

106. AES Convention Munich 1999

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New transducer technology A.R.T. = Accelerated Ribbon Technology - evolution of the air motion transformer principle

Abstract

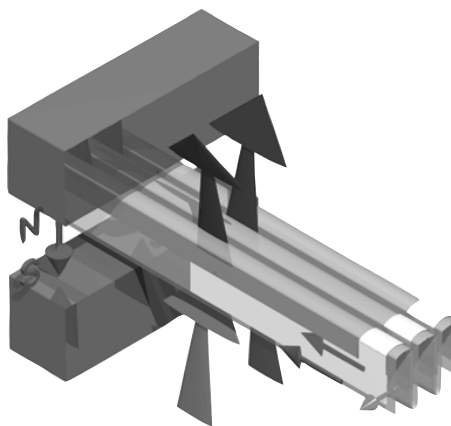
The paper describes new high- and mid-frequency loudspeaker drive units, based on the air motion transformer idea of Dr. Oskar Heil. Improvements concern geometrical layout as well as the use of new materials like capton-aluminium diaphragms and neodyme magnets. The membranes are made of very thin and especially folded diaphragms that are mounted in a strong magnetic field. They do not move air in a piston like action in a 1:1 ratio, but with a 4:1 diaphragm to air velocity transformation, thus improving transient response and dynamics of the system.

Design details and measurement results are presented.

Based on the original works of Dr. Oskar Heil, who invented his "Air Motion Transformer" back in 1972 [1], new tweeters and midrange units have been developed who are based on improved layouts and new materials.

As not everybody in the audience might be familiar with the principle under consideration I first introduce the fundamental kinematics, that set the air motion transformer apart from practically all the rest of electrodynamic or electrostatic transducers. Instead of using a piston like action to move air forth and back in a 1:1 ratio, the air motion transformer squeezes air in and out, thus achieving an estimated 4:1 velocity ratio between driving diaphragm and driven air.

It does so by using a folded diaphragm, that carries rectangular aluminium stripes, a device similar to what is used in magnetostatic transducers. This foil however is folded and brought into a strong magnetic field, leading to a diaphragm-air motion kinematic that can be seen here:



1: The Air Motion Transformer principle

Imagine this to be the position at the maximum of a positive sine half wave: the upper arrows show the air squeezed out, the lower arrows represent the air to be sucked in. At the zero crossings there will be equal distances between the folds, with no resulting air pressure. The maximum of a negative sine half wave will cause corresponding air pressure with all indicating arrows showing into the opposite direction. Because the folds are deeper than they are wide, the 4:1 velocity ratio mentioned above is achieved.

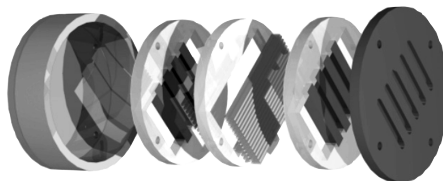
Compared to the original approach the design goals for the new drive units have been to

- build monopole units that can be built into "normal" speaker cabinets
- have no magnetic structure around the diaphragm with dimensions comparable to the wavelength of the higher frequencies transmitted
- have dispersion figures similar to 1" tweeters and 4" midrange units respectively and
- improve power handling.

Moreover, better materials and processes were to be found that show little tolerances only and make it possible to build units on a reliable basis. The new transducers have been named A.R.T. = Accelerated Ribbon Technology loudspeakers.

Tweeter

To obtain the results mentioned above new dimensions have been chosen, that are possible now after the arrival of neodyme magnets. As an orientation the area of a normal 1" dome tweeter was kept in mind. The air gap in this case is by far wider and deeper than usual with voice coil based systems; the demand for the total flux is immense. Even worse, where the induction has to come from, the air wants to go in and out. Good compromises had to be found to fulfil both needs.

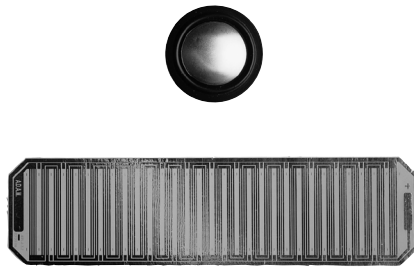


2: mechanical construction of the tweeter

Rows of front-back polarised neodyme magnets are positioned on both sides of the diaphragm. Front and back plate together with the surrounding capsule build the yoke. The magnetic circle is completely closed, practically no stray fields are observed, so the unit can be used near to CRT's.

The diaphragm consists of a capton – aluminium laminate, created by a purely physical heat-pressure process. It can withstand temperatures of up to 400 °C, thus improving the power handling and dynamic capabilities of the unit considerably.

An additional benefit of the folding is the fact, that the acoustically effective area is much bigger than the "mouth" of the unit, where the sound waves are emitted. Not the complete area is acoustically effective of course, yet a 2.5:1 ratio between the area of a 1" dome tweeter and the A.R.T. tweeter is obtained.



3: effective diaphragm areas of a 1" dome tweeter (above) and the A.R.T. tweeter.

The diaphragm is manually folded and glued to its carrying frame.

It was of special interest to bring the resonance frequency of the tweeter down to 1.5 kHz. Thus a successful integration within 2-way systems would be possible. An additional volume behind the diaphragm was attached, carefully damped for linear behaviour of the system.

The magnetically closed tweeter is mounted to a plastic front plate and is shown here:

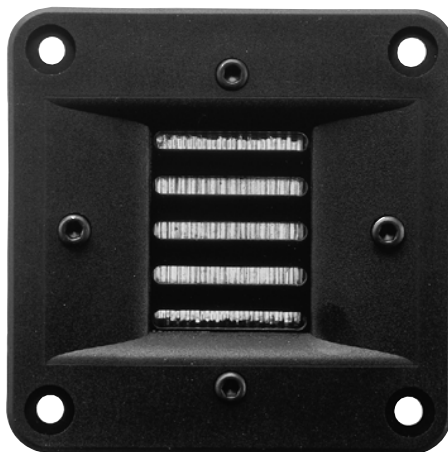
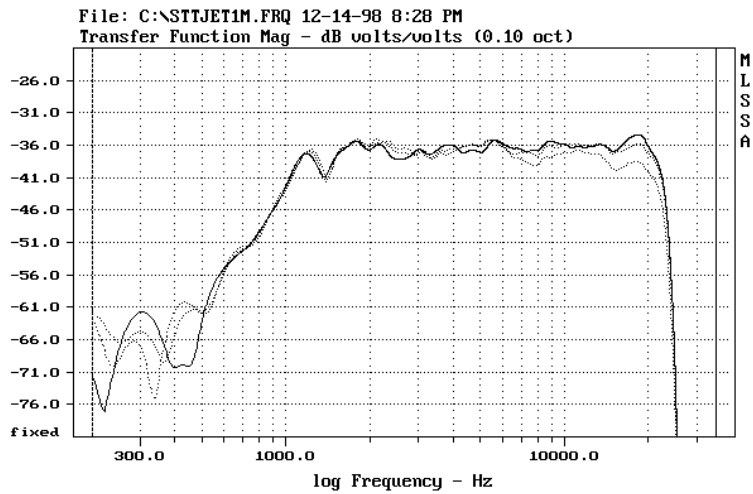


Abb. 4: The completed A.R.T. tweeter

Electroacoustic behaviour of the tweeter: the measurements.

Frequency response

The measurement has been taken with the tweeter built into our S2 studio monitor. Microphone distance has been 1m; the three curves show the behaviour in different angles.



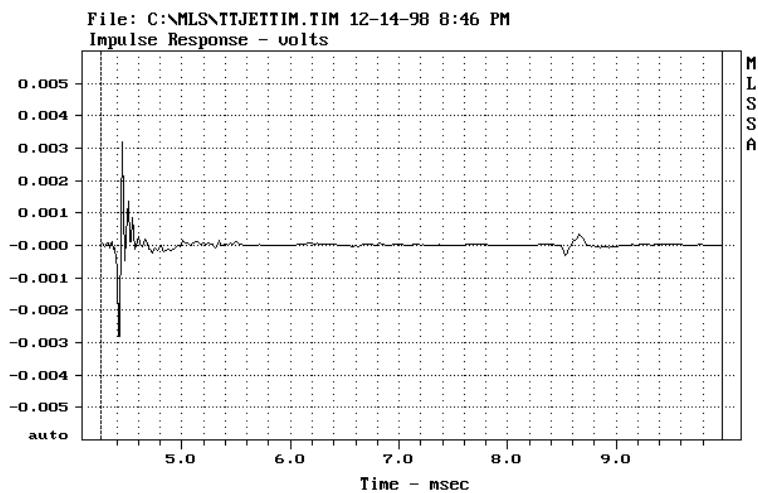
CURSOR: dy = 1.50858 x = 35002.0569 (10896)

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5: frequency response, microphone 1m, angles 0°, 15° and 30°

Impulse response

shows a quick decay of the energy within the first millisecond. The signal at 8.6 ms is a first reflection of course.

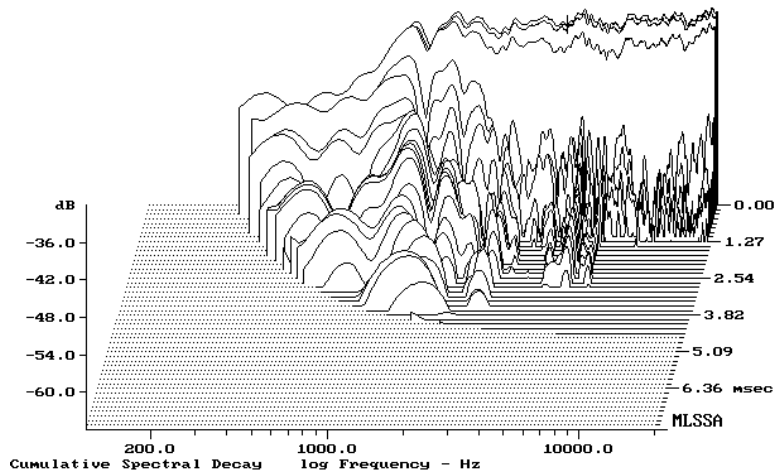


CURSOR: y = -1.15546e-005 x = 9.9773 (753)

TIME DOMAIN MENU: Go View FFT Waterfall Acquisition Setup Transfer Macro
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6: Impulse Response, microphone distance 1m

Cumulative Decay Spectrum



-37.14 dB, 5085 Hz (138), 0.000 msec (1)

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7: Cumulative Decay Spectrum from the above measurement

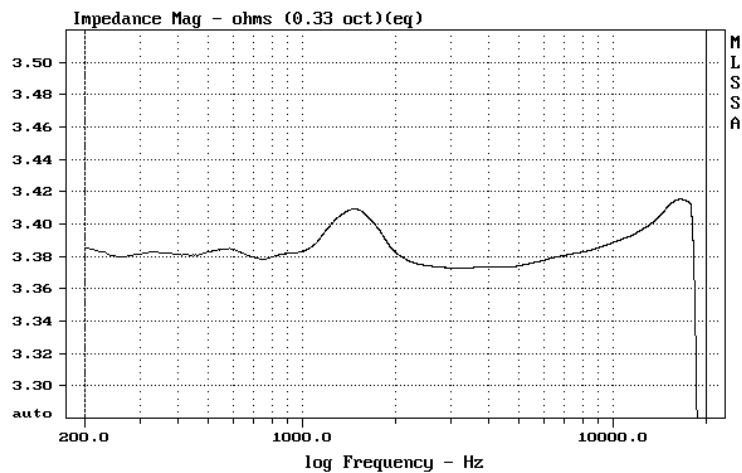
A typical delayed oscillating around the resonance frequency of 1.5 kHz is normal and will not play a role, because of the separating networks.

The first 30 dB of decay are very fast, within half a millisecond approximately, and as they are decisive for the perception of sound a superior transient reproduction can be expected.

The decay around 6 kHz goes on for another two milliseconds, and although it is vastly reduced in level already it remains a disliked property.

Impedance

As there is no voice coil the impedance curve is a flat line using normal scaling. To show the weak resonance of the system the following plot is useful:



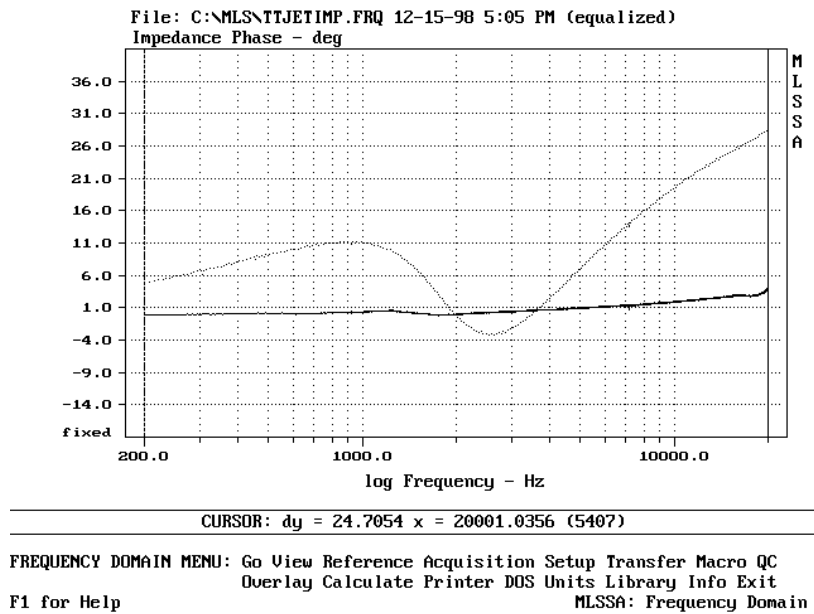
CURSOR: y = 2.75129 x = 20001.0356 (5407)

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8: Impedance (note vertical scale from 3,3 Ω to 3.5 Ω only!)

Phase

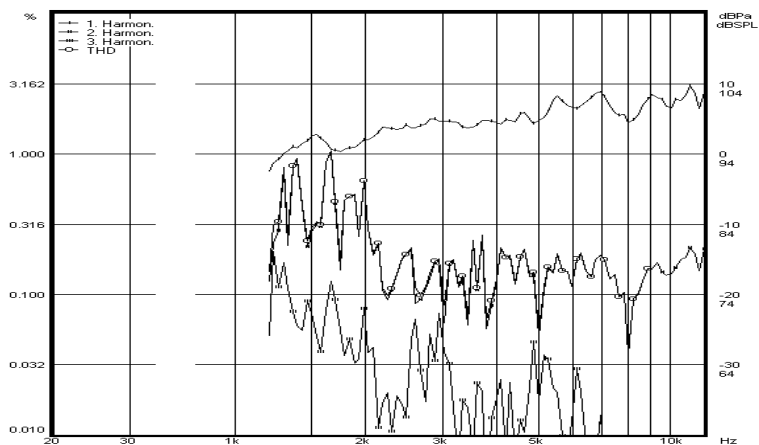
The phase consequently is a flat line too, and it is plotted here together with the phase response of a typical 1" dome tweeter:



9: Phase comparison A.R.T tweeter / 1" dome

Distortion

Harmonic Distortions have been measured separately for the different components; THD is shown as well:



10: Harmonic distortions: 2nd and 3rd harmonic plus. THD

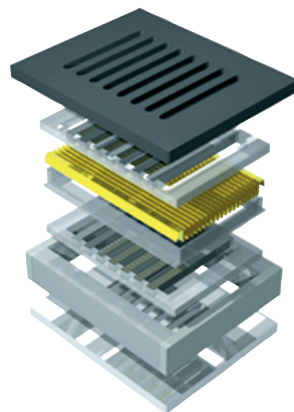
The second harmonic plus THD remain below 0.2%, above 2 kHz, the more dangerous 3rd harmonic is around 0,03 %. Higher order distortions (up to n=7) have been measured and always were less than 1/10th of these values. The results obtained are comparable to those of very good 1" dome tweeters.

All in all we have a tweeter that actually can replace a 1" dome, because its dimensions and dispersion are comparable. However, within the A.R.T tweeter a much larger diaphragm moves air in a 4:1 velocity ratio, having superior power handling and dynamic capabilities. Linear phase response and ultrafast decay behaviour can be measured.

The A.R.T. Midrange Unit

After finishing the tweeter it was an invitation of course to apply the new technique to a midrange unit as well.

As it could be expected, the geometry of the folds had to be enlarged to appropriate dimensions. As with the tweeter, a comparable voice coil driven speaker has been chosen, a 4" cone midrange in this case, that could be replaced, and whose dimensions gave the geometrical limits for the unit.



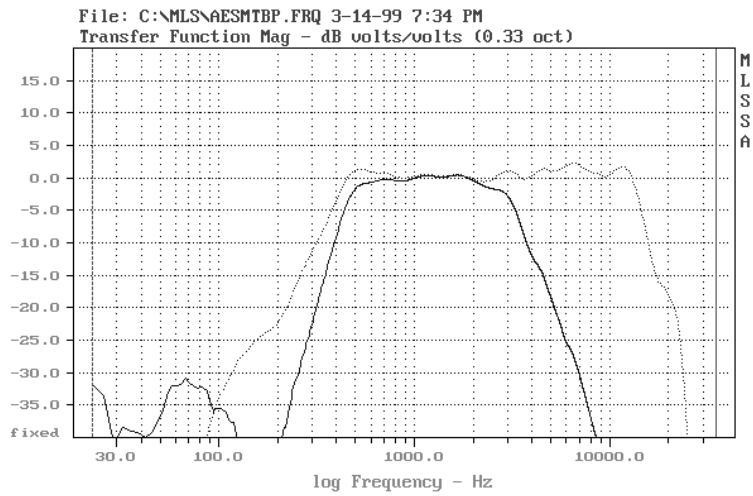
11: mechanical construction of the midrange unit

Upcoming problems have been a once more drastically enlarged air gap. Depth and width of such a unit make it difficult to get a very high total flux, which is necessary to have the efficiency needed in modern systems. An array of 28 neodyme magnets with 8mm depth is necessary to achieve this goal. The now rather big diaphragm had to be coated to avoid foil resonances.

The benefits however are very convincing. The folding results in an extremely wide frequency band, and the unit reached responses from 200 Hz to well beyond 20 kHz with uncoated diaphragms. To concentrate on mid frequencies thicker and more stable laminates had been chosen, with higher repulsing forces and therefore a higher resonance frequency. The coating lead to higher SPL's, but cost the area above 12 kHz, which we decided to be of minor interest for a midrange unit.

Frequency response

is measured with the unit built into the S4 Monitor. A bandpass filter with 500 Hz and 3 kHz is corner frequencies is applied for integrating the units in the ADAM studio monitors:

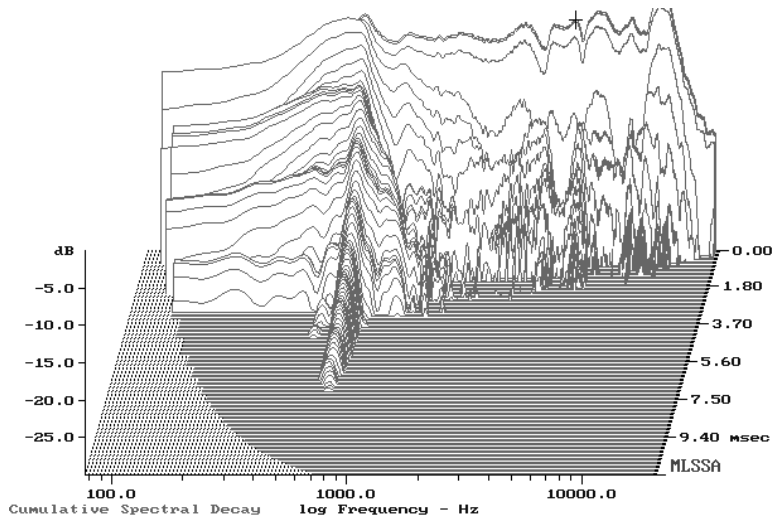


CURSOR: dy = -1.01342 x = 35002.0569 (10896)

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12: frequency response of unfiltered and bandpass filtered A.R.T. midrange unit

The **waterfall diagram** of the unfiltered version shows a very fast decay within the band transmitted, however a small resonance can be seen around 500 Hz:

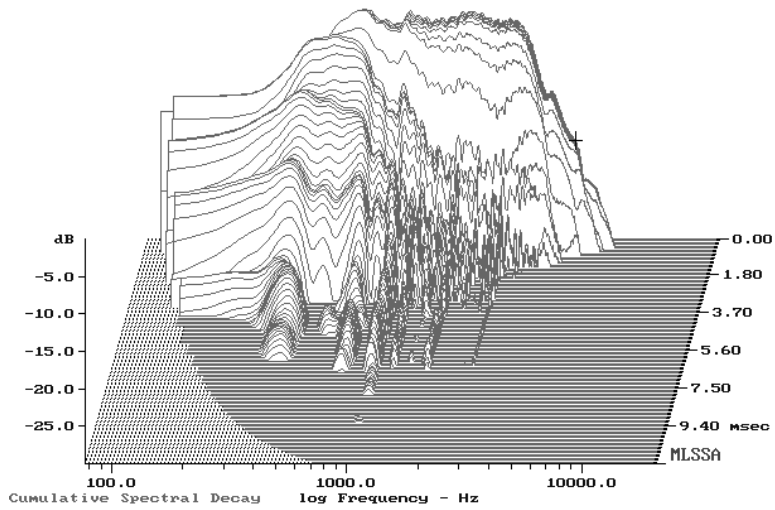


0.90 dB, 5050 Hz (393), 0.000 msec (1)

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4: cumulative decay spectra of the unfiltered A.R.T. midrange unit

The cumulative decay spectra of the filtered version show that the relevant energy has disappeared after 3 ms, including the resonance mentioned before:



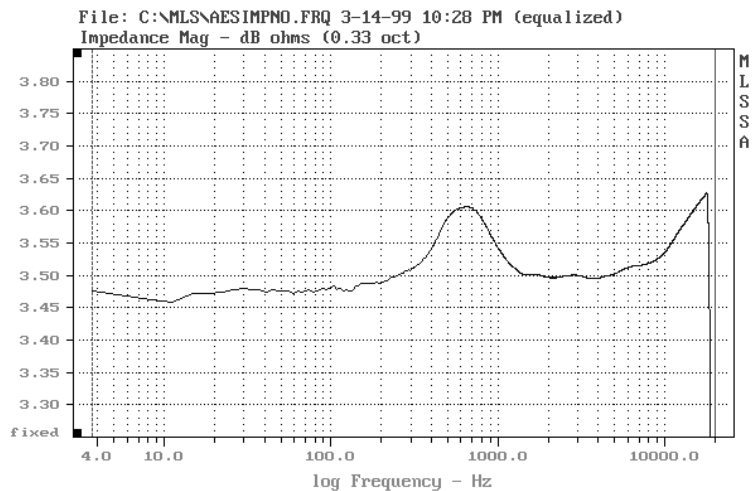
-16.83 dB, 5050 Hz (393), 0.000 msec (1)

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13: cumulative decay spectra of the bandpass filtered A.R.T. midrange unit

Impedance

Similar to what was found with the tweeter, the impedance of the midrange unit is extremely flat, showing a minimal dip around the resonance frequency:

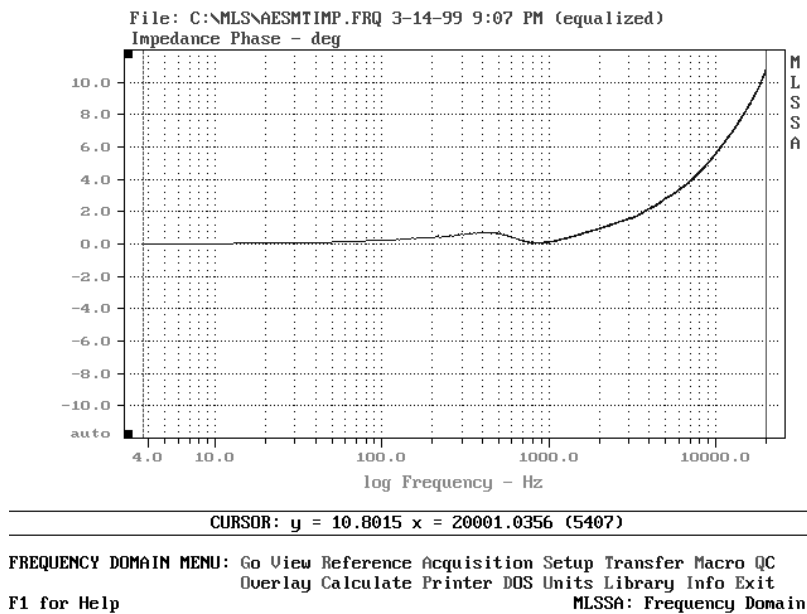


CURSOR: y = 1.855 x = 20001.0356 (5407)

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14: Impedance of built in A.R.T- midrange unit (note vertical scale from 3,3 Ω to 3.8 Ω only!)

Consequently again the phase response is flat as well. There is no literature known to the author presuming that a $\pm 1^\circ$ phase shift can cause audible effects:



15: Phase response of the built in A.R.T- midrange unit

Decoupling the midrange cabinet: to optimise the reproduction capabilities of the unit it is mounted in its own cabinet within the loudspeaker enclosure, swimming on a damping foam:



16: A.D.A.M. studio monitor with separately damped cabinet for the midrange unit

Conclusion

A new generation of transducers has been developed that move air in a different way compared to the piston like actions of voice coil based systems. Yet all classical engineering aspects have been observed: frequency response is linear in a wide range, dispersion is comparable to 1" domes and 4" cone midrange speakers respectively, and efficiency is high for the tweeter (93 dB/W/m) and reasonable for the midrange unit (89 dB/W/m). Impedance curves are flat $3.3 \Omega \pm 0.2 \Omega$, phase response consequently is ultralinear and distortion is on a very low level.

The obtained sound quality normally is acknowledged for its better transient response and more exact spatial information. The proof of course is in the listening.

Acknowledgment:

The author would like to thank Roland Stenz for his support throughout the development of this project.

[1] US Patent 3,636,278, 1972, Dr. Oskar Heil:

Acoustical transducer with a diaphragm forming a plurality...