- 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.

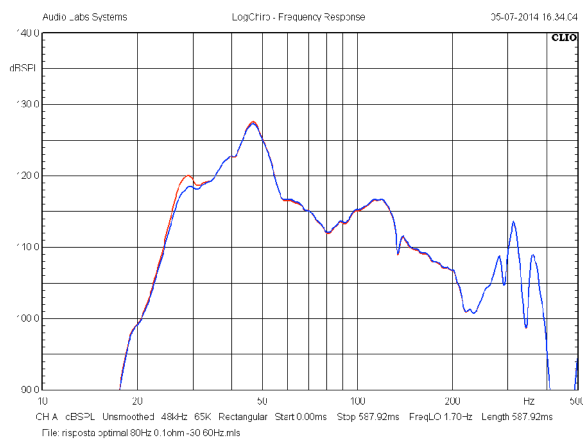

Figure 5 - A typical frequency response of the moving magnet system in a direct radiating system is shown, with and without some virtual output resistance. The effect of the application of just 0.2 Ohm of positive virtual resistance at the amplifier output, as mentioned it starts changing the roll-off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

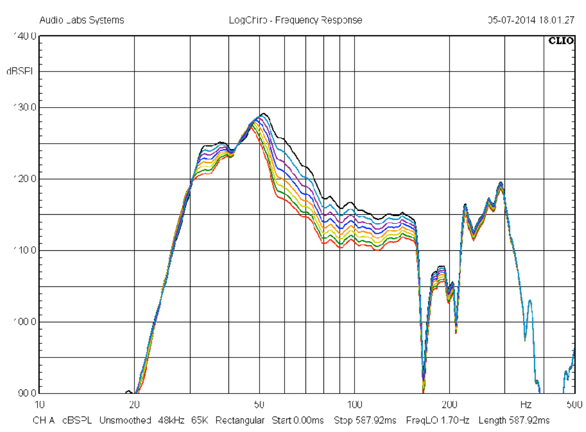

Figure 6 - Frequency response design for various level of inductance compensation of transducer, mounted on the same enclosure. The inductance compensation ranges from 0 mH to -1.4mH, compensation bandwidth is limited to 200Hz.

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.