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An alternative approach to minimize Inductance and related Distortions in Loudspeakers.

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ABSTRACT

Magneto-dynamic loudspeakers are affected from a wide variety of problems due to the voice coil inductance. This inductance is not a constant parameter but is dependent on the frequency, the displacement and the actual current flowing in the coil. Moreover these last two dependencies are also non-linear. Several causes of distortion, affecting mainly the vocal range, are derived from these phenomena. A practical solution to minimize the inductance is investigated. This solution is based on additional fixed coil positioned in the gap provided with 2 additional terminals offering various connection possibilities. This device is referred as A.I.C. (Active Impedance Control).
Advantages of this approach will be discussed and measurements results will be shown as well.

1. INTRODUCTION

1.1. Voice coil and Inductance

The loudspeaker moving coil is usually made out of multiple copper or aluminum turns exhibiting a significant value of inductance at the input terminals. This inductance is augmented by the presence of iron parts like the pole piece and the top plate. Its effect is clearly visible in standard impedance measurements vs. frequency leading to a general rise of input impedance when the frequency increases. This measured curve is anyway a result where many causes sum together: motional impedance, radiation impedance, the coil turns and geometry, materials and geometry of the magnetic circuit and so on. In order to be sufficiently precise, the term "inductance" here should not really be used because in the moving coil loudspeaker the voice coil does not exhibit a pure inductance but actually a "semi-inductance" [1]. The magnetization present on it, actually changes the properties of the iron parts resulting in different permeability. By the way, we will use the term "speaker inductance" here not meaning a real pure inductance but a semi-inductance. Anyway, this speaker inductance is the main obstacle to current flowing in speaker voice coil at high frequency. The rising of the impedance at high frequency is one of the first basic issues that a designer has to face in his first cross-over designs. In fact, a noticeable deviation in low-pass filters cut-off frequency from the theoretical one is a very common problem to deal with. If this was the only problem, a simple component values adjustment can easily work this out. The real issue is that the inductance value is firstly displacement dependent, and secondly current dependent as well. Moreover inductance modulation is directly accompanied by a magnetic flux modulation, so both come together at the same time.

1.2. Inductance modulation

While the voice coil is moving inward and outward from its rest position, the relative position between the coil and the iron parts changes causing a continuously changing inductance value from that the speaker has at the rest position. When a loudspeaker is driven by a voltage source, a very common case, the driving current is dependent in any moment from the impedance that this source "sees" from the output terminals. This cause the current flowing through the voice coil to be modulated by the impedance (admittance) variations caused by the inductance changing [2]. This additional phenomenon also causes additional secondary modulation to magnetic flux as well. Anyway, even if the voice coil does not move it self at all, an inductance and a magnetic flux modulation is already present while a current is flowing in the coil [3]. This modulation can be clearly observed if the speaker movement is completely inhibited like putting some strong glue in the gap. Distortion analysis over the flowing current reveals this current modulation. This happens because the permeability of the iron is significantly changed by the steady state magnetization that is present in the speaker magnetic circuit [4]. So, depending by the actual magnetic working point in which the iron is set, the voice coil shows a different value of inductance (significantly less) from that it would have without the presence of magnetization. This because the coil "feels" less permeability in its core. Moreover, since the flowing current creates a proportional variable magnetic flux that partially changes the steady one, the coil "sees" also a modulated value of the permeability of its core. In other words, modulating the magnetic flux, the material permeability is modified as well and ultimately the voice coil inductance. This continuously increasing and decreasing value of the voice coil inductance has quite the same effect of a low-pass filter that has his cut-off frequency changing continuously. This creates an amplitude modulation of the upper frequency region that changes with the frequency of the bass tones. Because of this variation of the input impedance, a proportional variation of the current takes places reflecting again in a relative additional flux modulation… and so on. The magnitude of these phenomena firstly depend on inductance value, magnitude of current, material permeability, relative geometry of iron path, voice coil height windings and as we will see, from the saturation level of the top plate and the pole.

The main direction to follow in order to reduce this distortion mechanism is try to minimize the inductance value as much as possible and, where possible, making it less dependent of the coil position improving the steel geometry. Additional attentions can improve anyway the situation like introducing some counteracting or compensation mechanism. These problems was largely faced in the past from many designers resulted in two different strategies [5] [6]. Both strategies turned out to be beneficial but in different ways, and with different effectiveness. The first thing that can be done is to apply a bigger quantity of magnetic energy to the speaker motor in order to saturate the magnetic circuit. This approach attempt to move the magnetic operating point of the steel in the magnetic circuit in a region of the B vs. H curve where even if very big changes of H will occur; only very small variations of B can be observed. This makes the magnetic circuit stiffer and less prone to modulation. A second strategy that can be pursued is placing shorted turns somewhere in the magnetic circuit. The magnetic flux modulation, if consistently linked, will induce in them a current that counteract the flux variation itself. These shorted turns can be positioned in several "strategic" positions in the magnetic circuit showing different behaviors and giving slightly different benefits. It should be clear that all these operations lead in any case to increasing costs. In fact, increased magnet size and or manufacturing complexity are introduced anyway in both ways introducing additional costs, but the second one can be the more cost effective among them.

2. APPROACHES TO INDUCTANCE REDUCTION

2.1. General approach

Several approaches to inductance and inductance modulation reduction are already in use from many years.

As we already mentioned, shorting turns placed somewhere in the magnetic circuit can counteract the magnetic flux modulation and we will see this. A first approach could be to put a shorted turn (a copper or aluminum ring) at the base of the pole piece. This ring couples very good with some "modes" of flux modulation, since it links completely with the magnetic circuit. Measurements could show that this solution is more effective in reduction of 2nd harmonic distortion products, those caused by non-symmetrical modes of flux modulation that need to be coupled through the magnetic path. By the way, since this ring is too far from the voice coil there is not really good effectiveness in inductance reduction. It's more effective in reducing magnetic flux modulation.

A better solution could be to put a shorted ring in the gap. If a shorted turn is positioned in the gap, it will couple very well to the main coil and eddy currents are induced in it. Once this effect takes place, the voice coil and the shorted turn behave like two coils in a transformer action. The low impedance of the shorted turn is reflected back to the voice coil input, resulting in lowering the inductance linearizing the impedance vs. frequency curve in the upper range in fact, the effectiveness of this approach increases as the frequency increases because the two coils couple better and better. The final result is an impedance curve that could be almost completely linearized from the minimum impedance frequency to above. The current flowing in the shorted turn also counteract (as mentioned) the magnetic flux modulation caused by the voice coil reducing distortion, showing good effectiveness in reducing 3rd order components that are produced by a symmetrical mode of flux modulation. But once again, measurements could show that it is less effective in reducing 2nd order distortion products since this couples directly with the voice coil that is in very close proximity and very few through the magnetic path. D. Button described these phenomena extensively in AES paper in 1991 [6].

There are some drawbacks in this approach: first it should not be forgotten that this current induced in the shorted ring also increase the heat dissipation in the pole piece since it is directly mounted on it; moreover, placing this ring means making the gap a little wider. This can cause to loose some magnetic flux there resulting in an efficiency loss that need an increased magnet if needs to be recovered.

This solution could be further improved in terms of 3rd order distortion reduction using instead of a ring in the gap, a complete sleeve that cover almost completely the pole piece. This solution probably allows for better circulation of eddy currents even at high frequencies where they should tend to concentrate in the upper and lower part of the gap. Incidentally, this add still more complexity to the design and cost more in terms of general efficiency.

By the way, all these devices turn out to be "passive" devices meaning that they work, as mentioned, as shorted secondary turn on a transformer circuit. An alternative approach can be pursued to deal with impedance linearization and flux modulation and this approach that we discuss here is basically a variant of them.

This alternative approach is based on the use of an additional fixed, multi turn coil, positioned in the gap. This coil could be made out of multiple turns of copper wire, rigidly wound around the pole piece facing the moving coil and accessible via two additional terminals. This coil is long almost as long as the gap and being wound around the pole piece results to be very close to the voice coil. If we make a current to flow into this coil apply it in order to make it having an opposite direction to the current in voice coil, the results are that the field generated by the additional coil has an opposite direction to that generated by the moving coil. This tends to cancel out most of the voice coil inductance and deeply reduce the flux modulation and the inductance modulation. There are many similarities between this device and a standards copper ring in the gap. These are also differences in terms of effectiveness and field of utilization.

First of all, this system differently from shorted rings is an active system with two additional terminals and we can impose a current at will into it. We can decide to drive it in some different ways:

- Driving it with an additional amplifier
- Driving it in parallel with the main coil
- Driving it through a filter that shapes the driving level with the frequency
- Simply shorting it

In other words we can have the chance to decide how to use this additional coil and try to figure out how to take advantages from it. Before continuing, we have to say that the last option seems not to be very useful because this coil has impedance many times higher than a shorted ring. The current induced in it would be in this case not enough to be really effective in distortion reduction compared to the effectiveness of a shorting ring.

It's interesting to observe in this alternative approach that the geometric distribution of the current in the space around the moving coil is also imposed remaining distributed all along the gap.

In this practically approached study, we will show some experiments we have run in order to investigate which benefits can be obtained by this technique and if there is some improvements over "standard" approaches and/or some drawbacks.

2.2. Correlation to the sound quality

As we have already mentioned, several advantages come out of the use of inductance reduction device positioned in the magnetic path:

1. Linearization of impedance in the mid and high frequency range along with his electric phase angle
2. Sensitivity and total SPL are significantly increased in the upper range
3. Inductance modulation and related distortion minimization

The first two benefits (clearly correlated each other) mainly improve the versatility in using the speaker. The last benefit instead, seems to be largely the more important in sound quality improvement since the type of distortions (Harmonic distortion, Intermodulation distortion, etc...) related to inductance modulation and to the flux modulation mostly affect the vocal region. They are really very annoying effects and, as largely proven, more audible than distortions caused by Bxl and Cms non-linearity. The use of an inductance modulation reduction system can lead to a significant reduction of distortion in the vocal range related to the same speaker not equipped with it. The other 2 benefits, as mentioned, are also important because they turn out to have an important role to improve amplifier to speaker interfacing and passive filters implementations reflecting themselves in a general versatility of use. Moreover, the resulting frequency response extension can be useful to improve the performances of mid range speaker when used horn loaded. In most systems, the possible crossover frequency could be also slightly increased. As a matter of fact, the impedance can be consistently lowered at high frequency both using this additional coil than using the shorting ring in the gap. This means that more current can flow in the voice coil and both the upper band sensitivity and the high frequency perception are increased. Moreover, early listening tests confirm a general improvement in the midrange quality exactly reducing the vocal harshness and roughness typical of inductance modulation related distortions.

3. COMPUTER MODELING

In order to understand the phenomenon of flux modulation, some computer simulations were run. It could be very hard to try to visualize and figure out what happens in the magnetic flux but FEM modeling can render a sufficient perception of "what is going on inside there". Animations can further make this even clearer but sadly can't be replicated on paper. Some explicative screenshots can be helpful anyway for the purpose.

Two different speaker types were modeled and studied. Both speakers were also made in different versions. These two speakers can be referred as model type "600" and model type "500". Both speakers were 10" cone mid-bass units. The 600-type speaker is equipped with 3" voice coil and the 500-type is equipped with a 2.5" voice coil. They also use two different "motors": 600-type has a stronger magnet and saturated pole and top plate. Its Bxl product is about 21.5 and its motor strength is about 80. The 500-type uses a smaller magnet instead: it shows a Bxl of about 16 and a motor strength of about 50. It doesn't have the pole or the top plate saturated. For both speakers were built several prototypes in order to test the same magnetic circuit assembly incorporating different approaches to distortion reduction. So, for both 600 and 500 models were built prototypes with A.I.C. (Active Impedance Control) device, with a shorted ring in the gap and with a shorted ring positioned at the base of pole piece. Honestly speaking it could be very hard to put over a paper all the distinct analysis for every distinct case. We decided to show a reduced set of simulations and measurements. The 600-type speaker as we have already mentioned has a very strong magnet and has saturated pole piece and top plate and represent itself the "stiffer" magnetic circuit case. It shows, as expected, less effectiveness of distortion reduction devices. There were some clear improvements but to us, was more useful to show the 500 type case because the phenomena were relatively easier to be shown.

The following simulations were run using a FEM software and modeling the two magnetic circuits equipped or not with those devices. Figures 1 and 2 show the "cut-view" of the two different magnetic structures: the 500 and the 600. It's easy to see in the picture where is located the second coil. Figure 3 and 4 show the magnetic path equipped with the ring in the gap or at the base of pole piece.

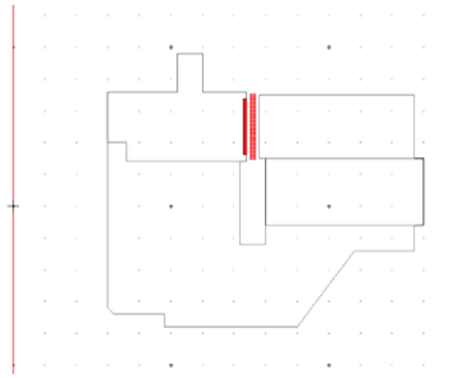

Figure 1: Model of a 600 type magnetic circuit.

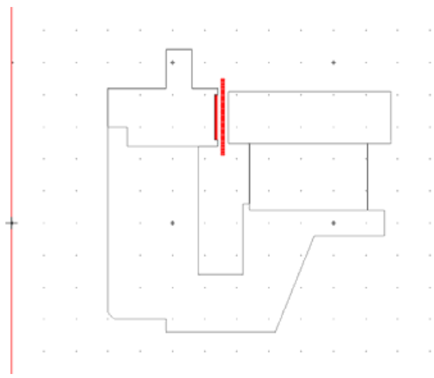

Figure 2: Model of a 500 type magnetic circuit

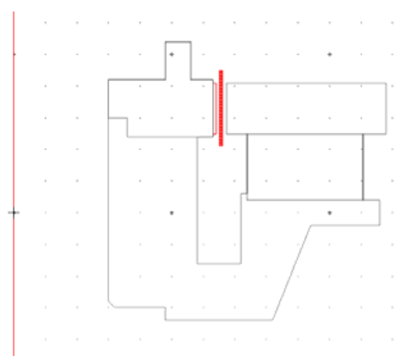

Figure 3: Model of a 500 type magnetic circuit with a shorting ring in the gap instead of the A.I.C. coil

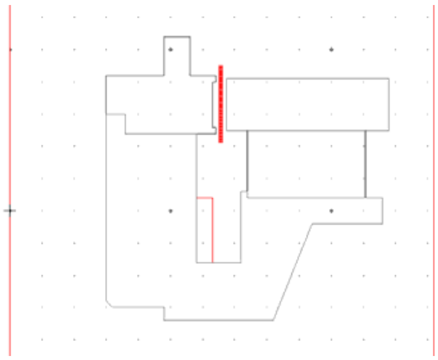

Figure 4: Model of a 500 type magnetic circuit with a shorting ring at the base of the pole piece instead of the A.I.C. coil

Note that even in the shorted ring implementation, the small lowered zone originally made to host the A.I.C. coil was left intact. This was chosen in order to maintain the same B in the gap and consequently the same motor strength.

The following simulations were run along a cycle of the chosen frequency. All the simulation set are composed by groups of 3 shots each just because three points of a sinusoidal cycle were taken: the positive maximum (shot 1), the zero crossing (shot 2) and the negative maximum (shot 3).

Figures from 5 to 7 represent 3 samples of a simulation of a 250Hz cycle. The modulation in the flux is produced by the current only. No coil movement is considered in it. It is interesting to see throughout the next 24 figures that even without moving the voice coil, the role that the current already plays by itself in modulation is already important. The second series of pictures, from 8 to 10, represents the same speaker equipped with the AIC. As it can be seen, at 250Hz the effect is not really noticeable. This was expected, since the main problem in the flux modulation at this frequency is a non-symmetric modulation that needs to be coupled through the magnetic path in order to be reduced. An appreciable improvement in reduction of eddy current in the steel is noticeable anyway: figures from 11 to 13 represent the current density (J) at the same 3 shots in a 250Hz cycle for the standard speaker and from figure 14 to 16 the AIC equipped one.

Two additional sets of simulations over the same model were run to analyze the behavior at 2 kHz. At this frequency it easy to see, in the standard realization from figure 17 to 19, the presence of an evident flux modulating mode in the gap and in close proximity of it. The modulation is clearly visible as a “hole” in the magnetic flux that moves up and down in the gap and in the steel in very close proximity of the gap. Also an asymmetric modulation can be observed as well, just at the end of the steel. The second series, from 20 to 22 shows the effectiveness of AIC in reducing the symmetric modulation responsible for 3rd harmonic distortion.

Figures from 23 to 25 and from 26 to 28 represent two additional series of simulations run at 2 kHz that show the changing of current density distribution (J) in the two cases.

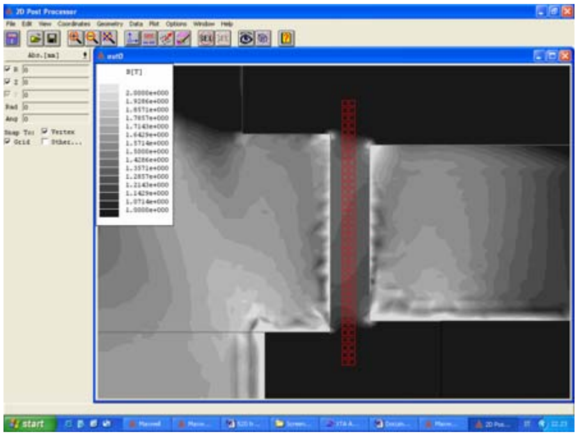

Figure 5: 500-type normal 250Hz - shot 1 – B [T]

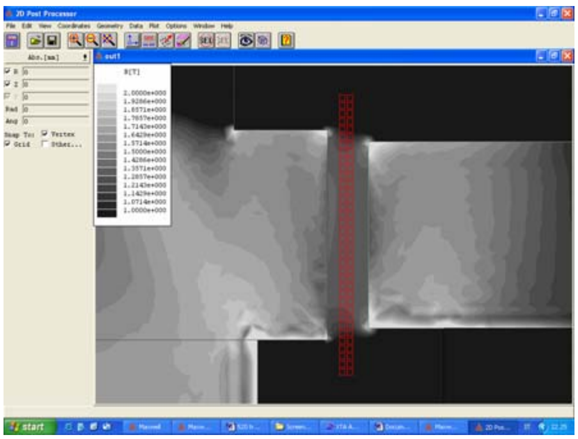

Figure 6: 500-type normal 250Hz - shot 2 – B [T]

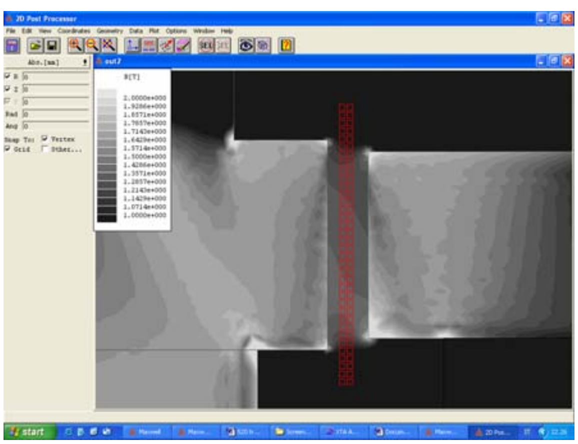

Figure 7: 500-type normal 250Hz - shot 3 – B [T]

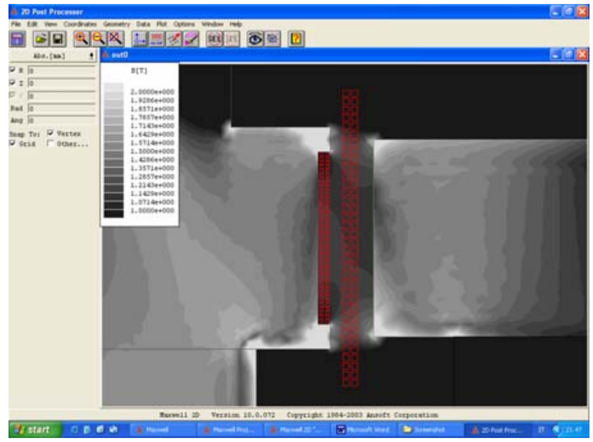

Figure 8: 500-type 250Hz with AIC, shot 1 – B [T]

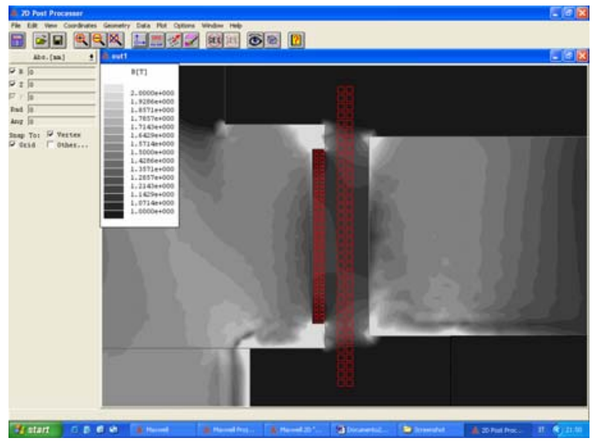

Figure 9: 500-type 250Hz with AIC, shot 2 – B [T]

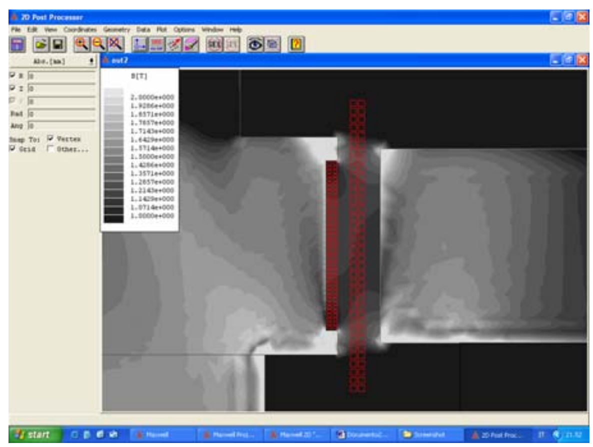

Figure 10: 500-type 250Hz with AIC, shot 3 – B [T]

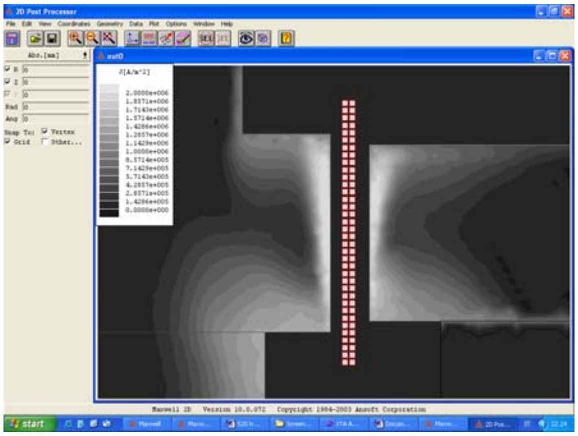

Figure 11: 500-type normal 250Hz - shot 1 - J [A/m^2]

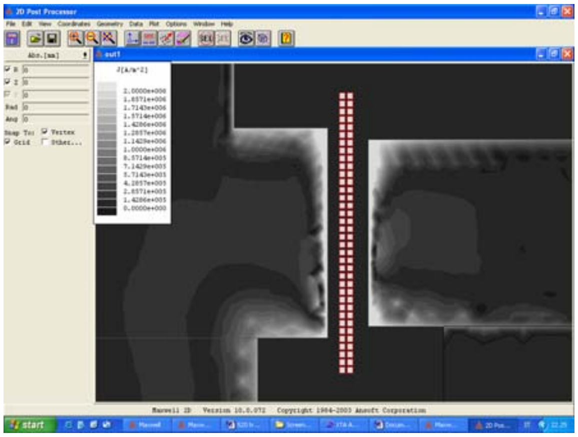

Figure 12: 500-type normal 250Hz - shot 2 - J [A/m^2]

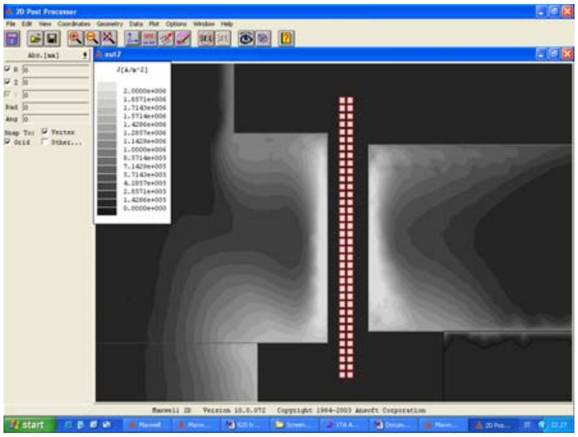

Figure 13: 500-type normal 250Hz - shot 3 - J [A/m^2]

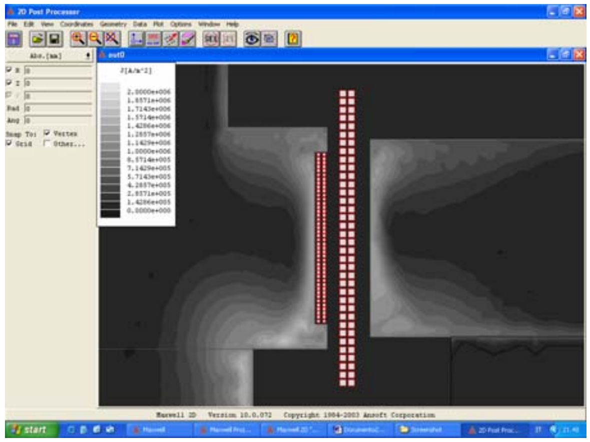

Figure 14: 500-type 250Hz with AIC, shot 1 - J [A/m^2]

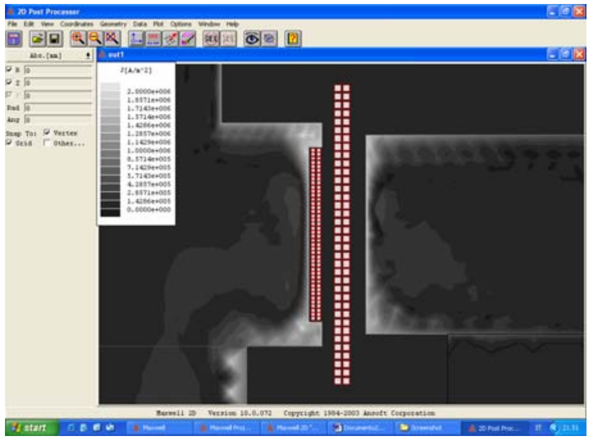

Figure 15: 500-type 250Hz with AIC, shot 2 - J [A/m^2]

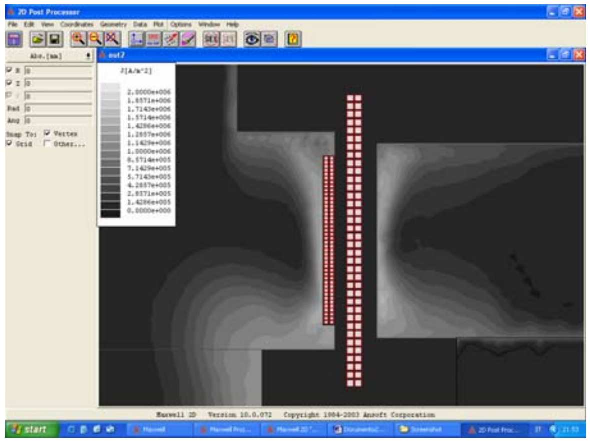

Figure 16: 500-type 250Hz with AIC, shot 3 - J [A/m^2]

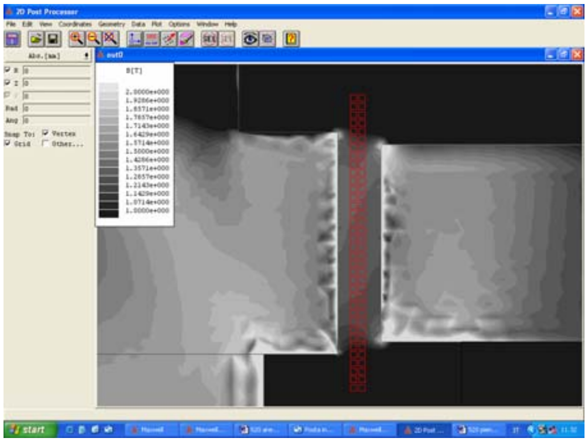

Figure 17: 500-type normal 2 kHz - shot 1 – B [T]

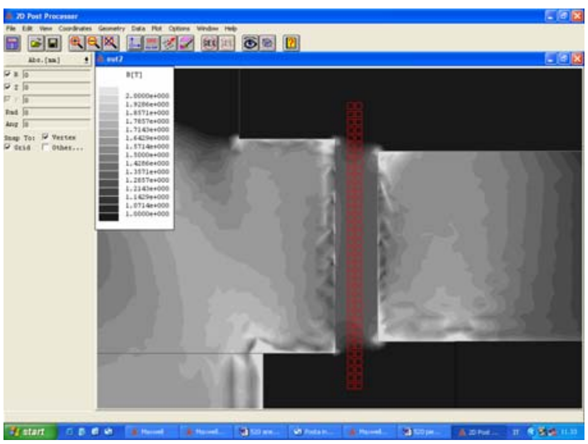

Figure 18: 500-type normal 2 kHz - shot 2 – B [T]

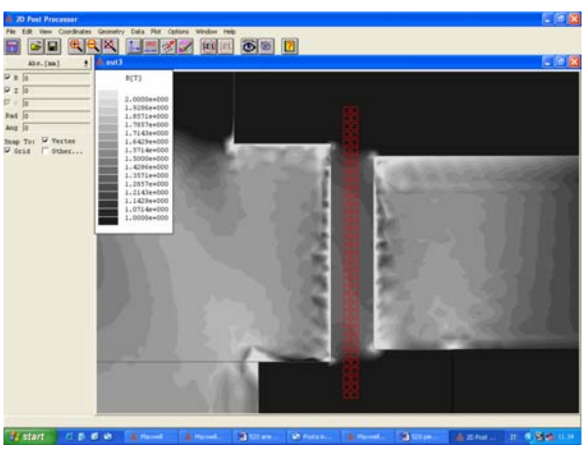

Figure 19: 500-type normal 2 kHz - shot 3 – B [T]

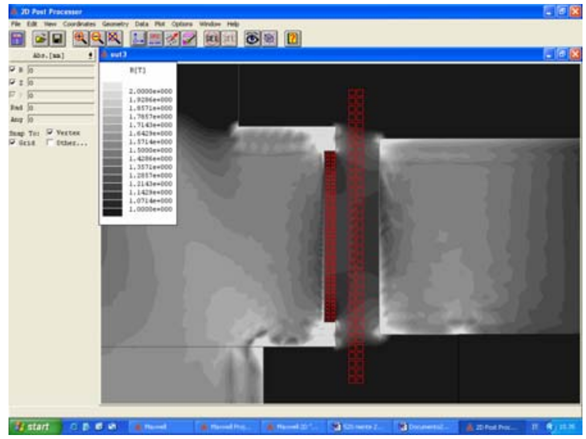

Figure 20: 500-type 2 kHz with AIC, shot 1 – B [T]

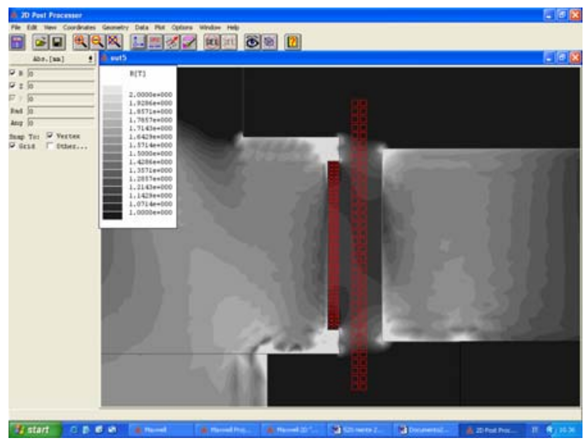

Figure 21: 500-type 2 kHz with AIC, shot 2 – B [T]

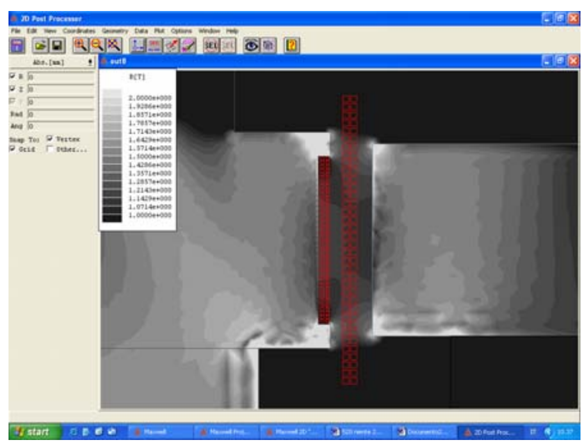

Figure 22: 500-type 2 kHz with AIC, shot 3 – B [T]

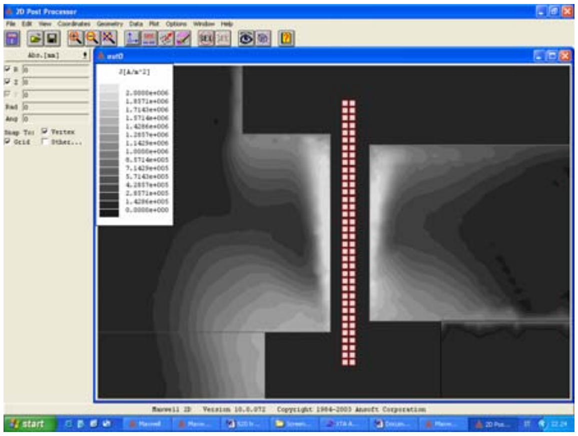

Figure 23: 500-type normal 2 kHz - shot 1 - J [A/m^2]

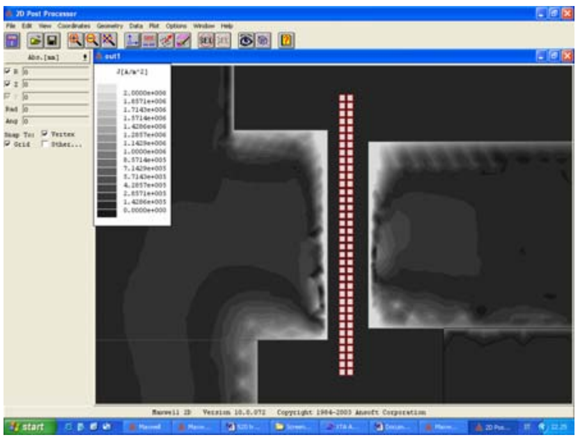

Figure 24: 500-type normal 2 kHz - shot 2 - J [A/m^2]

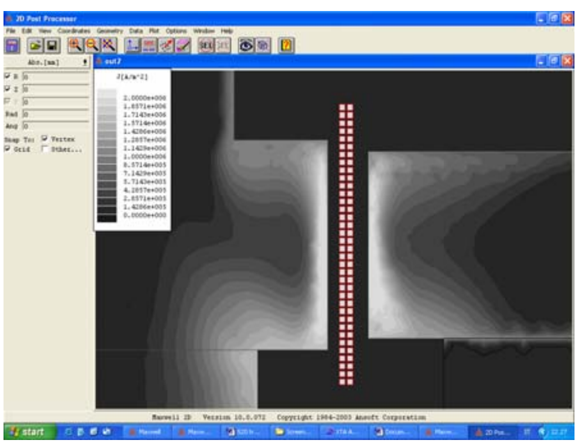

Figure 25: 500-type normal 2 kHz - shot 3 - J [A/m^2]

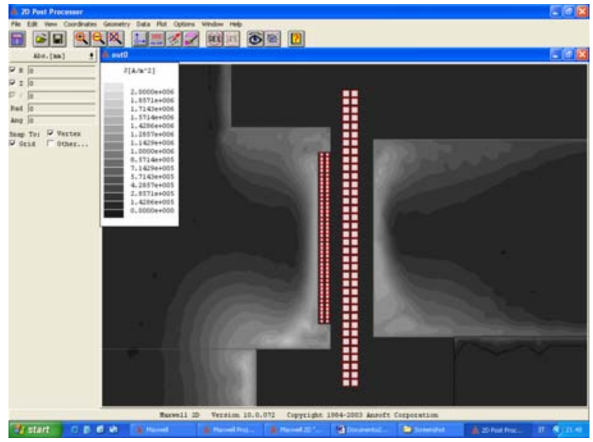

Figure 26: 500-type 2 kHz with AIC, shot 1 - J [A/m^2]

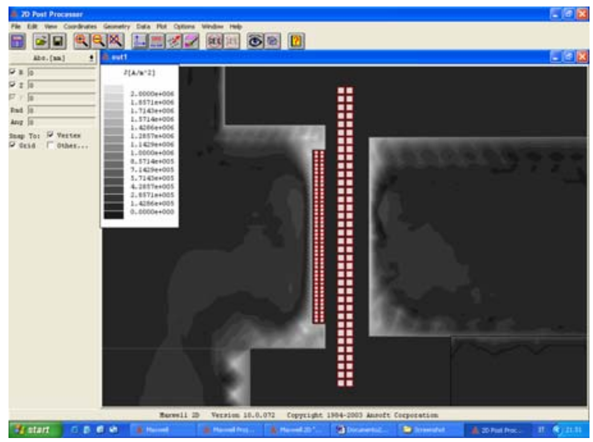

Figure 27: 500-type 2 kHz with AIC, shot 2 - J [A/m^2]

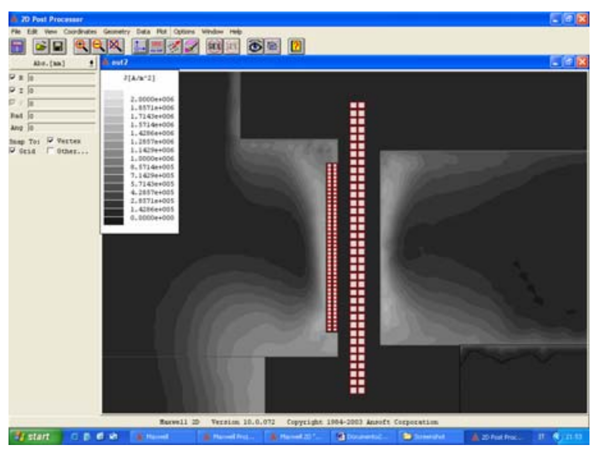

Figure 28: 500-type 2 kHz with AIC, shot 3 - J [A/m^2]

4. MEASUREMENTS AND RESULTS

4.1. Measurement methodologies

In order to investigate around these phenomena we have planned a number of experiments and measurements.

Several samples were built by the 18Sound technical department for the purpose of studying the behavior of different approaches to inductance and distortion reduction in speakers.

We set the researching path as simple as possible but this still made necessary to actually build several different samples that needed to be matched in the acoustical properties in order to put in evidence the electro-mechanical differences as much as possible. Still was very hard to have different samples of the same cone or the same suspension to behave exactly the same.

Most of the test were run over the samples driving the amplifier through a DSP based loudspeaker management system (XTA DP226) because we wanted to evaluate the distortions under an hypothetic real use conditions setting any speaker to show almost the same reference frequency response at 1 meter on axis. To us, this last point was really important to correctly compare different speakers. In fact, putting shorting turns in a speaker for example, a general reduction of distortion can be obtained but a sensitivity improvement can be observed as well. In real use conditions, this higher sensitivity would be re-equalized yielding an additional difference in distortion, since it needs less driving voltage to make the current flow. As far as we concern, this extra benefit to the final listening experience needs to be taken in count just like it will be in real use.

The cone speakers intended for the tests were all 10" ones that were designed in order to address mid-bass or mid range frequency region in large format multi way systems. As we mentioned above, we analyzed a 500 type that show a lower Bxl product (about 16) that could be used as a mid-bass unit in a 3 way system or as a low frequency unit in compact 2 way speakers with limited requirements in the bass region. A second type is the 600-type speaker. It is a mid-bass or mid range with saturated pole tips and high Bxl product (21.5). This speaker is not intended for 2-way use since it's not capable of delivering low frequency, because of its very low Qts.

All the 500 speakers and all the 600 speakers were measured in equivalent use conditions.

For the 500-type, the pressure measurements were run setting the speaker before for an intended bandwidth using the DSP based speaker management system. The Eq curve was set for getting from the 500-type a bandwidth that goes from about 150 Hz to 2 kHz flat on axis. So the extra sensitivity of those equipped with rings or AIC in the gap, an additional equalization has compensated this, since on real use it would be so.

For the 600 type speaker, the band was only slightly different: from about 200Hz to about 2.5 kHz.

Also the measurements over the current run both with multi-tones and with sinusoidal tests, were taken under the same conditions.

After the acoustical measurements and some listening test were completed, most of the speakers were blocked with strong epoxy glue in the gap in order to run measurements over the current but without the effect of voice coil moving.

4.2. Measurement results

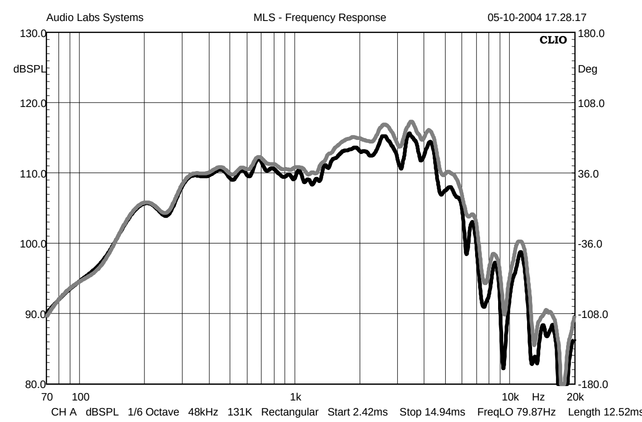

Figure 29: frequency response of a 600 type speaker, without AIC (black) and with AIC (gray)

In figure 29 we see easily the sensitivity difference we were talking about. These are un-equalized response curves taken over the 600-type mounted in a 15 liters closed box. The black curve is the frequency response obtained driving only the voice coil. The gray curve is obtained driving the additional coil paralleled with the voice coil.

Looking at the 500-type speaker we see here, in figure 30 the pass band set for this model and its related contribution of distortion to acoustical performances. In acoustical measurements the distortion we measure is not only caused by the flux modulations and so on. A very important role is played by the cone structural resonances and non-linearity.

(Note that in the following graphs, all the distortion curves in the acoustical measurements are raised by 20 dB while the distortion curves measured over the input current are raised by 30 dB).

A look over the current will show further information to us. In the next graphs, the black curves are the band-passed response of the speaker on the 15 liters closed box taken on axis. The darker gray curves represent the 2nd order distortion and the light gray curves represent the 3rd order distortion. The curves were measured from 70 Hz to 4 kHz, a band wide enough for the purpose of this speaker

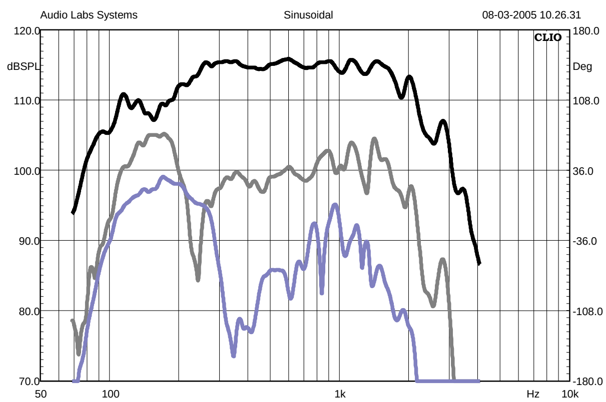

Figure 30: **Standard** 500-type, response and distortion

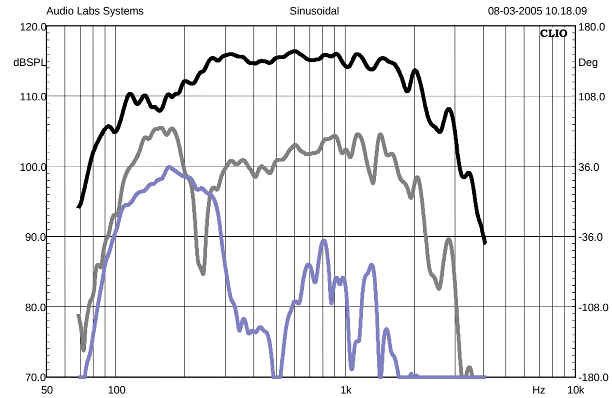

Figure 31: 500-type **with AIC**, response and distortion

Figures from 31 to 33 show the same speaker with AIC connected and with the two different ring solutions.

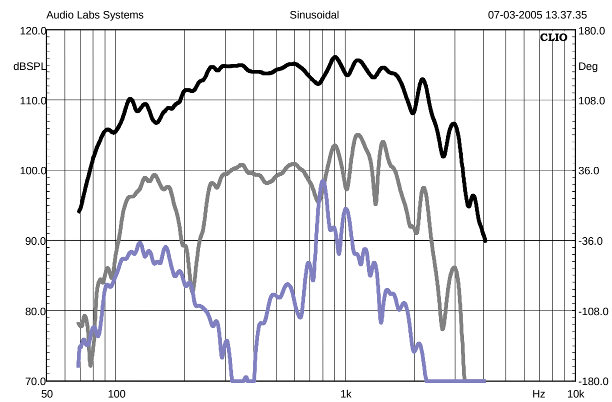

Figure 32: 500-type **with ring under the pole piece**

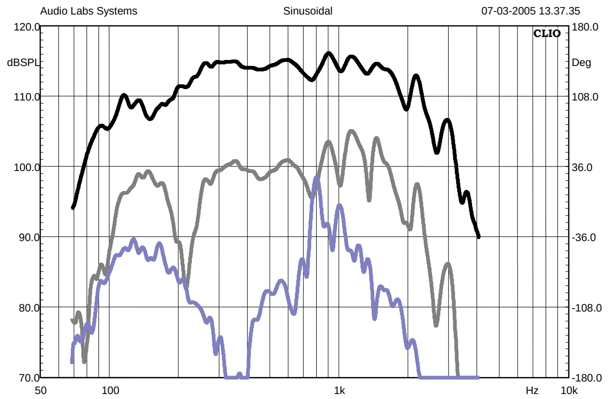

Figure 33: 500-type **with ring in the gap**

Next figures, from 34 to 37, show for the same set of speakers the distortion measured over the input current. The upper curve, the <u>black</u> one represents the level of the driving curve measured over a very low value shunt resistor. The <u>dark</u> gray and the <u>light</u> gray represent again respectively the 2nd and the 3rd order harmonic distortion, taken over the same shunt resistor. These are current waveform distortions.

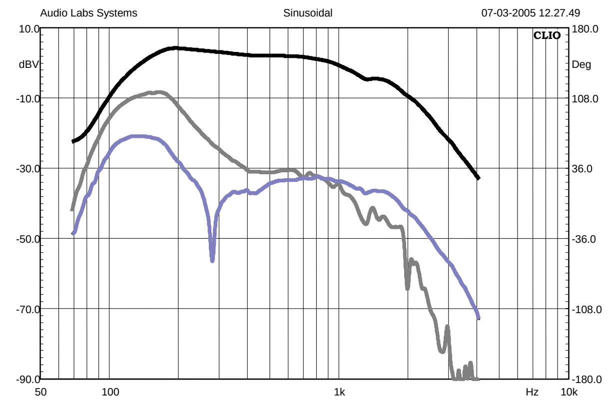

Figure 34: **Standard** 500-type, driving current response & distortion

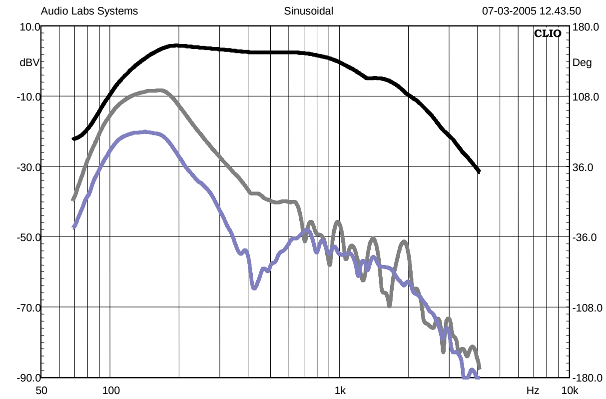

Figure 35: 500-type **with AIC**, driving current response & distortion

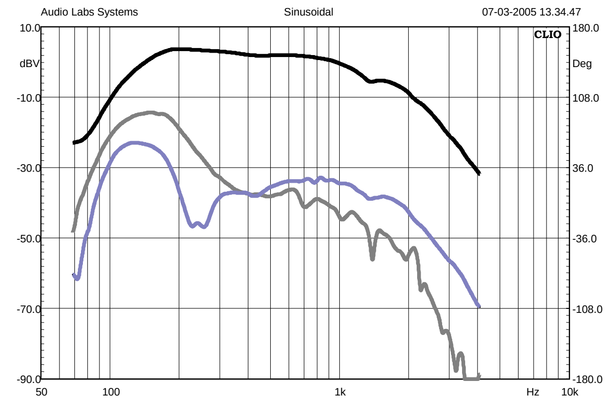

Figure 36: 500-type with **ring under the pole piece**, driving current response & distortion

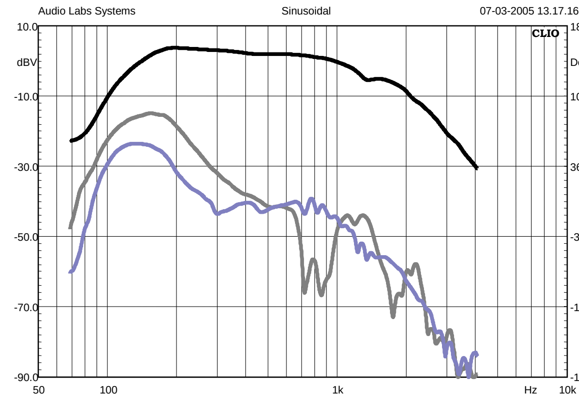

Figure 37: 500-type with **ring in the gap**, driving current response & distortion

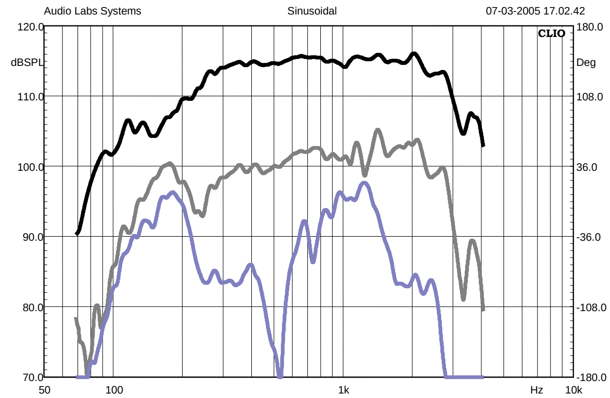

Figure 39: 600-type **with AIC**, response and distortion

The following 4 figures show some sample response taken similarly over the 600-type. They show how the effect of AIC over the 600-type speaker is beneficial but limited if compared to the 500-type. The reason for this is that the 600 speaker has a saturated pole and top plate. It can clearly be seen that the effect at high frequency is still more than noticeable and the benefits can be found in the distortion measured over the current.

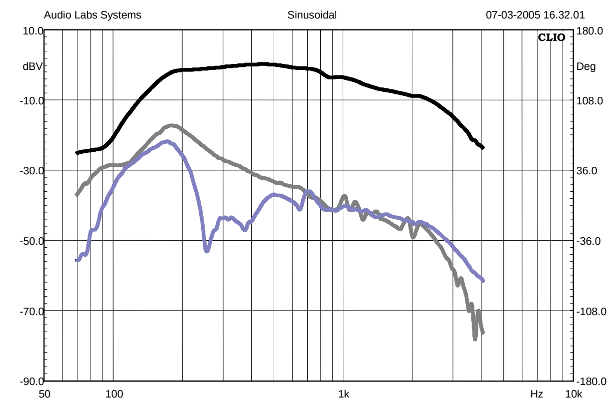

Figure 40: **Standard** 600-type, driving current response & distortion

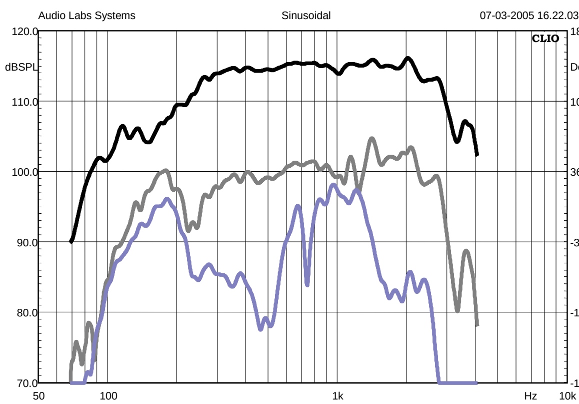

Figure 38: **Standard** 600-type, response and distortion

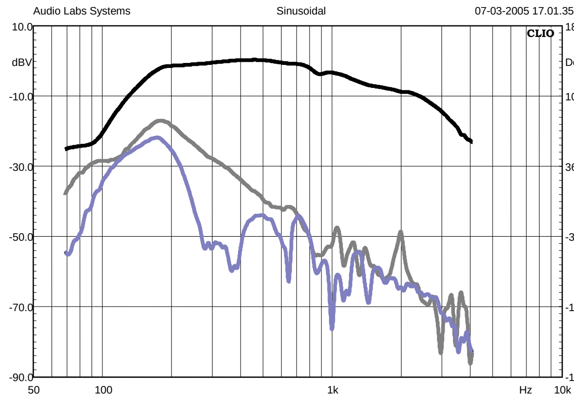

Figure 41: 600-type **with AIC**, driving current response & distortion

The following 4 figures represent the distortion curves measured over the input current in the **blocked units**. The driving current was equalized very nearly to flat at all frequency of the band that and was intentionally limited from 70 to 4000 Hz. Still the black curve is the fundamental, the dark gray curve is the 2nd order distortion and the light gray curve represents the 3rd order distortion.

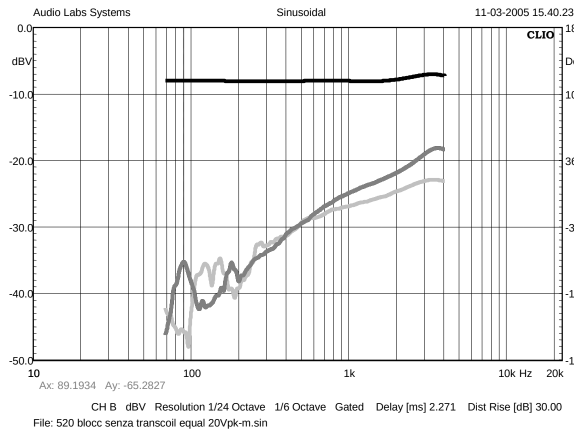

Figure 42: **Standard** 500-type, driving current response & distortion

It can be clearly seen how isolating the acoustic non-linearity the advantages of the distortion reducing devices is more evident. The advantages of the AIC system is noticeable higher in the mid and mid high range.

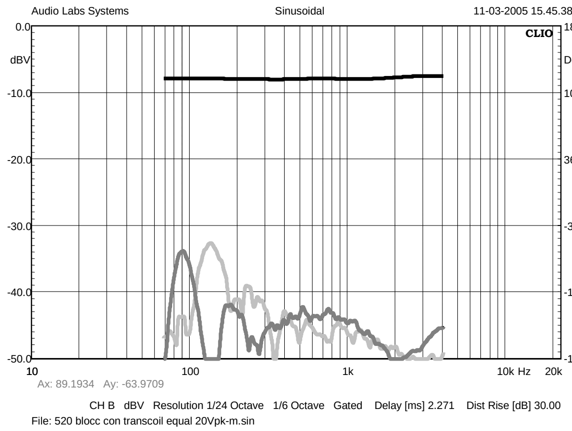

Figure 43: 500-type **with AIC**, driving current response & distortion

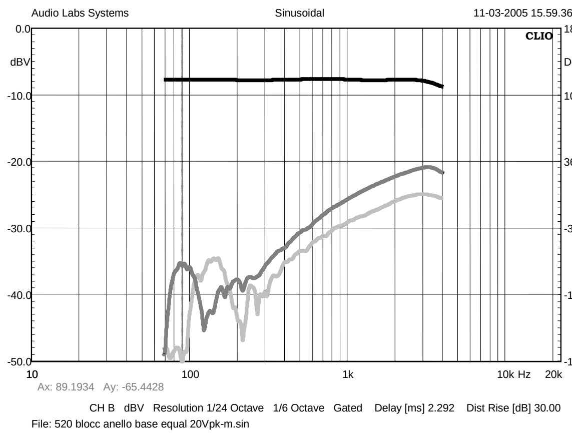

Figure 44: 500-type **with ring under the pole piece**, driving current response & distortion

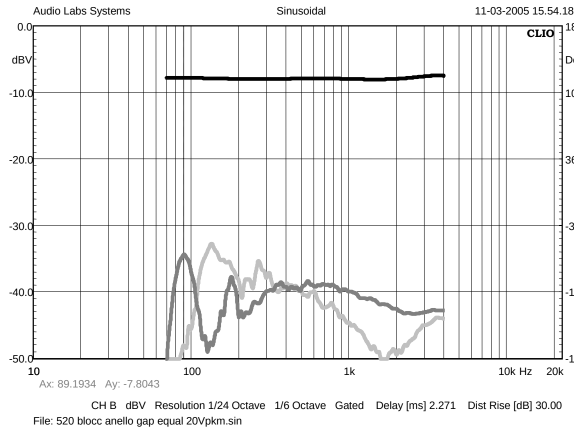

Figure 45: 500-type **with shorting ring in the gap**, driving current response & distortion

The following 3 figures show how multi-tone tests correlate with harmonic distortion measurements.

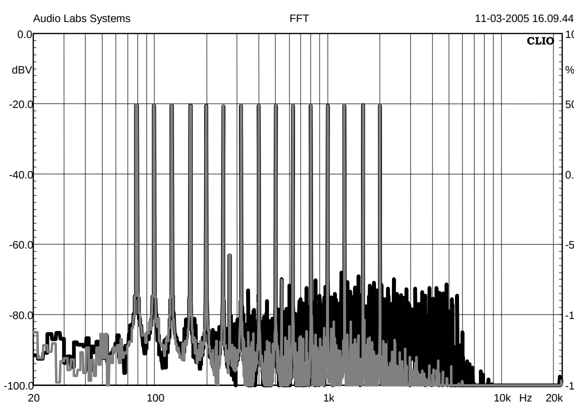

Figure 46: driving current FFT multi-tone test over a 500-type **with AIC** (gray) and without it (black).

The multi-tone test is performed with a 15 equal level tones signal spaced from ranging from 80 Hz to 2 kHz. The input current spectrum measured with the AIC coil paralleled to the voice coil (gray spectrum in figure 46) reveals a conspicuous reduction in mid frequency distortion products compared with the spectrum of the same speaker with the AIC disconnected. A similar spectrum can be observed in figure 47 where the standard speaker is compared to that equipped with the copper ring in the gap. Can be also clearly seen there how the ring in the gap turns out to be slightly less effective from this point of view.

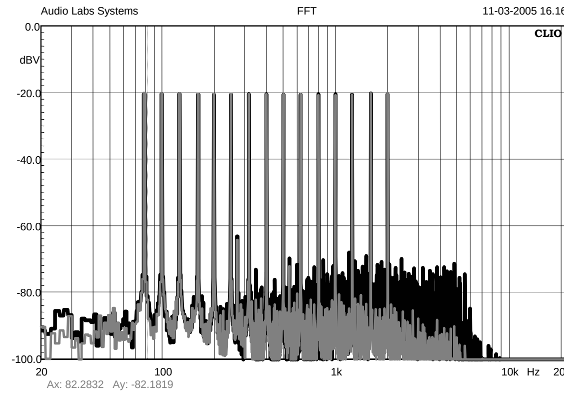

Figure 47: driving current FFT multi-tone test over a 500-type **with a ring in the gap** (gray) and without it (black).

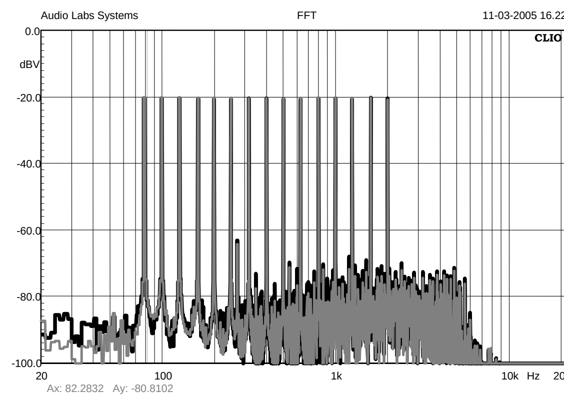

Figure 48: driving current FFT multi-tone test over a 500-type **with a ring under the pole piece** (gray) and without it (black).

In figure 48, the result of the same multi-tone test is shown. The speaker with the ring under the pole piece is now compared to the standard one. This system seems to be the less effective in reducing the current dependent modulations. A better effectiveness of this system can be found in reducing the displacement dependent modulations. It's interesting to point out that observing the FFT multi-tone spectrums, the four different implementations can be also investigated in searching for non-harmonic distortion components produced by them. Those are probably more responsible of the most of non-natural sound character in many speakers.

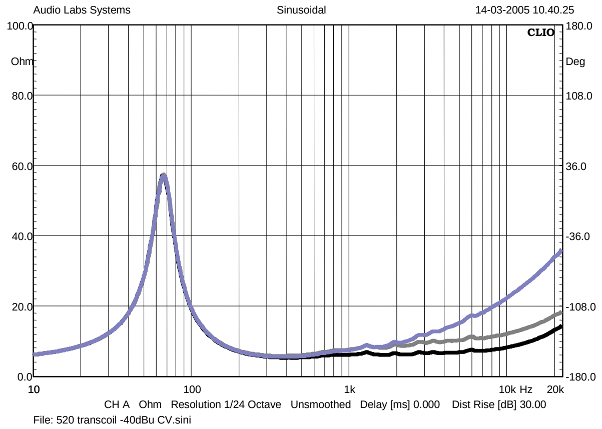

Figure 49: Free air impedance measurement over a 600-type loudspeaker: **AIC disconnected** (light gray), **AIC paralleled to the voice coil** (black) or **AIC shorted** (dark gray).

The impedance curves above show the effect of AIC if shorted or paralleled to the voice coil. The upper curve is measured with AIC disconnected.

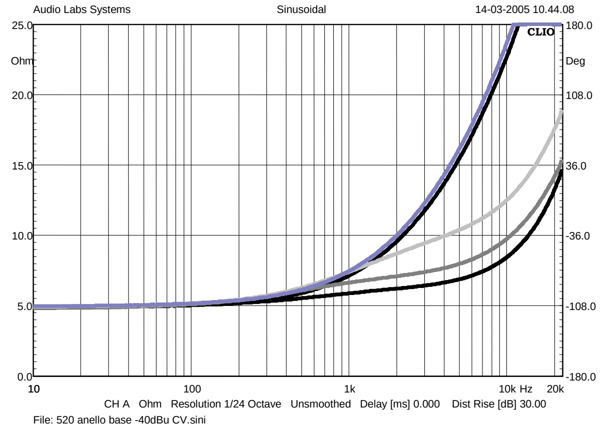

Figure 50: Impedance curves of the blocked speakers

Here in figure 50 there are the impedance measurements taken over the blocked speakers. The higher curve is the standard speaker, just below it there is the curve of the "ring under the pole" approach. The one in the middle is obtained with the AIC shorted. Below it there is the curve of the unit with a ring in the gap and the lower one is obtained with the AIC paralleled to the voice coil.

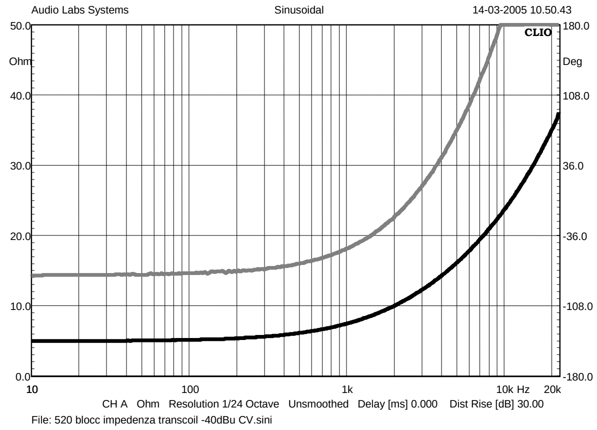

Figure 51: Impedance curves of the blocked speakers: the impedance of the **voice coil** (black) and the impedance of the **AIC coil** (gray curve)

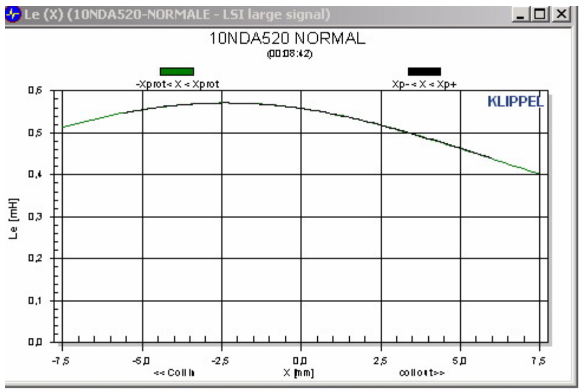

Figure 52: Le vs. displacement in the **standard** 500-type

Figures from 52 to 55 show measurements run over the 500-type speaker in the same 4 different implementations: they clearly show how much the inductance is reduced.

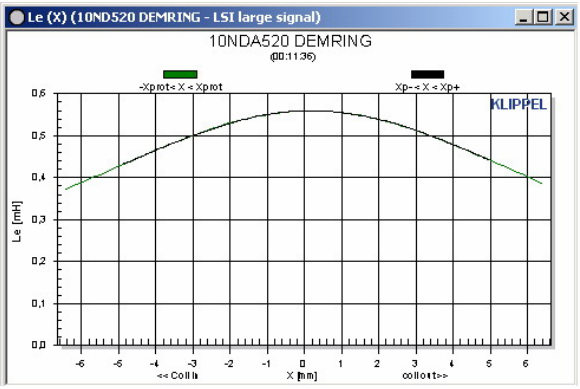

Figure 53: Le vs. displacement in a 500-type speaker **with the ring under the pole piece**

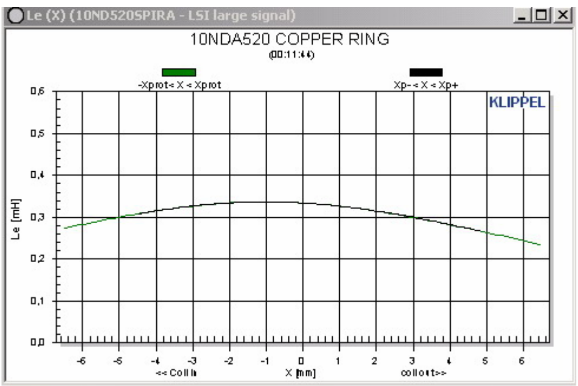

Figure 54: Le vs. displacement in a 500-type speaker **with the ring in the gap**

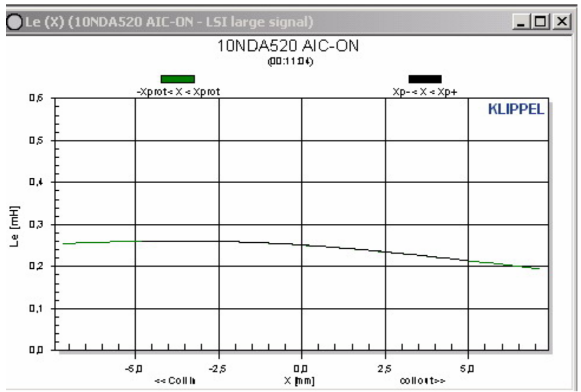

Figure 55: Le vs. displacement in a 500-type speaker **with AIC connected**

Further analysis should be performed over the AIC system but some simple considerations deserve to study how it behaves thermally.

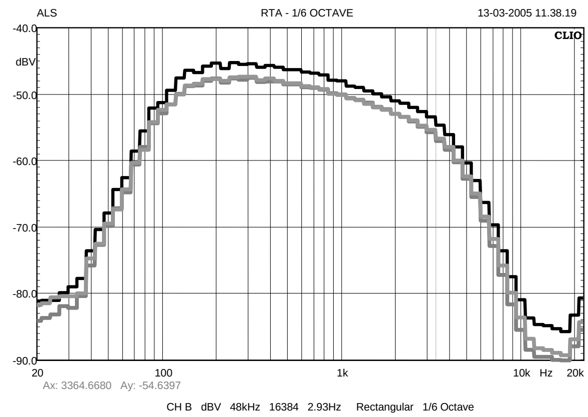

Figure 56: Spectrum of current applied for thermal analysis

A pink noise with the above spectrum (measured on the current) was applied at the blocked speakers. The black curve show the spectrum of the total current flowing in the AIC equipped speaker (voice coil current + AIC coil current) that is clearly a bit higher (+1.7 dB average).

The temperature chart in figure 57, recorded during an 8 minutes test over the pole piece, shows just a little higher tendency to heat up the pole piece. This was expected since more power is dissipated there and as we have seen also more current is globally flowing into the speaker. The pole piece temperature difference with the speaker equipped with the ring in the gap is anyway modest and the final temperature of the pole piece with the AIC connected in parallel with the voice coil is about 6 degrees higher than that.

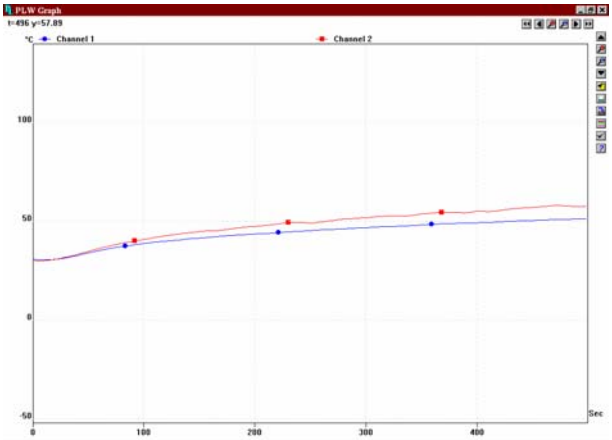

Figure 57: Difference in temperature after about 8 minutes at ¼ of power between the AIC-equipped speaker (the upper curve) and the same speaker but equipped with a copper shorting ring in the gap (lower curve).

5. CONCLUSIONS

The aiming of this study is oriented to show how much can be reduced the inductance modulation effects and the related flux modulation in midrange loudspeakers. Several practical solutions were discussed and some of them are already well known. Among them, the Active Impedance Control (A.I.C.) clearly shows some advantages in distortion reduction turning out to be particularly effective in reducing inductance modulation while minimizing its absolute value as well. This reduction seems to be particularly maximized in the vocal range in comparison with other well known devices like the copper ring positioned in the gap and the demodulating ring at the base of pole piece. Early listening test run over some samples already confirm these results in improved mid-range sound quality. This device is also particularly effective in linearization of impedance vs. frequency curve allowing for simpler passive crossover design.

6. ACKNOWLEDGEMENTS

We would like to thank very much the 18 Sound facility and technical staff for their “hardware” and “hard work” support and for their.... patience.

7. REFERENCES

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