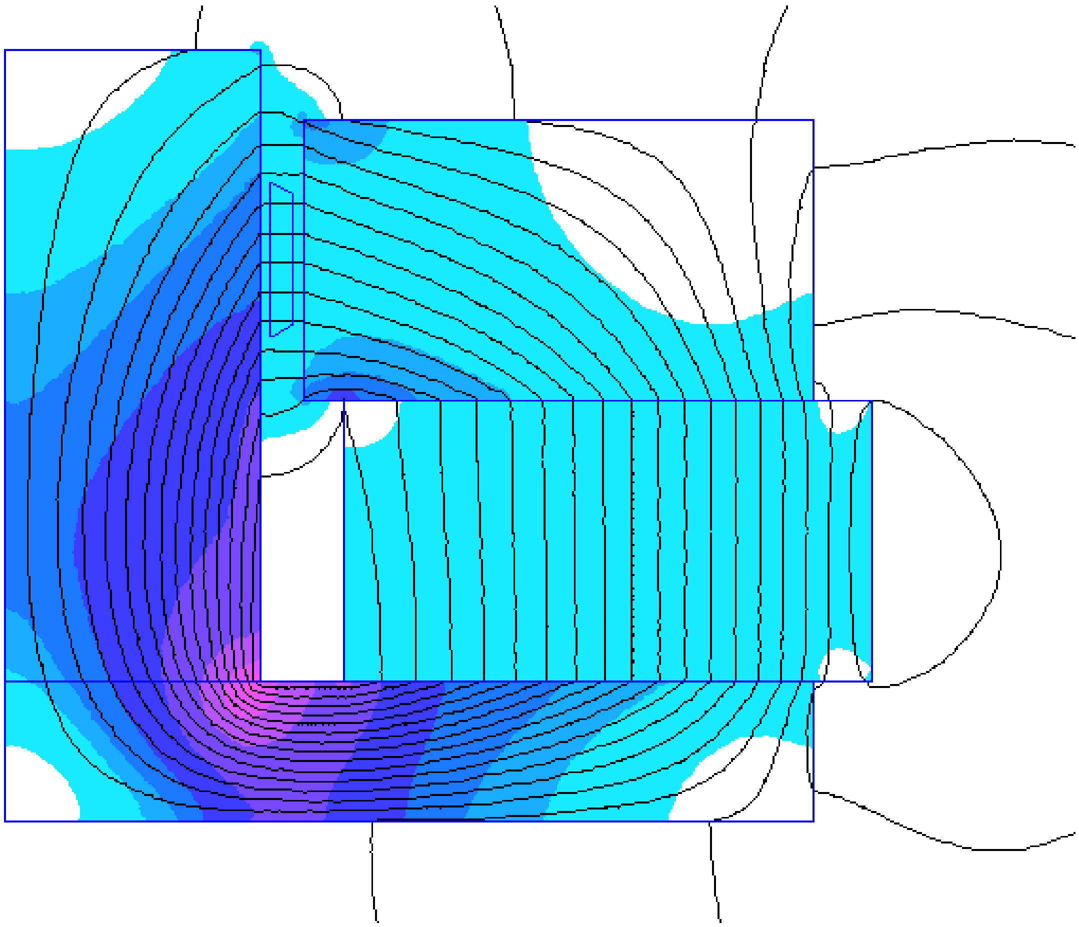

Figure 11 - Underhung flux diagram

This design is also quite old, and still sees limited use today. The voice coil is very short, so the inductance can be reduced, and moving mass is also lower as compared to the overhung or evenhung designs. However we see a significant loss of BL because a large amount of flux in the system is not integrated.

The voice coil integrates only a small portion of the flux in the gap at the zero position, but maintains that integration over a large range of motion. The total flux integrated is nearly constant until the voice coil starts to leave the gap, which in this example would occur after 2.7mm of motion.

The flux in the gap, and in the fringe field around the gap, would have a magnitude of:

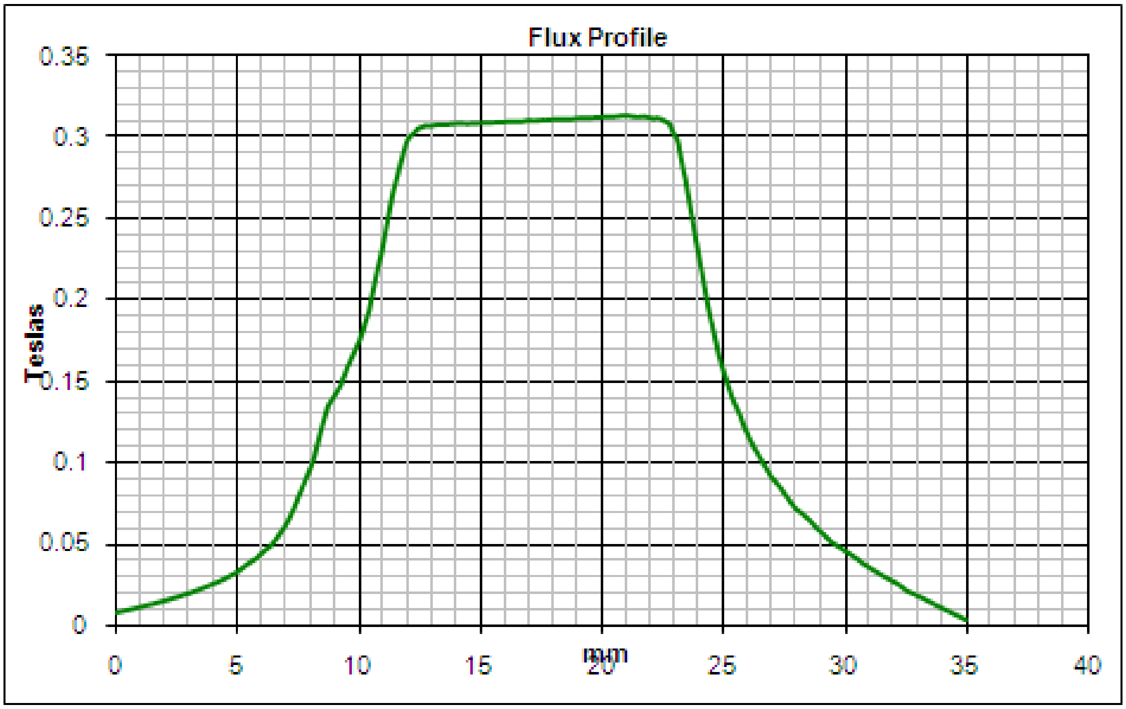

Figure 12 - Flux profile for an underhung motor

For the aforementioned 8mm voice coil, the BL curve generated by an overhung motor has a typical shape like this:

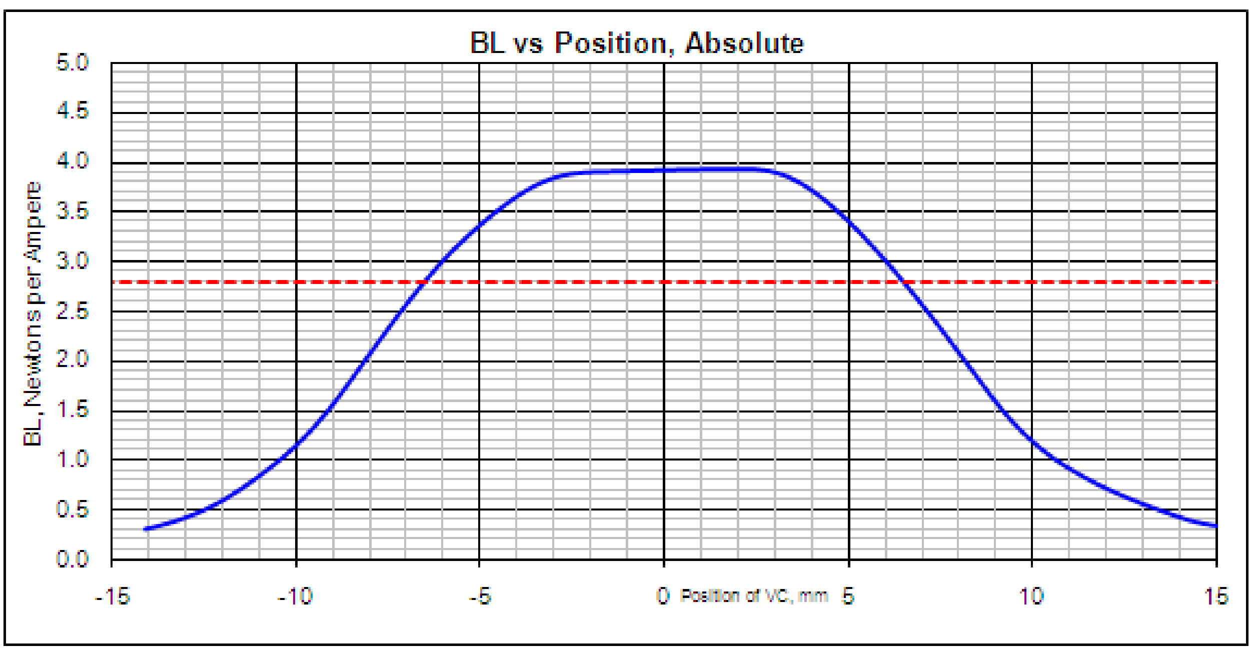

Figure 13 - Typical underhung BL curve

In this case, we have a 12mm tall gap with an 6.6mm long voice coil. The curve is flat in the middle, with a fairly fast drop in BL on either side. We see the BL starts to drop after 2.7mm, when the voice coil starts to move out of the gap, and the actual linear excursion limits are 6.5mm one way (where the blue BL curve intercepts the red linear limit).

For the above BL curve we have a THD curve like this:

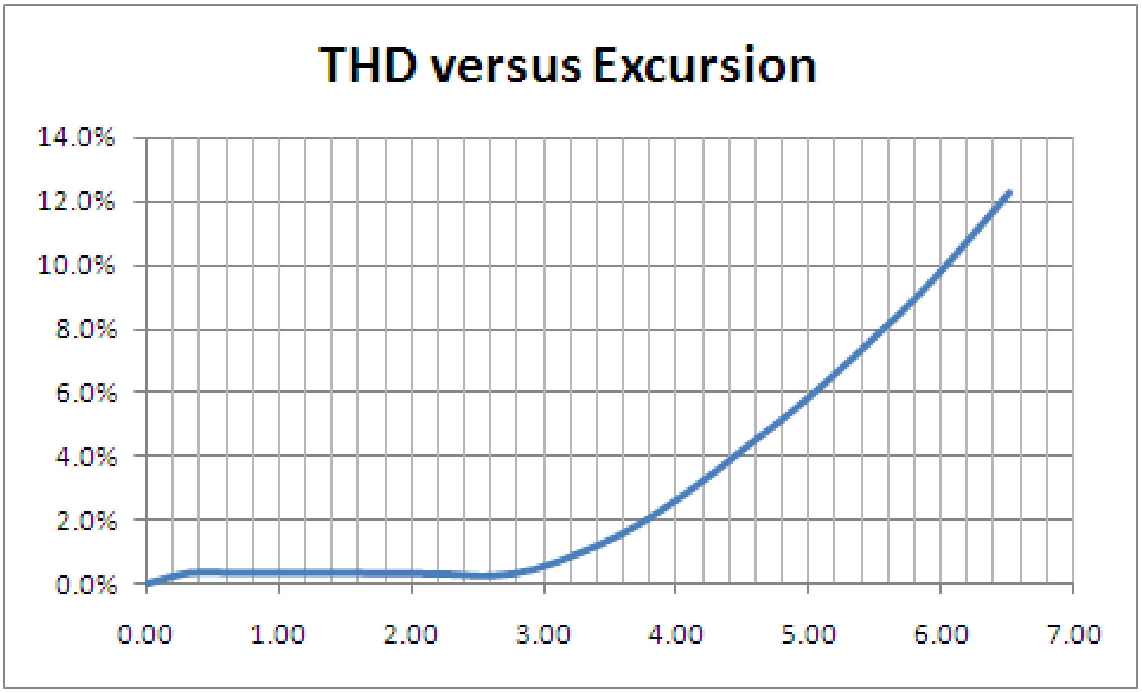

Figure 14 - THD of example underhung motor

We see the THD is very low until the voice coil starts to leave the gap, at which point THD increases at a rate similar to the overhung and evenhung versions.

Another drawback is the obvious reduction in BL. The lack of integrating the fringe field lowers the BL because of the lower B and lower L. And of course because of the shorter voice coil, power handling is reduced.

5 XBL

XBL is a new, patented motor technology. A groove is placed within the magnetic gap, creating two smaller, high intensity fields. The voice coil is set to a length so that an equal portion of each gap is covered at rest, and the voice coil will integrate a constant amount of flux as it moves.

For the XBL example, the voice coil is 9.8mm long, the gap is 12mm tall, and the magnet is reduced to 12mm thick since we do not need the extra height for clearance. A shorter magnet will start to lose flux, so we chose 12mm as the lower limit.

The actual motor part dimensions are:

Top plate: 41.5mm ID, 85mm OD, 12mm thick with a 5.4mm tall rebate that is 2mm deep
Magnet: 45mm ID, 90mm OD, 12mm thick Y30 grade ceramic
Back plate: 16mm ID, 85mm OD, 6mm thick
Pole piece: 16mm ID, 37.8mm OD, 27mm high (3mm extension)
Voice coil: 38.5mm ID, 0.1mm thick former, 0.25mm diameter copper wire, 4 layers, 9.5mm long

With this design, we end up with the following Thiele Small parameters[xxii]:

Fs	48.7 Hz	Re	6.02Ω	Sd	126 cm^2
Qms	4.67	Le	1.12 mH	Xmax	8.6mm
Qes	0.789	BL	5.99 N/A	SPL	85.4 dB
Qts	0.675	Mms	15.26 g	Xmech	13.3 mm
Vas	15.47 L	Cms	0.7 mm/N	Driver Mass	1.6 kg

The flux pattern for this example would be:

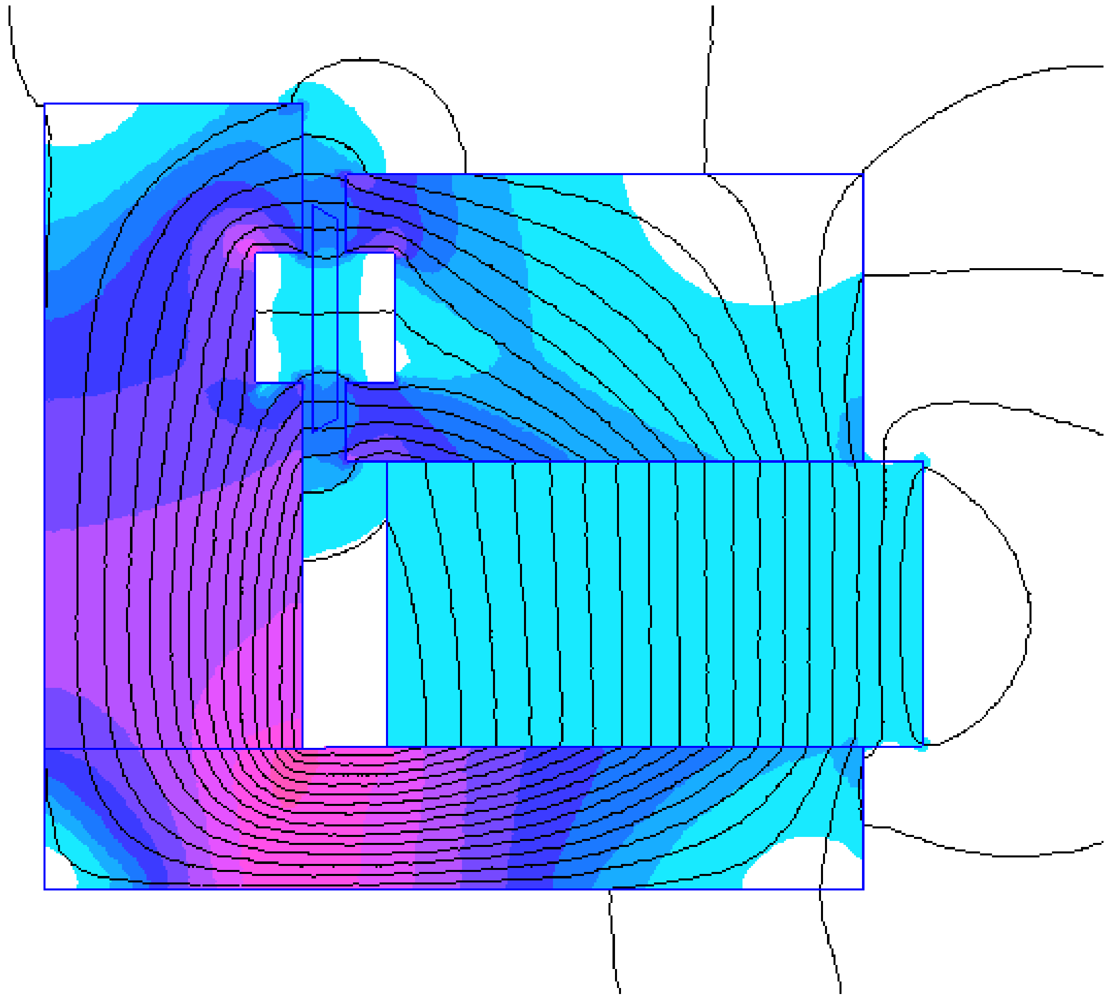

Figure 15 - XBL flux diagram

This design is covered by US Patent 7,039,213. For this example, the top plate is 12mm high, the rebate is 5.4mm tall, meaning each gap is 3.3mm tall. The voice coil is 9.5mm long, and centered on the top plate.

The voice coil integrates a full gap's worth of flux, plus a considerable portion of the fringe field either between the gaps or outside the top plate. The total flux integrated is nearly constant until the voice coil starts to leave the either gap towards the outside of the plate, which in this example would occur after 8mm of motion.

The flux in the gap, and in the fringe field around the gap, would have a magnitude of:

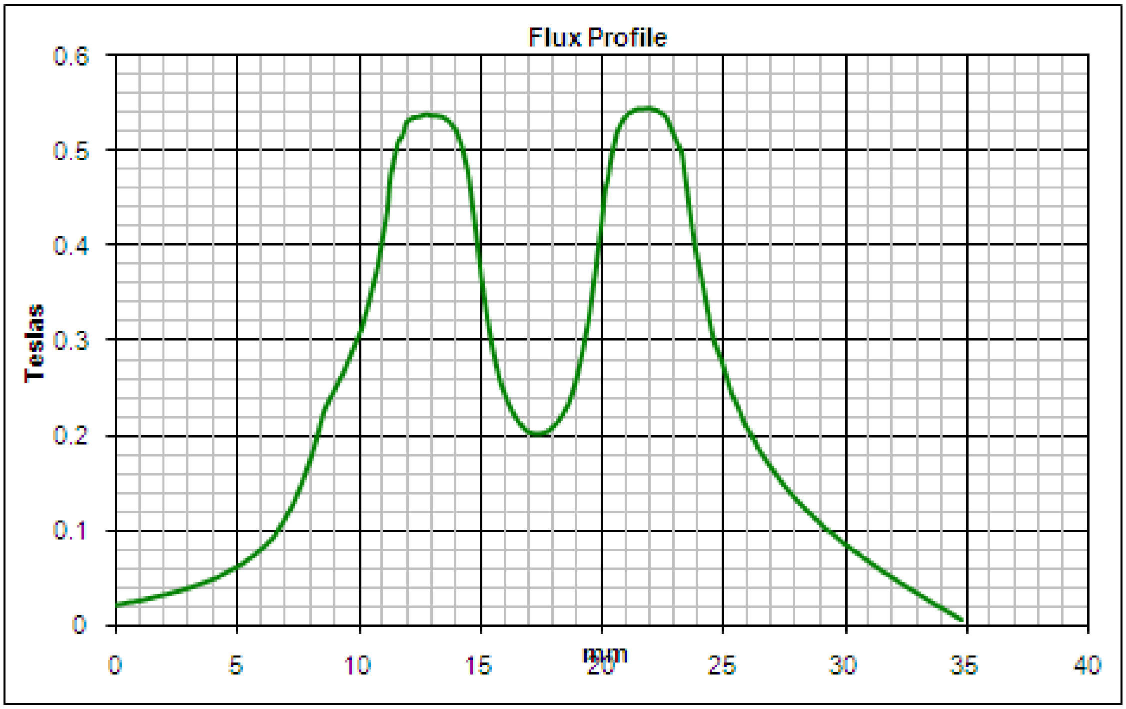

Figure 16 – Flux profile for an XBL motor

For the aforementioned 9.5mm voice coil, the BL curve generated by an overhung motor has a typical shape like this:

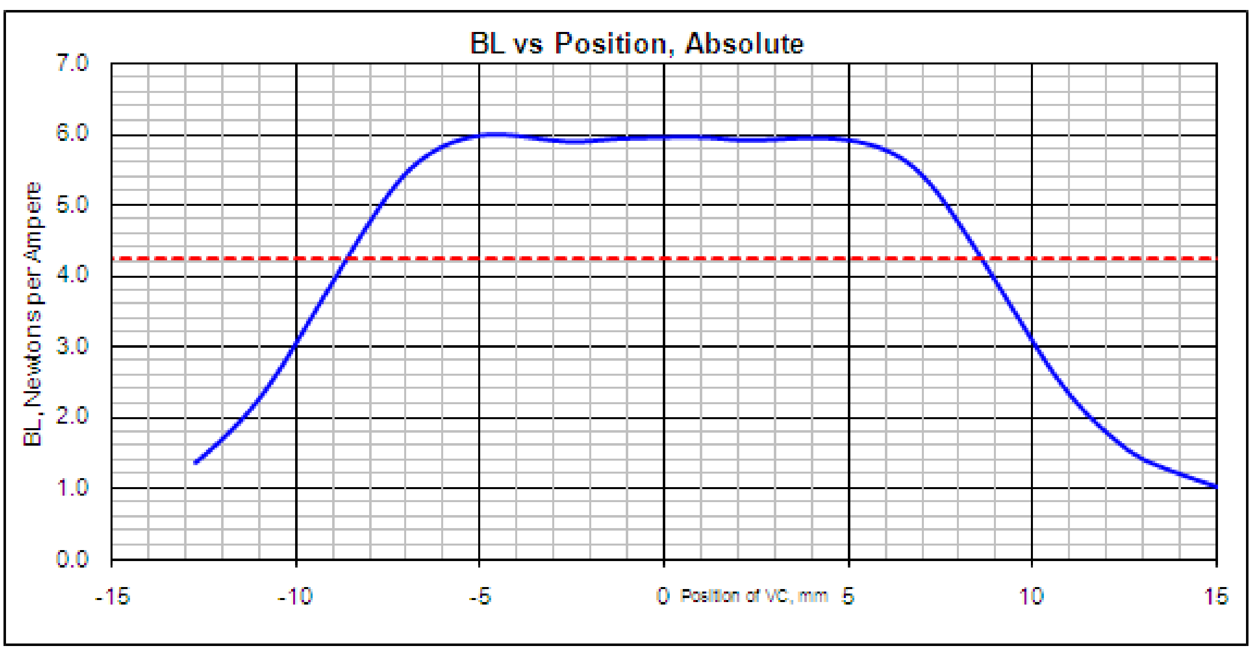

Figure 17 - Typical XBL BL curve

The curve is flat in the middle – the center 12mm of the curve is essentially flat within 1%. And we see a fairly fast drop in BL on either side. We see the BL starts to drop after 6mm, when the voice coil starts to move out of the gap, and the actual linear excursion limits are 8.6mm one way (where the blue BL curve intercepts the red linear limit).

For the above BL curve we have a THD curve like this:

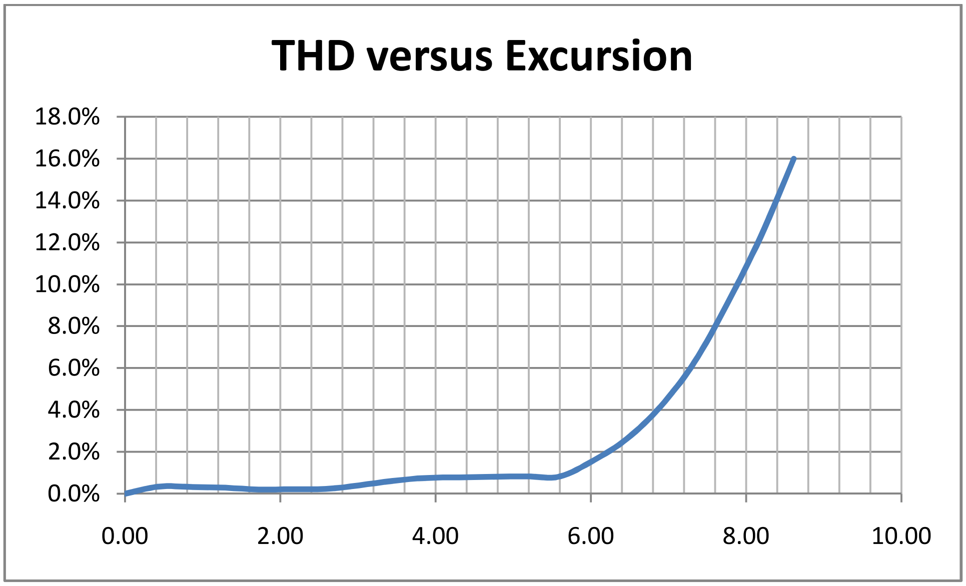

Figure 18 - THD of example XBL motor

We see the THD is extremely low until the voice coil starts to leave the outside edges of the gap, at which point THD increases at a rate similar to the overhung and evenhung versions. The THD is below 3% until 6.6mm one way excursion.

While the voice coil is shorter than the overhung or evenhung, it is the same length as the underhung meaning it has acceptable power handling. Inductance and mass are between the evenhung and underhung, and considerably less than the overhung. Most importantly, the XBL driver has the best THD performance by a large margin.

6 Conclusions

Overall, the XBL motor shows significant advantages over the overhung, evenhung, and underhung designs.

As compared to the overhung, the XBL motor has a higher BL for a given Re and Mms. Additionally, it has more stroke, a lighter motor structure, and can have a shorter motor as well.

As compared to the evenhung, the XBL motor has greatly increased linearity of stroke.

As compared to the underhung, the XBL motor has more stroke, higher BL, and lower distortion.

Overall when given a consistent set of target parameters, an XBL motor typically yields the lowest THD, the highest stroke, nearly the highest BL, and one of the lowest moving masses and inductances possible. And it does so in potentially the shortest overall motor height.

7 Endnotes

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[i] US Patent 7,039,213
[ii] http://en.wikipedia.org/wiki/Magnetic_flux
[iii] http://en.wikipedia.org/wiki/Ferrite_(magnet)
[iv] http://en.wikipedia.org/wiki/Alnico
[v] http://en.wikipedia.org/wiki/Neodymium_magnet
[vi] http://en.wikipedia.org/wiki/Voice_coil
[vii] http://en.wikipedia.org/wiki/Electromagnet
[viii] A good primer on drivers is found at HowStuffWorks: http://electronics.howstuffworks.com/speaker7.htm. Also, Wikipedia (http://en.wikipedia.org/wiki/Woofer) contains some good information.
[ix] http://en.wikipedia.org/wiki/Teslas
[x] http://en.wikipedia.org/wiki/Meter
[xi] http://en.wikipedia.org/wiki/Newtons
[xii] http://en.wikipedia.org/wiki/Ampere
[xiii] http://en.wikipedia.org/wiki/Electrical_impedance
[xiv] http://en.wikipedia.org/wiki/Bass_reflex
[xv] http://en.wikipedia.org/wiki/Audio_level_compression
[xvi] http://en.wikipedia.org/wiki/Distortion
[xvii] http://www.klippel.de
[xviii] http://www.mhsoft.nl/TSP_ex.html
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