Subwoofer design with moving magnet linear motor

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Subwoofer design with Moving Magnet Linear Motor

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ABSTRACT

A new electro-dynamic transducer has been studied, based on a moving magnet linear motor instead of a traditional moving coil, and it has been carefully described into a recently presented paper from Claudio Lastrucci. This moving magnet motor could considerably improve the conversion efficiency and the sound quality at the lowest frequency range. It has been developed around a fully balanced and symmetrical moving magnet motor geometry and it can reduce the distortion, in the lowest range, to a fraction if compared to that of a conventional moving coil loudspeaker in the same range. It also offers a considerably higher power handling and overall robustness thus being able of reproducing the lowest range on bass spectrum with an unprecedented level of quality and output. The novel motor design also shows a considerable high acceleration that makes it suitable for the application also in the upper bass region. This paper proposes a review of the methodology that can be pursued in subwoofer design while using this motor technology. The new motor technology will require a different approach to subwoofer design. Several aspects that are in common with conventional loudspeakers will be outlined while also described those characteristics that differs significantly. The application of the technology and relative results will be shown through examples of practical applications and with measurement results.

1. INTRODUCTION

Moving Magnet Transducers systems have remained very little explored for long time. One of the main reasons for this is the limited availability, up to some years ago, of magnetic materials capable of concentrating high magnetization energy in a limited volume and mass. Then the inherent simplicity of the moving coil transducer realization has still kept showing several advantages in low frequency transducer system.

In fact, although the theoretical concept of a moving magnet transducer was already valid also with lower grade magnetic materials, the developing of the idea has become more interesting and effective with the recent availability of high-grade neodymium magnets that allow for concentrating a very high magnetic field in a relatively limited mass and volume, at a reasonable cost. This is a crucial aspect for a moving magnet linear motor because it allows reducing the moving mass to a reasonable value, thus obtaining acceleration values that could be comparable or even higher than standard designs.

This new motor has been developed around a fully balanced and symmetrical geometry. This characteristic allows for considerable large amount of very linear excursion with a lower distortion figures if compared to conventional moving coil design. In addition to this, the balanced symmetrical geometry is inherently stabilized and self-retained within the boundaries of the magnetic field.

2. THE MOTOR

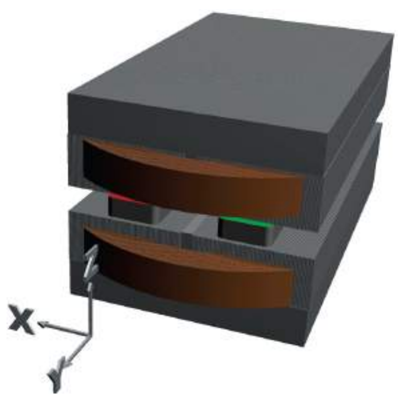

Figure 1 - Simplified drawing of the Moving Magnet Motor

This novel motor design has been designed around a very simple mechanical structure. As already mentioned, it represents a symmetrical fully balanced driving structure that is very linear and is able to achieve significant reduction in distortion, especially at the lowest frequencies and at highest excursion. Moreover, this novel motor geometry allows for a very good inherent self-protection from any possible over excursion, nevertheless, because of its symmetry and its linearity, it is virtually free from the DC component that usually affects low frequency transducers at large excursion.

The active magnetic portion of the device is based on two parallel bars of Nd-Fe-B magnets of the same size, facing to a common plane but with opposed magnetic field orientation (orthogonally to the plane XY in Figure 1).

Two coils are placed facing the bars of magnet, one coil for each side, creating a “sandwich” structure that holds the magnet within the coils.

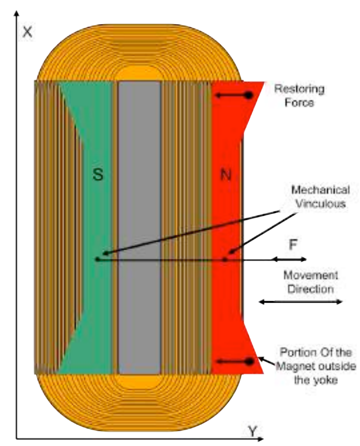

Figure 2 - Schematic drawing of the magnet bars and coil arrangement

The coils are wound using a ribbon of solid conductor, forming a winding of rectangular shape. The magnetic field generated by the magnets is forced to cross the conductor of the coils. Once the coils are subjected to current, a relative force between the coils and the magnet bars will be generated. This force will depend linearly on the intensity of the field generated by the magnets and the current flowing into the coil.

To maintain a very low reluctance path for the magnetic field generated by the permanent magnets, a mix of conductive material such as copper or aluminum and ferromagnetic material such as Silicon Iron have been incorporated into the exciting coils. The ribbon of conductor has been interleaved with properly shaped sheets of low losses Fe-Si, in a way to create a high permeability path across the coil turns.

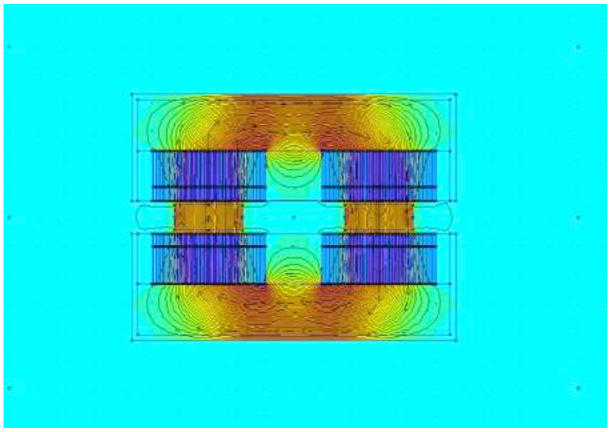

Figure 3 - Section view of the magnetic field generated by the magnets and the relative distribution inside the ferromagnetic structure, with no coil current excitation

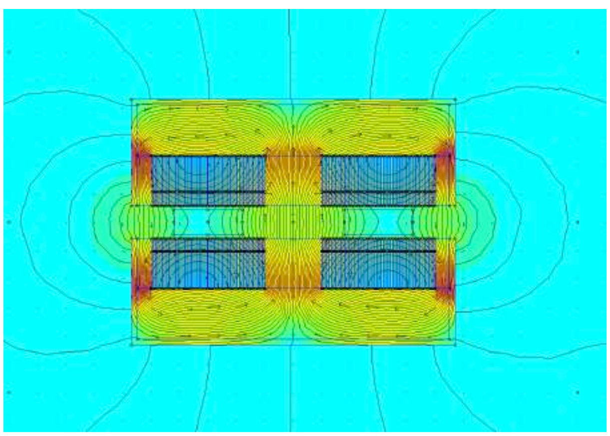

Figure 4 -Section view of the magnetic field generated by the coils excited by a current of 150A and the relative distribution inside the iron path.

Noteworthy coils arranged in such way they present a very anisotropic magnetic behavior:

The particular arrangement described so far, in fact, allows for high permeability through the coil plane (XY) and a very low relative permeability along transversal conductor direction. An outer ferromagnetic shell has been implemented to allow easy circulation of the steady field generated by the magnet bars and to create a defined path for the variable flux produced by the current flowing in the coils.

The magnets are positioned on a frame of composite material that provide a mechanical connection to the radiating part of the complete acoustical transducer.

Due to the natural symmetry of the device, this can be considered a push pull device, where both magnet bars and coils work completely symmetrical in respect to the axial displacement and each portion of the conductors provide either push or pull action on one magnet bar in a complementary fashion to the other specular portion of the motor.

Being symmetrical in the X and Z directions, the resulting pulling forces from the magnets to the steady ferromagnetic structures are nulled out and, with proper magnet bar shaping, it is possible to achieve magnetic centering of the moving parts without the need of springs or suspension.

3. FEATURES OF THE MOTOR STRUCTURE

One of the most evident features of a moving magnet design is the absence of conductors in the moving portion of the motor. The forces are provided by the interaction of the field that is generated by the steady coils and the field generated by the magnets that do not need to be energized by any connection. With proper design, no eddy currents flows inside the magnets and the heat generated in the motor is due only the losses in the coils conductor. Furthermore, the absence of flexible conductors connected to the moving parts improves reliability during the transducer operation, even with extreme acceleration and displacement.

The stationary coils of this motor design are built with very large cross section conductors, not having any constraints other than the cost of the conductor material and weight of the motor. These coils can dissipate more easily the heat and have at least one surface facing towards outside of the device, allowing very low thermal to ambient resistance. Moreover, being built on large cross section and compounded with thermal filler, the motor does not have a specific thermal hot spot. The thermal model is very simple and based on thermal capacity and thermal resistance of the entire device, and is much higher than that of a high power moving coil design, up to two orders of magnitude.

As a peculiarity, it is possible to further increase the efficiency of the motor by increasing the cross section of the conductor's coils without any loss of field, as the anisotropic behavior of the compounded coils maintains the conductor cross reluctance constant against the width of the conductive ribbon.

This freedom of design provides a unique chance to reduce the coils resistance arbitrarily, whilst keeping the Bl value and the moving mass of the system unvaried. Some tests have been performed and they confirmed the possibility to design this device in a way that can exhibit values of Motor Strength above 12,000 (Bl of 20N/m and coils resistance of 30 milliOhm).

This is a very important point, in fact, the performances of a moving magnet transducer depend on the capability to accelerate the "load" fast enough to provide the power bandwidth for a certain application. Some of the real world samples tested, with a specific design of the coils and yoke allows the motor to achieve a Peak Force to Mass ratio of 6500N/Kg of magnet, over a linear displacement of 30 mm peak to peak. This level of displacement can be requested in extremely high SPL applications up to 100 Hz. Different dimensioning of both the coils and magnets can further increase the excursion capability. This is still a trade-off between low frequency maximum output level and power bandwidth, as it happens with conventional moving coils.

The limit of the Peak Force to Mass ratio also comes from the properties of the magnet material; highly coercive materials with high Energy Product clearly deliver the best performances and it appears a promising technology, with further developments in near future. The trend of magnet performances envies a constant progress toward extremely high-energy product compounds, improving the results even further.

Another crucial feature of this motor design is represented by the fact that the design of the yoke shape permits magnetic centering of the moving parts. In this way it is possible to create a magnetic restoring system that acts like a mechanical springs.
The nature of any magnetic circuit seeking the lowest energy condition, allows geometric definition through the shape of the coils and the magnets, creating a pulling profile that pull back the moving parts to the rest position. An "end of stroke" non-linear behavior of these magnetics springs can provide a steeper fall of compliance toward the extreme displacements condition, behaving as a gentle limiting action in the event of over excursion situations.

4. GENERAL SUBWOOFER DESIGN WITH T/S PARAMETERS

The general approach to subwoofer design is based on Thiele and Small parameters to calculate the acoustic transfer function of the loudspeaker transducer combined with its box, in addition to impedance curve, cone excursion and other performance parameters. The use of T/S parameters has been diffused since the late 70's and it represents a very simple and practical method that is largely embraced by most of the loudspeaker designers.

Anyway, the traditional approach to the using of the T/S parameters is aimed to optimizing box parameters to hit a desired target acoustic response. For the vented box design, for examples, very often a maximally flat response is desired down to some possible LF extension, sometime else it is desired an acoustic transfer function with more gentle roll-off, or alternatively, the maximum possible low frequency extension with under-damped design and some limits of acceptable ripple in the response. These targets can be achieved with a number of box Volume (Vb) + Tuning Frequency (Fb) + Loss Factor (Qb) combinations, eventually assisted by some electronic high pass filter with some specific response shape determined by the filter Q. Closed box design, could be also approached in a similar way and also in this case, a number of possible "alignments" could be found interesting for the target frequency response. There are a number of additional LF box design that may use the closed box and vented box design combined together or combined with other acoustic loading. I all these cases, the traditional design approach aims to make the LF system delivering (with some approximations) some desired target acoustic frequency response, regardless the amplifier that will be used to drive it. Typically, this frequency response will be maximally flat down to the low cut frequency point.

So, whatever it is the desired target response, this approach is intended to design a subwoofer that can be eventually driven by any generic amplifier available, in a classic "Voltage Driven" approach, where the amplifier is considered an ideal voltage source with the minimum possible output impedance, and where the overall result will be very similar, regardless the specific amplifier that is going to be used to drive it. This approach has been widely developed during the years, from when the very low output impedance amplifiers based on solid-state circuitry are available.

And following this approach, in order to match easily the typical target acoustic response, the transducers should usually have a preferred set of parameters. For example, in a typical vented box design, a moderately low Qts (0.25 to 0.42) is desired to easily achieve good and flat LF extension while keeping box dimensions relatively small.

So, the optimal transducer to mate with this approach will have a set of parameters that will be very different from those of a very high efficiency loudspeaker. Both Don Keele and John Vanderkoy, several years ago, they have already shown the eventual advantages (and disadvantages) of very high efficiency loudspeakers based on very high Bl (very high Motor Strength) design. Beside the substantially higher efficiency of these designs, in fact, there are some disadvantages if they are driven very from a standard and low output impedance amplifier available on the market, especially if they are based onto traditional analog design.

Very high motor strength transducers, in fact, will show an impedance curve around the resonant frequency that could be extremely high, even with low values of voice coil resistance (Re) thus resulting in a very low sensitivity in their low frequency range and they require very high voltage level to be driven. In addition to that, such transducers will be very reactive producing a considerably high level of back e.m.f. that will result in a large amount of dissipated heat in the output stage of linear amplifier designs. This “over-damped” behavior might also result in a lack of feeling (and perception) of the bass range, also with appropriate voltage driving, because the electrical damping effect of the back e.m.f., it will act like a strong electro-mechanical brake on the cone movement.

So, a new perspective for high performances and high efficiency subwoofer designs was offered by the availability of switching amplifiers design (also referred as Class D amplifiers) that, for instance, are perfectly able (with some attentions) to manage large amount of back e.m.f. arriving from the loudspeakers and are also able to take advantage of recycling it into the power supply.

In addition to this, with the designing of specific dedicated amplifiers capable of very high output voltage, the necessary voltage to drive these transducers will not be a problem anymore.

Last, but not least, if the dedicated amplifier design will have an adjustable output impedance that can be eventually set to a desired value, different from zero, the “amplifier + transducer” combination the loudspeaker behavior can eventually be changed to match a specific acoustic design. The adjustable output impedance will work as a “virtual output resistance”, changing the amplifier to transducer interaction without any power loss. The overall system can still take advantage of the very high efficiency of an over-damped transducer but the resulting transfer function and system damping can be set to a specific desired behavior.

5. SUBWOOFER DESIGN USING THE NOVEL MOVING MAGNET DESIGN

Subwoofer design with the novel moving magnet transducer largely refers to the concept expressed into the last part of the previous chapter. The moving magnet design, in fact, being a very high motor strength transducer, it may feature a Bl^2/Re that can easily range between 2000 and 4000. This is a characteristic of a highly over-damped transducer and it is almost one order of magnitude higher than that of a normal moving coil loudspeaker in the market. In fact, normal values of Bl^2/Re for moving coil transducers can range from a minimum of 20 for very simple woofers or mid-bass to about 150 of high power subwoofer transducers, and up to about 500 of very high Bl, large format, very high power subwoofers.

For instance, the T/S parameters of two typical large format, moving coil transducers units for subwoofer application like 18” and 21” nominal diameter could be similar to these:

For a typical 18”:

- Fs = 35 Hz
- Re = 5 Ohm
- Bxl = 26 Tm
- Sd = 1225 cm^2
- Qts = 0.31
- Qes = 0.32
- Qms = 7.2
- Vas = 230 Lt
- Mms = 200g

- Xmx = +/- 10mm
- Vd = 1.22 Lt
- Le = 1.8mH
- Bl^2/Re = 135

For a typical 21”:

- Fs = 30 Hz
- Re = 5.5 Ohm
- Bxl = 34.5 Tm
- Sd = 1730 cm^2
- Qts = 0.26
- Qes = 0.27
- Qms = 6.1
- Vas = 375 Lt
- Mms = 315g
- Xmx = +/- 12mm
- Vd = 2.07 Lt
- Le = 2.5 mH
- Bl^2/Re = 216

Using such moving coil transducers to design a vented box, for instance, we could consider the following logical path:

a) Analysis of the target parameters: frequency response limits and final box dimensions

b) Analysis of the parameters that the possible transducer should have to fit with our needing

c) Analysis of the transducer limits and optimization of the design in order to maximize total output

d) Final calculation of the box parameters, eventually considering some help from external electronic to take care of driver excursion limits

e) Eventual final frequency response and phase response optimization with a dedicated DSP.

So, in the case of normal transducers that feature a moderate motor strength and a normal level of electroacoustic efficiency we could easily find that each size of transducer would lead us to a box sizes and relative tuning that will stay inside some regular ranges that will be adequate to not generate too much pressure inside the box and to accommodate for reasonably sized vents, and the resulting acoustic output will be relatively flat, down to the low cut frequency.

Alternatively, in the case of using a very high motor strength transducer, we could find that following the same procedures we may end up with results that need to be carefully considered. A subwoofer design that uses such a kind of transducer, in fact, it needs to be analyzed and to have targets parameters set under a different perspective. For instance, as it can be easily verified with a simulator or with practical experience, if we design a vented system using an highly over-damped transducer to obtain a simple, maximally flat, high pass characteristic, we could end up with a box that features a very small internal volume. In some cases this volume would be so small that it cannot even allow to have the transducer physically mounted into it, and with a high pass roll off point well above the frequencies of interest. Moreover, in order to produce very high acoustic output level this loudspeaker system needs to “move” a considerably high quantity of air, generating unconventional pressure inside the box and unwanted high speed of air into the vents. So, let’s give a look at a typical parameters of the moving magnet design, both with a 22” and a 30” cone attached:

Moving Magnet motor with 22” cone attached:

- Fs = 36 Hz
- Re = 0.26 Ohm
- Bl = 24 Tm
- Sd = 1661 cm^2
- Qts = 0.15
- Qes = 0.15
- Qms = 7
- Vas = 50 Lt
- Mms = 1501g
- Xmx = +/- 25mm
- Vd = 4.15 Lt
- Le = 5.9 mH
- Bl^2/Re = 2215

Moving Magnet Motor with 30” cone attached:

- Fs = 30 Hz
- Re = 0.26 Ohm
- Bl = 24 Tm
- Sd = 3420 cm^2
- Qts = 0.16

- Qes = 0.17
- Qms = 7.3
- Vas = 230 Lt
- Mms = 1995g
- Xmx = +/- 25mm
- Vd = 8.55 Lt
- Le = 5.9 mH
- Bl^2/Re = 2215

Then, looking at these parameters, we can easily see that we are working with a considerable moving mass, driven by a 2215 Bl^2/Re motor, with +/- 25mm of travel and a considerably higher value of displaced volume. We see that the starting point of a subwoofer design that uses such transducers it would also be considerably different from a normal approach that uses a conventional moving coil transducer. In addition to that, it appears very clearly that we also need a dedicated amplifier design to drive them. So, a possible logical path to approach this design it could be as follows:

a) Analysis of the transducer limits in terms of maximum excursion and power handling capability
b) Analysis of the consequent physical dimensions needed to accomplish the use of the full potential of the transducer electrical and mechanical capabilities
c) Consequent definition of a resulting design
d) Analysis of the resulting transfer function
e) System tuning using the amplifier output resistance to find the optimal value of electrical damping
f) Final frequency response and phase response optimization using a dedicated DSP stage.

Some further considerations would be useful while designing subwoofer systems around very high motor strength transducers, especially with this novel moving magnet design:

a) In order to convert such a high motor strength into a large acoustic work and consequently in acoustic output, we need to apply some kind of considerable acoustic load to the diaphragm, possibly to both faces of the diaphragm. So it will be very useful once designed some LF vented load for it to apply an additional acoustic load on the other face of the cone
b) Very high motor strength results in a highly reactive load where we can have the voltage almost in quadrature with the current for most of the working bandwidth. In addition to that in order keep the voltage swing still inside reasonable limits, and in order to minimize the thermal dissipated power into the transducer coil, a very low DC resistance (Re) is highly desired. This calls for a specific dedicated amplifier design, as already mentioned.

6. AMPLIFIER DESIGN AND MATCHING

As already mentioned, a crucial advantage for the novel motor design is represented by the relative easiness in producing unprecedented value of motor strength (BL^2/Re) and, consequently, high acceleration that allows for driving the most demanding acoustic load. As a consequence, this transducer system can be inherently more efficient at the very low frequency than other conventional designs, also producing a minimum quantity of heat, especially if compared to the extremely high power level that this system is capable to handle.

The recent developments that the Switching Mode Amplifier technology had in the last 20 years have largely expanded their use into the professional market. This technology has largely replaced the conventional and well-established Linear Amplifier technology that has some limitations in the maximum amount of deliverable powers and suffers for large heat dissipation, particularly when coupled to very efficient, very high motor strength loudspeakers. Thus, the developments in switching amplification technology remove some of the issues that have limited the development of alternative solutions to the conventional moving coil loudspeaker realizations. The novel moving magnet motor design, featuring its high motor strength, it is showing, in fact, an extremely high reactive behavior.
This kind of transducer is the perfect companion for switching amplifiers that are naturally capable of driving very high reactive loads without suffering from heavy amount of dissipated heat. In addition to this, switching amplifiers, as mentioned, are also capable to recycle the reactive power received from the loudspeakers back into the power supply. Surprisingly enough, for this kind of amplifier, the novel motor design it could be even easier to be driven than a conventional transducer.
And as mentioned, the very nature of this transducer also requires some additional features from the amplifier side that can optimize the use of it in real

world applications. An adjustable output impedance amplifier is required, in fact, to adapt the very high motor strength transducer design to various types of acoustic applications of it. So, the novel moving magnet motor will require a dedicated amplifier that might be specifically designed for it, to take advantage of its outstanding and unique characteristics.
The dedicated switching mode amplifier must have, in fact, adjustable virtual output impedance that allows for moderating the very reactive behavior of the transducer to the subwoofer design without sacrificing the transducer efficiency. So, the main target of the subwoofer design will not be the frequency response per se, but it will be the trade-off between maximum output level and box dimensions for the specific use. Then the resulting frequency response will need to be processed to match the desired target response.

The low resistance value, the high Le/Re ratio and the consistent energy stored in the moving parts and compliances require a driving amplifier featuring a specific and very wide SOA. The output stage that provides the power to the transducer is required to deliver very high currents and voltages to exploit correctly the force capabilities. So, in the case of this moving magnet motor, a specific amplifier unit has been developed in order to fulfill the demands of the transducer.

In order to give a practical example, considering the driver that has been described into the previous section of this paper, the necessary amplifier stage beside being able to perform a voltage swing peaking up to +/- 300V and a peak output current capability up to +/- 200A, it also has to provide a very short latency signal path through an on-board DSP some very important features.

One of these features is the possibility to have programmable output impedance. This, as previously explained, it will be necessary to adapt the very high electrical damping of the transducer to real world designs, with a virtual output impedance adjustment that may change the speaker acoustic behavior without losses thus without sacrificing the inherently high system efficiency. In the specific case of the dedicated amplifier designed for the novel motor, this programmable output impedance can act both in the resistive and the inductive parts.

The virtual resistive contribution ranges from -10 Ohm to +10 Ohm. This wide range of operation may drastically change the behavior of the transducer connected to it.

In addition to that, there is the additional virtual inductive contribution that ranges from -2mH to +2mH and for the specific case of the moving magnet transducer it was designed to partially compensate the highly inductive behavior of it.

The adjustment of the output impedance might have a considerable effect onto the transfer function of the subwoofer system. The application of a positive resistance, in the case of the moving magnet system, will lower the electrical damping of the system. The result is equivalent to lower the transducer Q and its typical effect is to smooth and flatten the frequency response, especially into the low cut corner frequency zone.

Figure 5 - A typical frequency response of the moving magnet system in a direct radiating system is shown, with and without some virtual output resistance. The effect of the application of just 0.2 Ohm of positive virtual resistance at the amplifier output, as mentioned it starts changing the roll-off of the lower response corner frequency.

If we try to evaluate the effect on loudspeaker parameters of the adding of some virtual resistance at the amplifier output we could say that the Qts should rise a little bit. In the specific case, a addition of 0.2 Ohm is giving already a considerable effect. For instance, the transducer attached to the 30” diaphragm will change its T/S parameters as follows:

Fs (30Hz), remain the same, as well as Bxl (24 Tm), Mms (1995g) and Vas (230L). Re = 0.26Ohm and it will become 0.46Ohm changing the Qes from 0.17 to 0.30 and consequently Qts from 0.16 to 0.29. This will make the loudspeaker behave like a different kind of driver, just because of the specific interaction with amplifier output and make it more suitable for one of the standard alignments. It worth to mention that this adjustment of the virtual output resistance is not affecting at all neither the overall amplifier headroom nor the system efficiency. From a listener point of view the effect it will be to make the deep bass frequencies not too damped and then perceived as more warm and generous.

On the other hand, the effect of the adjustment of the inductive part is directly resulting as a driver inductance cancellation and it will reflect immediately in the driver upper band response. Consequently it will have its effect into the transient response and, ultimately, it will have a strong effect into the upper bass impact and articulation from a listener point of view. This time, the net effect of this adjustment is affecting, in some extend, the overall system headroom, differently from the resistive part. In order to tailor the resistance and the inductance compensation for the specific needing of each design, the compensation can also be bandwidth limited to an upper frequency limit that it is also adjustable.

A clear example of the effect of the application of several values of inductance cancellation to the system is shown into the following picture.

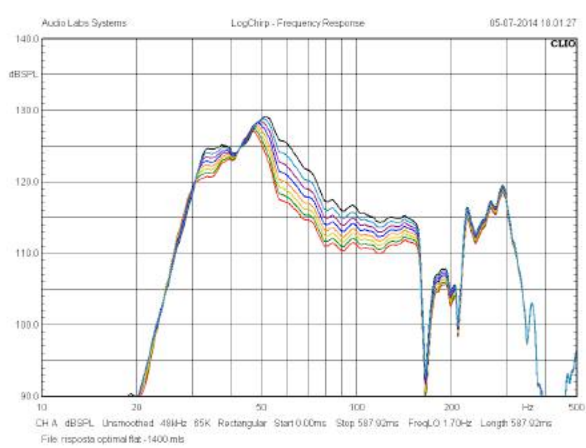

Figure 6 - Frequency response design for various level of inductance compensation of transducer, mounted on the same enclosure. The inductance compensation ranges from 0 mH to -1.4mH, compensation bandwidth is limited to 200Hz.

6.1. Amplifier additional features

Another unique feature that this amplifier implements, taking advantage from the very low latency DSP is represented by the possibility to create a global feedback control loop in the system that includes the complete acoustic design into it.

A Differential Pressure Sensor detects the overall pressure acting on both the radiating surfaces of the diaphragm and a feedback loop bring this signal back to the “Zero Latency” DSP in a closed loop control architecture. This method allows for the definition of a predictable behavior in the electrical–mechanical–acoustical signal chain, and allows for reducing the sensitivity of the system performances against aging and boundary conditions. The Differential Pressure Control technique may allow for the computer controlled DSP to synthesize a range of desired Thiele-Small parameters for a given physical transducer virtually changing its behavior with the combined effect of the programmable output impedance and the differential pressure feedback loop control.

Additional necessary features that have been implemented into the amplifier are dedicated to protection, control and power management. Due to the very high values of Voltage and Current that this amplifier must be capable of, these additional controls where strictly necessary to be included. A supervision of all the main operating parameters like Output Voltage, Output Current, continuous Output Power, Acoustic Pressure, Diaphragm Displacement and forces are monitored and maintained within safe conditions and limits both for long term transducer and amplifier protection. In addition to this, to be able to maximize the performance of the transducer, a very effective energy recycling output stage has been designed. Combining this feature with high transducer’s efficiency the result is a considerable reduction in the size of the power supply. Power Factor Correction functionality integrated into the power supply further minimizes the overall mains current requirement.

Figure 7 - A 3D drawing view of the dedicated amplifier design.

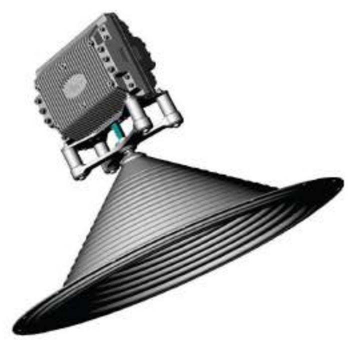

Figure 8 - A 3D drawing view of moving magnet transducer attached to a 30” cone.

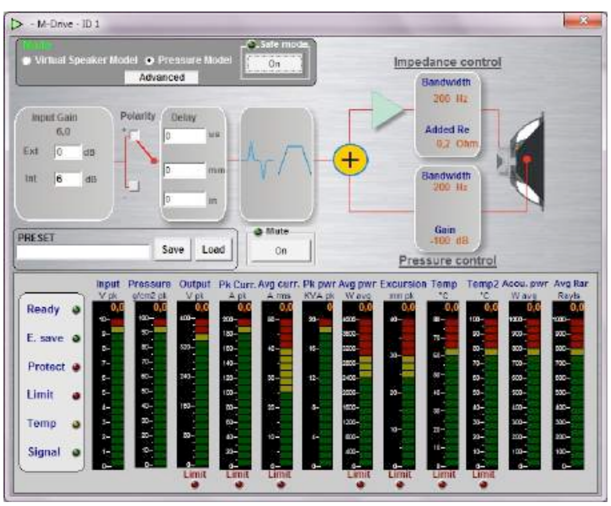

Figure 9 - Amplifier Computer Interface

7. SYSTEM EXAMPLES

We present here a short review of some examples of subwoofer systems that have been developed as case studies of practical applications of the novel moving magnet transducer. There are three simple examples here that have been chosen, among others, in order to give some ideas of application.

There will be shown a vented direct radiation box, designed for very high output and very high Q at the lowest frequency, tuned at 30Hz. Its volume was kept reasonably small but port size has been kept very generous. The second example represents ad vented box of the smallest possible dimensions to contain just the motor, the cone and the amplifier, and it was vented at slight higher than the previous one at about 34Hz. This box also features a small cavity in the front of the speaker that creates a sort of acoustic loading in front of the cone that increase a little bit the efficiency of the system in the upper bass range. Everything in this case was optimized, anyway, for the minimum possible dimension. Final box external dimensions, in fact, ended up at 80cm x 80cm x 80cm (31.5in x 31.5in x 31.5in).

The third design that is taken into consideration is an hybrid short transmission line design that is a particular design that combines some of the advantages of a short ¼ wavelength transmission line but trying to keep it as small as possible, with some advantages of an over damped vented box design. This third solution, both in terms of output and in terms of physical dimension it seems to be very interesting because it increases the overall output compared to a direct radiating while keeping dimensions and weight still very reasonable. Overall dimensions were 80cm x 96cm x 107cm (31.5in x 37in x 42 in). Also bandwidth seemed to be relatively wide and easy to equalize.

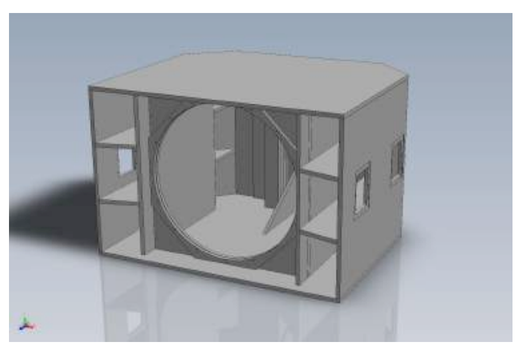

Figure 10 - High output, Hi Q vented box design tuned at 30Hz

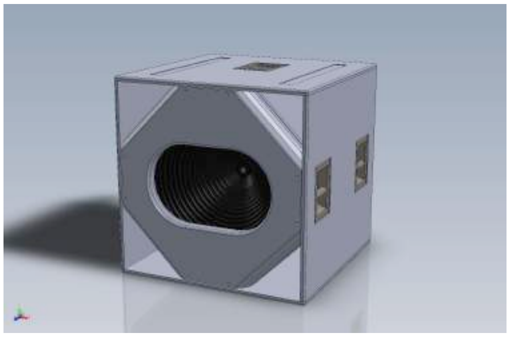

Figure 11 - Small size compact vented design tuned at 34Hz

Figure 12 - Hybrid short transmission line

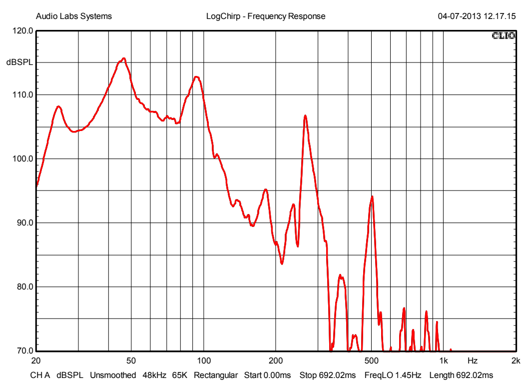

Figure 13 - Frequency response of the Hybrid short transmission line without output virtual resistance. Adding 0.2 to 0.3 ohm of virtual resistance the 3 peaks on the frequency response will considerable smooth down

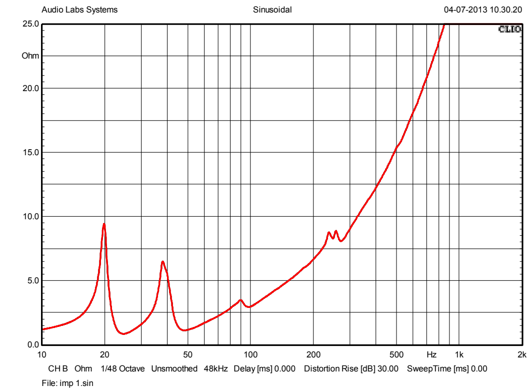

Figure 14 - Impedance curve of the hybrid transmission line design. Note the very evident rise of the impedance curve at the high frequency is due to the high driver inductance

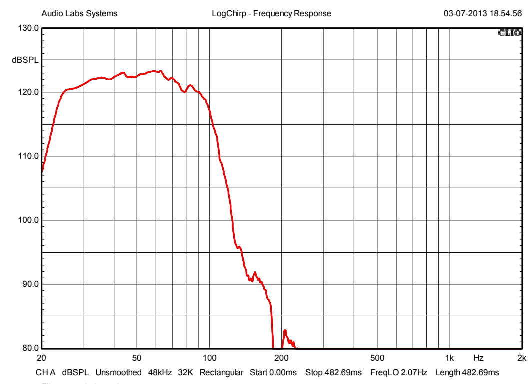

Figure 15 – Frequency response capability of the hybrid transmission line design after the proper DSP processing and equalization.

Figures 13, 14 and 15 show some of the characteristics of the hybrid transmission line design. The resulting natural frequency response, in fact, even though seems to be very troublesome, will be equalized and matched to the desired pass band shown in figure 15, using a combination of amplifier output impedance adjustment and overall filtering and eq. processing.

8. ADDITIONAL TESTS AND MEASUREMENTS

Some additional test measurements are reported in this section just to give a perception of other performance parameters. Figures 16 and 17 they report the THD level for the moving magnet transducer and for a dual high power 18” subwoofer, both driven at -10dB in respect to their maximum power. It is interesting to see how lower are the distortion figures in the 30 to 50 Hz range, comparing figures 16 and 17. In addition to that, in figure 18 there is an example of a fourth example of box of very small size that is using the moving magnet transducer.

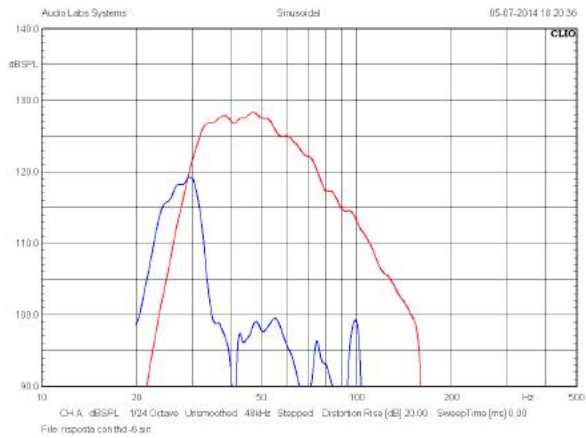

Figure 16 – THD of the moving magnet transducer at -10dB level from the maximum power

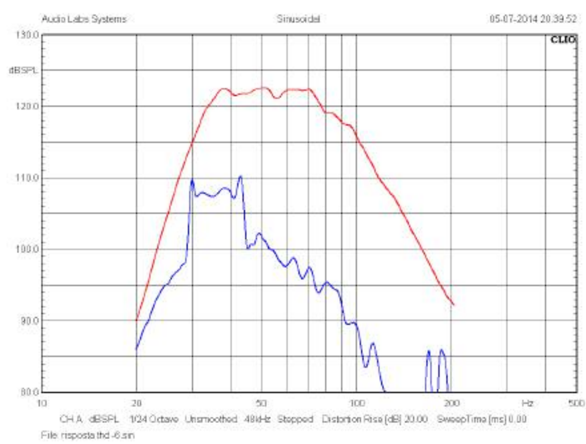

Figure 17 – THD of a dual 18” subwoofer at -10 dB level from the maximum power

The measurement in figure 18 is referred to an additional fourth type of design. Also in this case the comparison between the natural response and the processed final response clearly show how they can be different each other. Also in this case, the final result is obtained only with amplifier impedance compensation, in addition to EQ and Xover settings.

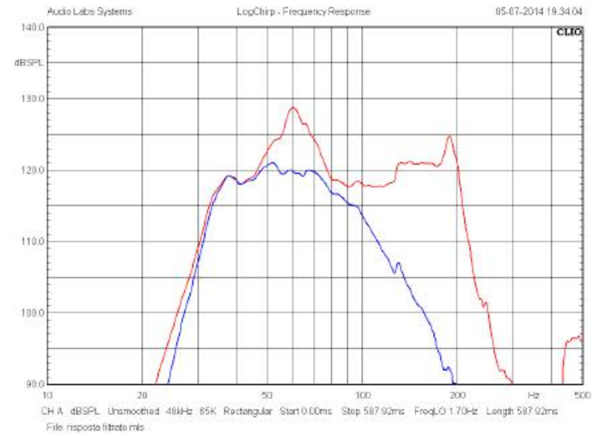

Figure 18 – Example of unfiltered response featuring only complex impedance compensation and filtered response

In the following section, from figure 19 to 21 there are three example of MOL measurements (Maximum Output Level) performed with the ANSI/CEA standard method. These measurements take in consideration both the acoustic and transducer side and in addition to that, they also take into consideration the electrical limitations in terms of voltage and current that may occur into the driving amplifier. These curves are not calculated but are really measured and they represents the continuous level that these systems can produce at 1m of distance in half space, also considering the overall distortion level to be below a certain threshold at each frequency. The distortion threshold is determined by following a curve contour that is somewhat related to the human hearing at low frequency.

In figure 19 is possible to compare the MOL for the moving magnet system compared to the extrapolated value of MOL after the power compression could take over. As it might be seen, the power compression effect for this driver is almost negligible.

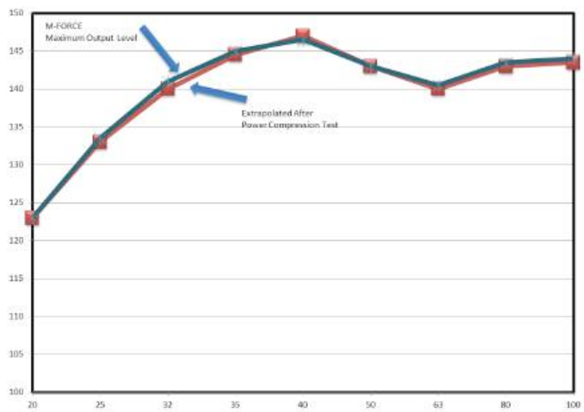

Figure 19 – Maximum Output Level of the moving magnet transducer with extrapolated power compression data

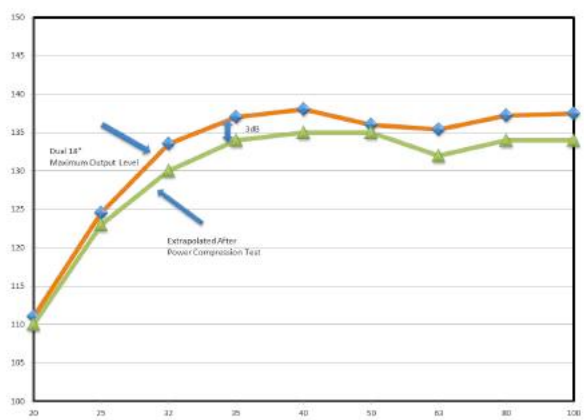

Figure 20 – Maximum output level of the dual 18" subwoofer with extrapolated power compression data.

As it can be clearly seen from the figure 20, the power compression effect into a conventional moving coil speaker is already very evident after some minutes. Then, if we estimate overall maximum output level we should necessarily take into account that after few minutes, the output level coming from the moving coil transducer will be quickly reduced of an amount that could be also in excess of 3dB. In figure 21 there is the most important comparison and it takes place between the moving coil subwoofer and the dual 18" subwoofer. The two curves are extrapolated from the data after the power compression test. This comparison reveal that the output difference between the subwoofer based on moving magnet attached to a 30" cone it can be up to 12dB of more output if compared to the conventional dual 18" design after the power compression takes place. So, in addition to the higher efficiency and the capability of easily manipulating transducer behavior with the complex impedance compensation, considering these last measurements, this could be another clear advantage of the moving magnet design over a conventional moving coil.

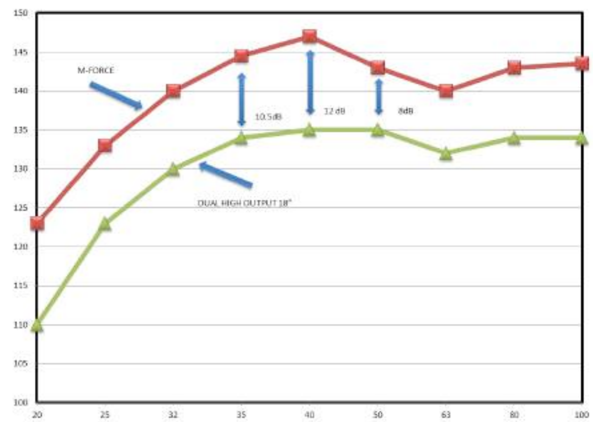

Figure 21 – Final comparison of MOL with calculated power compression effects for the moving magnet transducer and the dual 18" subwoofer.

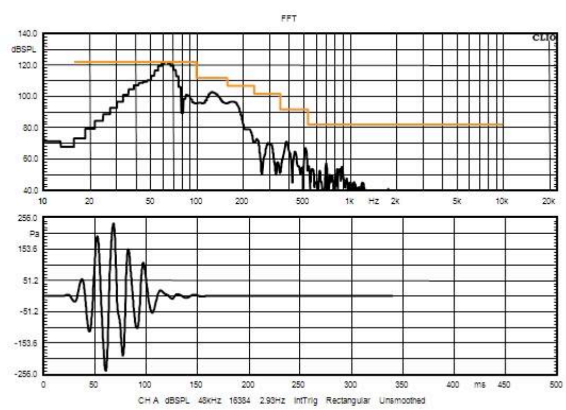

Figure 22 – An example of ANSI/CEA maximum output level measurement in one frequency point.

In figure 22 it is possible to see an example of measurement at one frequency point using the ANSI/CEA standard method.

9. CONCLUSIONS AND FURTHER DEVELOPMENTS

The novel moving magnet transducer offers very interesting fields of application. Even though not mentioned in this paper, some of those could be found also outside of the audio field. Anyway, regarding the professional audio subwoofer applications, in this paper it has been shown a suggested approach to subwoofer design using very high motor strength transducers that is not based onto flatness of the acoustic output but is based on MOL and box dimensions optimization. Of course this approach is clearly based onto the availability of a specific DSP assisted amplifier, specifically designed and optimized to drive very high motor strength transducers. Few simple applications have been shown here in order to clarify the use and the advantages but the practical experience that comes from these examples suggests that other results, even more outstanding that these, can be achieved if this new transducer is used in designs that feature much higher acoustic loadin. So, further developments of this work will certainly be in a deep investigation of the use of this transducer in horn design and in other high demanding acoustic loading, where the use of amplifier output parameters and differential pressure feedback control could certainly be even more interesting.

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