

COVER PAGE

Document downloaded by @DAEL

Sat Nov 28 09:40:11 2026
For personal use

When automatic English translation is provided, only the original document is authentic.
The EAA cannot be held responsible of any translation error

Bibliographical reference

Line Array Sound Reinforcement Systems using Air Motion Transformer, Arne Muscheites, Dieter Leckschat and Christian Epe, Acta Acustica **vol. 102** (Number 3), 2016, pp. 592-599

DOI
https://doi.org/10.3813/AAA.918976

Acta Acustica united with Acustica
Vol. 102 (2016) 592 – 599

DOI 10.3813/AAA.918976

Line Array Sound Reinforcement Systems using Air Motion Transformer

Arne Muscheites, Dieter Leckschat, Christian Epe
University of Applied Sciences, Duesseldorf, Germany. arne@muscheites.de

Summary
Tweeters according to the Air-Motion-Transformer (AMT) principle are famous for good impulse response and low distortion and are therefore enjoying increasing popularity in audio entertainment as well as in studio monitoring applications. The idea of exploiting these advantages in live sound business sounds tempting. However, manufacturers of sound reinforcement systems are reserved to Air-Motion-Transformers due to the alleged lack of maximum level. Nevertheless, the AMT is perfect for a line array because of its natural properties as a line source. Together with an industrial partner the University of Applied Sciences Düsseldorf developed a compact and efficient line array using a newly developed Air Motion Transformer. This AMT Line Array reaches maximum levels at least equal to current systems and provides the desired precision sound of AMT tweeters.

PACS no. 43.20.Mv, 43.38.Ar, 43.38.Dv, 43.38.Hz, 43.38.Lc, 43.38.Yn, 43.58.Ry, 43.60.Fg

1. Introduction

Line Arrays are a corner stone in today's large scale audio systems. From music festivals, concerts of all kinds to installations in churches and stadiums, where ever sound has to be evenly distributed among large crowds, only this technology can deliver an adequate quality of music and speech reproduction.

The underlying theoretic principle of cylindrical waves has first been described by Harry Olson and later expanded by Heil/Urban [1]. In short, when realizing narrow spacing between adjacent low to mid frequency transducers, the radiated waves interfere constructively in the plane of the array. For high frequencies, a specially designed wave guide has to be utilized which forms a cylindrical wave out of the emitted spherical wave from conventional high frequency transducers. Combined and used as a vertical array, these speakers have the advantage of radiating cylindrical waves over their entire frequency bandwidth. These cylindrical waves only decay with 3 dB per doubling of distance as opposed to spherical waves, which show a 6 dB decay per doubling of distance [2]. As described later by Heil/Urban [3], cylindrical wave radiation is still achieved, even when angling the sources relative to each other as well as when creating gaps between them. In conclusion Line Arrays can be used to precisely cover large areas using their vertical focus and their superior wave radiation. All the while their horizontal dispersion can be designed the same way as for conventional speakers. In practical applications, line arrays are typically divided into several cabinets, each having a waveguide for the high frequencies and relying on the array for the low frequencies. The number of cabinets can be individually adjusted for each usage as well as the desired opening angle. Typical smaller sized Line Arrays have a frequency range of 100 Hz to 16 kHz, achieving a peak SPL of 120 dB in the low to mid frequencies and up to 130 dB in the high frequencies with a single cabinet. Because of the constructive interference in the low and mid frequency range, the SPL increases coherently by 6 dB or more when doubling the cabinet number. This is less true for higher frequencies because of the cylindrical wave radiation and their inherent low coupling characteristics.

After a previous work, which centered around optimizing the construction and the radiation of an Air Motion Transformer, a subsequent project was initiated at the University of Applied Sciences Duesseldorf in cooperation with an industrial partner. The advanced Air Motion Transformer was to be used in a suitable application as a high frequency unit in a Line Array. A fully operational Line Array system for demonstration purposes, employing 16 cabinets, was to be designed, developed, constructed and thoroughly measured as well as tested to showcase the capabilities of the AMT.

Received 29 May 2014,
accepted 02 March 2016.

2. Theory Part 1: Air Motion Transformer

An Air Motion Transformer is an electrodynamic transducer. It utilizes a polyimide membrane (e.g. kapton) with aluminum conductive paths printed on one side. The diaphragm is then folded like an accordion and placed in a strong permanent magnetic field, as can be seen in Figure 1. Because of the Lorentz force, if a current flows through the conducts, the membrane folds will be attracted or pushed away from each other depending on the polarity. Thus the air in between the folds will get pushed out

© S. Hirzel Verlag · EAA

rapidly or sucked in (large arrows), whichever the membrane motion. The result of this pattern is a movement transformation between the diaphragm movement and the resulting air movement. The air excursion in front of the diaphragm is about five times higher than the diaphragm excursion (thus the transformer ratio is approx. 5:1). From this principle we can easily see the derived name *Air Motion Transformer*. Employing a very light membrane, which, through the folded structure, also has a much larger surface than any other comparable driver, results in very low distortion and precise audio reproduction even in high SPL applications.

Historically, Air Motion Transformer or similar transducers have been used either as large format full range sources or, in the recent past, as high end high frequency unit in Hi-Fi and studio applications. Their power handling is traditionally quite low, reaching 30 to 40 W RMS, due to the fact that the conducts quickly overheat and fuse. Their sensitivity, that is SPL at 1 meter distance when 1 Watt power is applied, is typically around 90 dB/1W, 1 m.

In the professional market prevalent compression drivers which rely on the compression of air between the larger diaphragm area and the small throat aperture can achieve very high sensitivity values of up to 110 dB SPL (1 W, 1 m) while retaining decent power handling of about 50 W RMS. To challenge these magnitudes, the AMTs have been drastically increased in size to ensure higher SPL values, the diaphragm and conducts geometry as well as their material have been optimized to drastically increase power handling. The resulting drivers achieve good sensitivity values of 102 dB and have a nominal power handling of about 250 W RMS. Typical dimensions of the diaphragm are between 100 mm and 300 mm in height and 20 mm to 40 mm in width.

3. Theory Part 2: Line Arrays

Contrary to conventional loudspeaker systems, which radiate spherical waves whose SPL decreases with 6 dB per doubling of distance, Line Arrays propagate cylindrical waves with a characteristic SPL decrease of 3 dB per doubling of distance. It was shown [3] that for a finite line source including discontinuities, the radiated sound field can be separated into a near field experiencing cylindrical wave propagation, and a far field region with spherical wave radiation.

The transition range between these two can be calculated by

$$d_b = \frac{3}{2} F H^2 \sqrt{1 - \frac{1}{(3FH)^2}},$$

where F is the frequency in kHz and H is the height of the line source in meters.

The dependency of the spherical wave propagation on array height as well as frequency, which can be derived from the former equation, is also illustrated in Figure 2 for a line source of 5 meters height. The corresponding angles

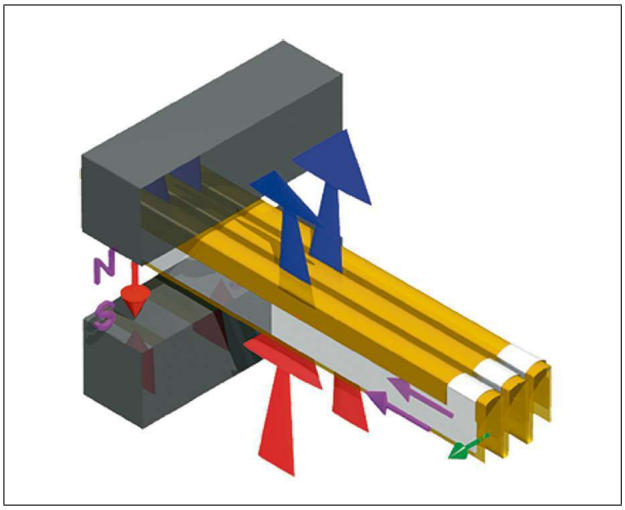

Figure 1. Sketch of the Air Motion Transformer showing the functional principle [4].

for each octave highlight the opening angles, which can be experienced in the far field.

Advancing from the theoretical approach using Fresnel calculations, two criteria were described [1] which define conditions to be met for the effective coupling of multiple sound sources as well as limitations for tilt angles and the influences of cabinet heights. These criteria demand a maximum spacing of $\lambda/2$ at the highest radiated frequency between the acoustic centers of individual sound sources, e.g. conventional cone drivers. For high frequencies, these would require unrealistic small units since at 10 kHz the maximum spacing would already have to be 17 mm. For line sources, a minimum covered vertical radiating area of 80% was required. To shift the radiation property of circular piston drivers to behave as a line source, specially calculated equal length waveformers have to be utilized.

In contrast, Air Motion Transformers are line sources by their mechanical nature. Their propagated sound field is characterized by their horizontal and vertical dimensions. This allows a direct implementation without having to use a waveformer. Additionally, a classic horn design can be used to attain the desired horizontal directivity. The dimensions of the diaphragm have to be chosen accordingly.

4. Conceptual Design

To begin, the sound reinforcement market was surveyed prior to the actual design process to get an overview of the Line Array market. The goal of the development was to show the AMT would be a valid alternative to the common compression drivers.

Based thereon specifications for the concept could be defined. Target parameters where as follows:

Target Parameters for the AMT Line Array

Frequency Response: 90 Hz–18 kHz,
Nominal Horizontal Coverage angles: 100°,
Max SPL: 130 dB per Cabinet.

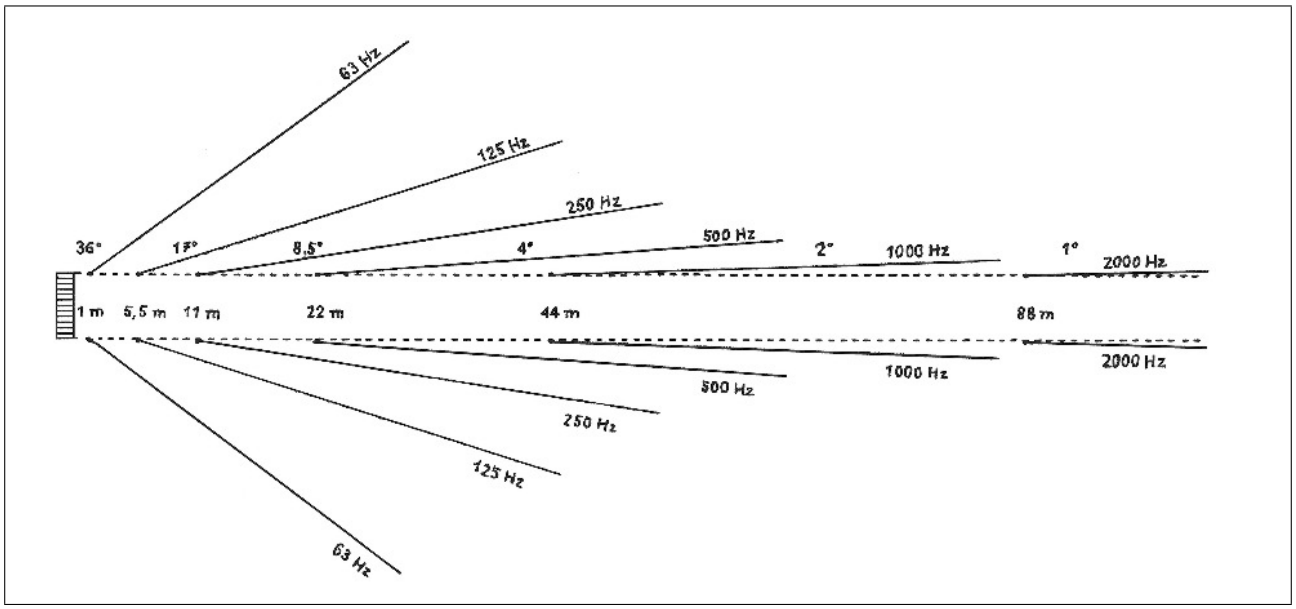

Figure 2. Sketch of the frequency dependent shift from cylindrical to spherical wave propagation [3].

These specifications are only achieved by the very best products in the market, as will also be seen in the comparative measurement results later in this paper. As a side note, Max SPL is defined as SPL at 1m distance to the source, not exceeding 10% THD nor damaging the speaker using sinusoidal bursts of 170 ms length (equivalent to 8k samples at 48 kHz sampling rate). This test has been widely used in independent tests of relevant journals which have been used for reference purposes.

One example is shown in Figure 3. Here, a set of three cabinets has been tested. The three frequency curves represent the maximum achievable SPL at 1% (lower curve), 3% (middle curve) and 10% (upper curve) total harmonic distortion respectively. As can be seen, this system reaches an average of 131 dBSPL from mid to high frequencies with a few peaks even higher. This also serves as an example for a Line Array system from the professional sound reinforcement market.

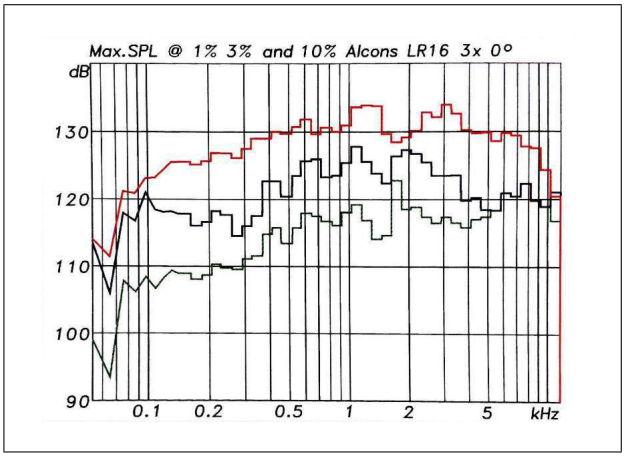

Figure 3. Maximum SPL Diagram of a reference Line Array System showing 1% (green lower curve, colour online), 3% (blue middle curve, colour online) and 10% (red upper curve, colour online) THD [5].

4.1. Speaker System

The market survey clearly indicated two possible routes for the design. Either a full range, 3-way system which would play down to around 50 Hz or a 2-way system, which would be extended by subwoofers below 100 Hz to full range capabilities.

Because the focus of this development was put on the high frequency reproduction, the 2-way system was favored. For the target parameters to be reached, a 2½-system was to be developed, utilizing two 8"-low/mid woofers, one of them being solely for extended low end sensitivity, and one single AMT as high frequency unit.

When arrayed, all channels would each be switched in parallel and filtered separately. Therefore six channels of amplification and digital filtering were needed for a stereo setup.



Figure 4. Close-up of a single Cabinet of the AMT Line Array. From left to right: Low frequency transducer, low-mid frequency transducer, high frequency Air Motion Transformer behind horn aperture.

4.2. Low Frequency Woofers

The conceptual design for the low and mid frequency woofers required a few careful considerations. Both Max SPL as well as directivity would have to be examined to find the best fitting design. The limiting factors for the speaker performance regarding Max SPL are multisided.

At low frequencies, high excursion of the woofer dramatically increases THD. Because the magnetic flux is most strong within the gap for the voice coil, once the coil starts to move out of the gap because of increasingly more excursion, the movement becomes nonlinear. Typical power ratings for this situation are 250 W for high excursion drivers. The target parameters are designed to allow for easy coupling and extension using subwoofers, whose lower cut-off frequency typically is around 100 Hz. Consequently, the bass reflex tuning will have to be laid-out to allow maximum SPL down to 100 Hz. Woofers that are capable of reaching the defined low end frequency response would typically have a sensitivity of 90 dB/1W, 1m at this range (see Figure 5).

Above around 500 Hz the power rating of the voice coil itself, the thermal power rating, is the limiting factor. Here the sensitivity should be at an even high value of 100 dB while power ratings can be as high as 1000 W. It is easy to conclude from here that above afore mentioned 500 Hz one chassis would suffice to reach the target parameters (130 dB SPL) while at lower frequencies two woofers are required. Because of fully constructive interference, the second chassis would add 6 dB of sensitivity while the power rating can be doubled as well for the two woofers.

When arrayed, the radiation impedance increases for adjacent woofers, thus increasing the sensitivity for each driver at low frequencies further. This results in more than 6 dB gain when doubling the number of low frequency drivers. It is shown later how this helps in raising the low frequency radiation to the levels of mid and high frequencies.

To fulfill the desired goals regarding directivity, the two low end woofers were placed directly adjacent, thus leaving the horn and the Air Motion Transformer off on one side and creating a nonsymmetrical setup. This results in a frequency-dependent shift of the acoustic center; however, the angle of this shift is only 0.5 degrees for a listener in 20m distance and thus it is not noticeable. With little variations in design parameters, a symmetrical design is also possible but these considerations are out of the scope of this investigation.

4.3. High Frequency Concept

At high frequencies, one AMT with a height of about 170 mm will have to suffice. Having an estimated sensitivity of 102 dB (see Figure 6), it will have to withstand a peak power of about 1 kW to reach the targeted 130 dB Max SPL. These parameters where communicated and discussed with the developers of the transducer manufacturer. They built a prototype for tests based on these specifications.

For the high frequencies to be emitted with a constant coverage, a reasonably sized horn was needed, which would limit the dispersion and also increase sensitivity. The defined directivity of 100° was to be achieved.

Horn calculation has been carried out using a BEM simulation. The horn contour was designed according to the wavefront of the driver. This way, dispersion can be held perfectly constant and reflections inside the horn can be reduced to a minimum.

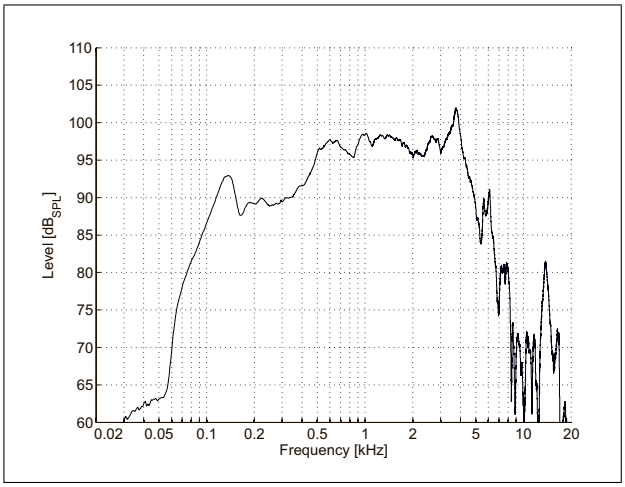

Figure 5. Sensitivity 4V/1m Inner and outer woofer.

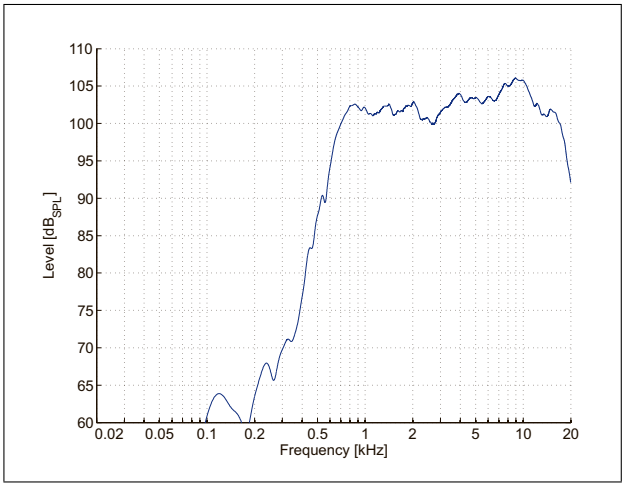

Figure 6. Sensitivity 2.83V/1m High frequency Unit AMT.

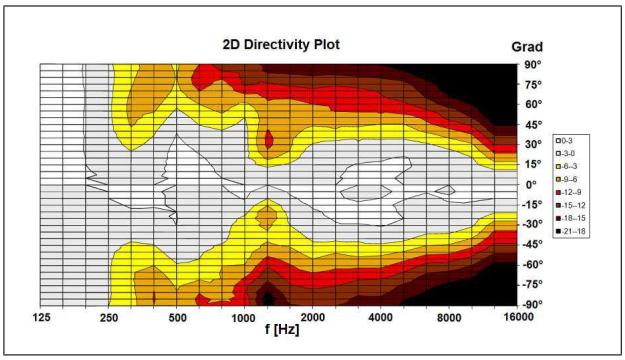

Figure 7. Isobars of the horizontal polar dispersion.

Figure 7 shows an isobaric plot of the horizontal dispersion pattern of the AMT Line Array. Below 1 kHz the dispersion is characterized by the beaming of the woofers. At 1300 Hz, the crossover point can clearly be seen. Here, destructive interferences between the two separate sources, mid and high frequency driver, cause cancellation effects outside of the main axis. This is simply due to the gap be-

tween the two sources and cannot be directly affected by filters. Above 1300 Hz the horn and the Air Motion Transformer define the dispersion and show the desired propagation.

While the horizontal dispersion angle can be enhanced and as such be constant, the vertical dispersion angle can be adjusted by angling the cabinets to each other. As defined again by Urban/Heil [3], the maximum inter cabinet angle was specified to be five degrees. Figure 8 and 9 show the vertical dispersion measured with three cabinets at 0° splay angle (Figure 8) and 5° splay angle (Figure 9). Even in the extreme setup with a five degree splay angle between the cabinets, the wavefront does not break up. The spherical wave propagation continues seamlessly.

5. Evaluation of the Concept

Deriving from the target parameters, appropriate 8"-woofers were sampled from the loudspeaker manufacturer market. Based on their Thiele-Small Parameters, simulations have been carried out to evaluate low frequency behavior as well as Max SPL and finally construct a prototype cabinet.

The final bass reflex tuning was set to 106 Hz, which gives an average low-end sensitivity of 90 dB for one woofer and about 96 dB for two woofers. To avoid beaming of the dispersion, the second woofer was filtered at 400 Hz with a third order Butterworth filter. This resulted in a net gain of 6 dB in the crucial range of 100 to 300 Hz without hindering directivity.

When taking distortion limits into account, the two woofers reached an amplitude of 120 dB below 200 Hz, rising up to 128 dB at 500 Hz. It will be shown later that coupling of several cabinets in the lower frequency region smoothes the curve showing Max SPL as a function of frequency. The 2 ½-way design also allowed for an evenly decreasing dispersion angle.

The engineers of the loudspeaker manufacturer designed the AMT driver based on the parameters and specifications derived from the target parameters for the Line Array. The magnetic motor and the diaphragm were designed to allow for the specified sensitivity as well as power rating. Thus it was possible for the driver to attain the desired sound pressure level. The dimensions of the diaphragm define the radiation pattern of the AMT. In order for the horn to be effective, the dispersion of the high frequency unit would have to be wide. Therefore the width of the diaphragm was to be 30 mm which, including the horn, allowed a constant directivity up to 10 kHz with a slight beaming above that frequency. For evaluation of the driver behavior in the vertical dimension, an investigation of the wave front has been done to assure the cylindrical wave propagation. For that purpose, the phase angle at 20 points which were spaced 1 cm along the driver axis was determined at several frequencies. The phase deviations were so low that it can be stated that a cylindrical wave front appears in front of the tweeter. Measurements on total harmonic distortion, impulse response as well as directivity

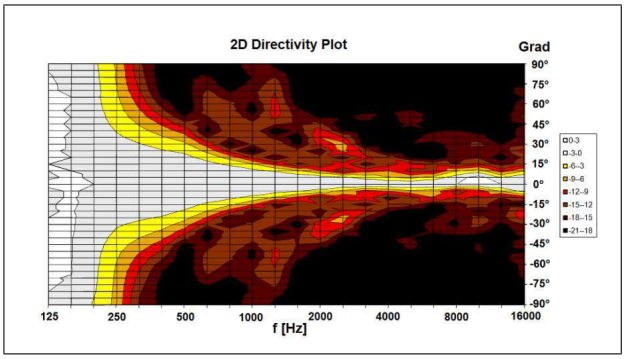

Figure 8. Isobars of the vertical dispersion. 3 Cabinets at 0° inter cabinet splay angle.

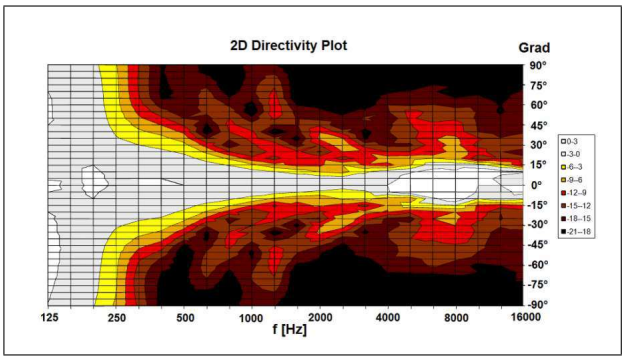

Figure 9. Isobars of the vertical dispersion, 3 cabinets at 5° inter cabinet splay angle.

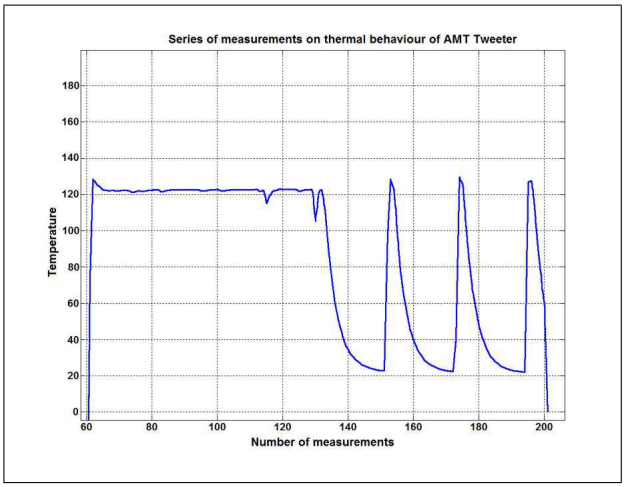

Figure 10. Measured temperature of the AMT diaphragm using constant excitation (left half) and sinusoidal bursts (right half).

and power rating have been carried out during the design process to evaluate each parameter.

While peak power and the corresponding Max SPL is a very important factor, especially for the high frequency unit, RMS power handling and long term stability is just as well a defining factor. To increase reliability and longevity, an active forced air cooling system using a fan on the back side of the unit can be provided but was not used in our experiments described here.

Figure 10 shows the measured temperature curves of the AMT driver. At roughly 150°, the glue holding the di-

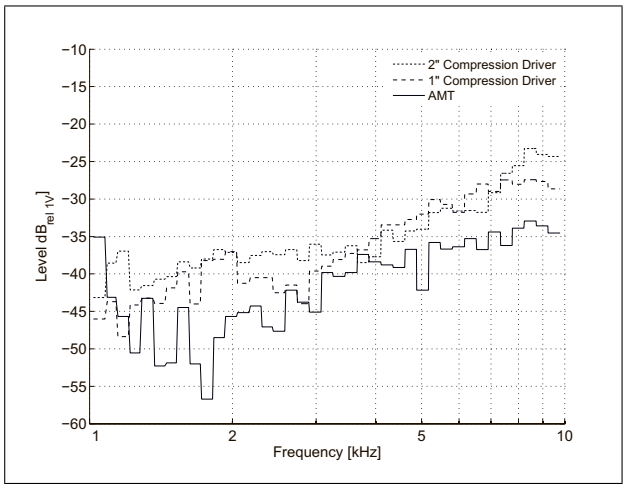

Figure 11. Comparative THD measurement at 110 dB SPL. Dotted: 2" compression driver, dashed: 1" compression driver, solid: AMT driver.

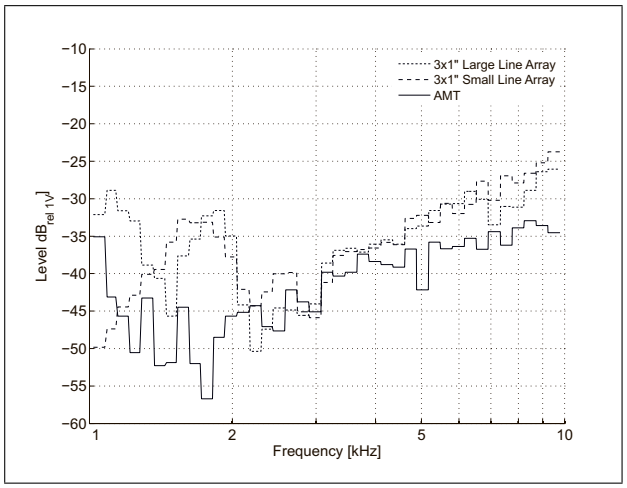

Figure 12. Comparative THD measurement at 110 dBSPL. Dotted: 3x1" Large Line Array, dashed: 3x1" Small Line Array, solid: AMT driver.

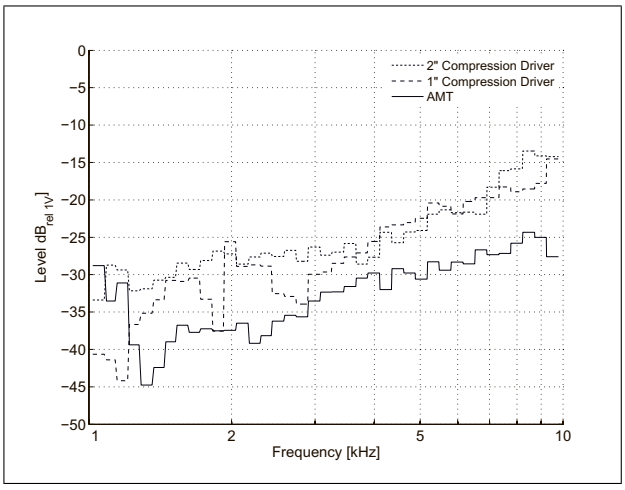

Figure 13. Comparative THD measurement at 120 dBSPL. Dotted: 2" compression driver, dashed: 1" compression driver, solid: AMT driver.

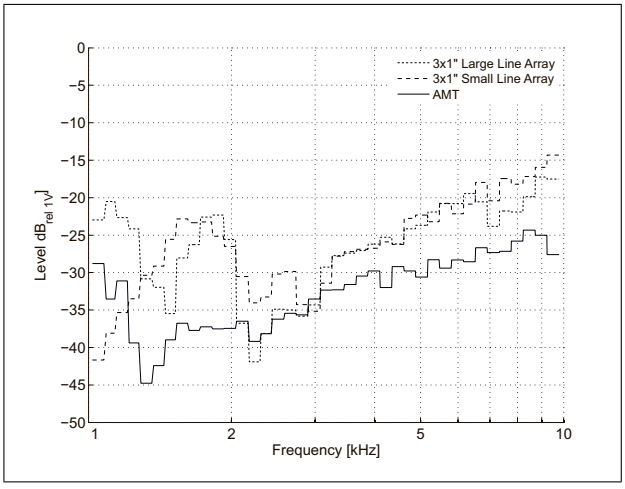

Figure 14. Comparative THD measurement at 120 dBSPL. Dotted: 3x1" Large Line Array, dashed: 3x1" Small Line Array, solid: AMT driver.

aphragm in its frame will loosen. In the first part of the measurement, a steady excitation using a single sinusoidal tone has been used to determine the RMS power handling heating the diaphragm up to 130°. The second part shows short term peak power handling, using sinusoidal bursts.

6. Benchmarking with Compression drivers

The suitability of AMT drivers for high power sound reinforcement systems can only be proven when the capabilities and limitations of these transducers are benchmarked against the conventional design which utilizes compression drivers with circle-shaped or ring-shaped diaphragms and a horn flange typically between 1" and 2". For comparison, commercial products from the upper price range of a well known manufacturer were selected and measured against a single-unit AMT with a length of 8". The candidates were a 1" Compression Driver, which was mounted on a 85°x55° constant directivity horn and a 2" Compression Driver on a 40°x30° constant directivity horn. In addition to this there were two Line-Arrays, each using three 1" Compression Drivers mounted on a waveformer, one Large Line Array system, achieving 100°×7°, the other a smaller version with 100°×15° dispersion angle.

One measurement was carried out to point out the potential of AMT drivers at moderate levels, assumed here as 110 dB SPL in 1 meter distance. In Figures 11 through 14, the summed level of all harmonic distortion components in relation to the fundamental frequency is shown. As an example, 40 dB attenuation corresponds to 1% THD. It can be clearly seen that the AMT has less distortion than the compression drivers, especially above 3 kHz.

The same holds true when the level is risen to something realistic for a system which is run at high volume, but at a safe level with some decibels of headroom (120 dB SPL in 1 meter distance, resulting in 104 dB SPL in a distance of 40 meters for a line source). Figure 15 shows even clearer the significantly lower distortion for the AMT.

At last, the maximum possible sound pressure level for a given THD limit of 10% was evaluated for the differ-

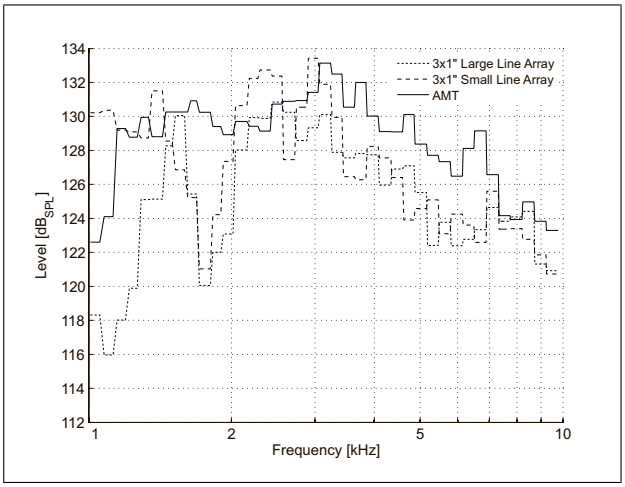

Figure 15. Comparative Measurement of Maximum SPL when 10% THD is admitted. Dotted: 3x1" Large Line Array, dashed: 3x1" Small Line Array, solid: AMT driver.

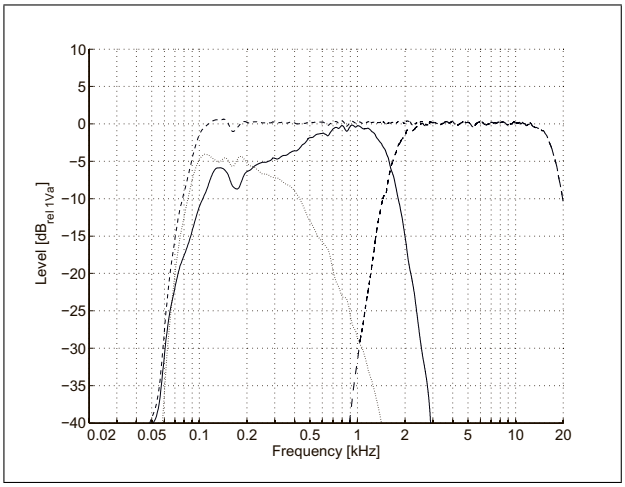

Figure 16. Frequency Response of the Red Line Array at the top. Below are the responses for the individual drivers. Low frequency driver (dotted), low-mid frequency driver (solid) and high frequency driver (dashed).

ent driver types. For the AMT, a short term power of 1000 Watt had to be applied (compare sensitivity in Figure 5) to achieve these levels. Assuming a compressed music signal with a crest factor of 10 dB, the average power would then be 100 Watt which is safe for the driver without active cooling. From the diagram it can be seen that the AMT outperforms both conventional drivers by 3–4 dB in the significant tweeter frequency range.

7. Measurements of an AMT line array

In total, sixteen cabinets of the designed and evaluated concept were constructed and built. For assembling, a rigging system providing the possibility to angle the cabinets in the vertical plane was designed, computed and constructed.

The final filter compositions were conducted for different setups separately. FIR Filters were used for equalization, crossovers and to accomplish a linear phase behavior. As previously mentioned, one of the woofers was low pass filtered with a third order Butterworth filter at 400 Hz. The Crossover between mid and high frequencies was set to 1500 Hz with a slope of 96 dB per Octave, seen also in Figure 16.

The attainable Maximum SPL levels are as high as 130 dBSPL in the high frequency region for a single unit, 130 dBSPL evenly across the entire bandwidth for 4 cabinets with high frequencies going as high as 136 dB and 138 dBSPL broadband for 8 cabinets (see Figure 17). As can be seen, the increase is highest in the low frequency region below 500 Hz. As stated before, the radiation impedance for the 8" woofers increases and with it the sensitivity. Therefore, the more cabinets the array employs, the higher the increase in low frequency reproduction.

For protection purposes thermal as well as peak limiters were configured. The parameters were set in a way to prevent total harmonic distortion above 10%. Also, a separate Matlab program has been written to measure the thermal behavior of the chassis under load. Thus the true RMS power handling, based on the impedance changes caused

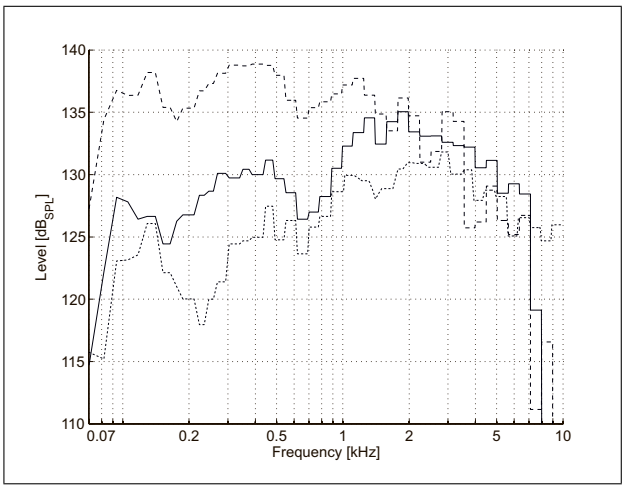

Figure 17. Max SPL at 10% total harmonic distortion for 1 cabinet (dotted), a set of 4 cabinets (solid) and 8 cabinets (dashed), measured in 4m and calculated back to 1 m.



Figure 18. AMT Line Array assembled for test purposes at the University of Applied Sciences Duesseldorf.

by thermal load, could be used as a limiter parameter (see Figure 10) input.

The final measurements of the complete Line Array System are clearly showing the high quality of the AMT Line Array. Emphasis can especially be put on the peak sound pressure level.

7.1. Perceptual Evaluation of Sound Quality

The technical benefits have been discussed and verified so far. Now, the acoustic quality grade can only be evaluated by listening to the speaker system. Actually, a formal listening test has not been carried out yet. The effort for that testing is quite significant. It should take place in a stadium or other venue where moderate to maximum levels can be driven. It is not easy under the aspect of sound immission in neighbourhoods since our (2×8 cabinet) system delivers impressive 120 dB SPL in 50 m distance.

However, at present there have been several opportunities to use the system in live setups and mixing. FOH (Front-of-House) mixing engineers, who are long-term used to conventional equipment on a daily basis, have stated that our AMT line array sounds very clear and especially dynamic to their ears. The feeling is that this loudspeaker setup can be used at low, moderate and high sound levels, which is not the case in many conventional products. Other opportunities for informal testing were at the International Tonmeister Convention, or at the PL&S (Pro Light and Sound) fair, where the system was judged very positively by a critical audience of audio professionals.

8. Conclusion

A fully operational Line Array has been designed, developed, constructed and measured to showcase the capabilities of the AMT.

At first, a market survey has been carried out to get an overview of existing systems. This has been used to perfectly outline demands and define target parameters. By intransigently designing the system to fulfill the requirements, it was possible to achieve the very high standards of today's large scale PA systems.

Development has been targeted to attain highest SPL values by choosing appropriate woofers, setting a relatively high tuning for the bass reflex enclosure, optimizing the system and matching the limiters to the power handling of all chassis. Careful analysis of the horizontal dispersion allowed for a very even directivity without sidelobes or destructive interference from the two woofer concept. The vertical dispersion has been confirmed in measurements and follows exactly the theory [3].

Comparing the results of this work with contemporary Line Array systems leads to the conclusion that the overall performance is more than competitive. Regarding perceived sound quality, the AMT Line Array impresses by achieving a very clear and low-distortion sound. Compression drivers are well known for their associated sound, which is actually just a testament of the way they handle music reproduction. Air Motion Transformer on the other hand do not make the music sound a certain way, they are felt to reproduce the original signal as it is.

Going forward, there is still some work to enhance the reproduction and safety of the system, e.g. further fine-adjusting and confirming the limiter and EQ parameters. By now, it has been proven that Air Motion Transformer are capable of the performance of classic compression drivers while at the same time being a far superior transducer, especially for Line Arrays or any cylinder source.

Acknowledgement

The work underlying this publication was supported by an innovation program of the Ministry of Innovation, Science and Research (MIWF) of Nordrhein-Westphalen, Germany.

We are thankful to two anonymous reviewers who helped to streamline the text giving highly useful comments.

References

[1] C. Heil, M. Urban: Sound fields radiated by multiple sound sources arrays. AES Convention Paper #3269, Vienna, 1992.

[2] L. Beranek, T. Mellow: Acoustics – sound fields and transducers. McGraw Hill, 1954. 48–50.

[3] M. Urban, C. Heil, P. Bauman: Wavefront sculpture technology. AES Convention Paper #5488, New York, 2001.

[4] Adam Audio: Functional principle of the x-art driver. www.adam-audio.com/de/technology/x-art, 2012.

[5] A. Goertz: Alcons audio lr16. Special Print from Production Partner, 04/2004.

[6] O. Heil: Acoustic transducer with a diaphragm forming a plurality of adjacent narrow air spaces open only at one side with the open sides of adjacent air spaces alternatingly facing in opposite directions. US Patent 3636278, 1972.

[7] O. Heil: Electro-acoustic transducer. US Patent 3832499, 1973.

[8] R. Mundorf: Magnetic drive device for a transducer or speaker structure with at least one AMT speaker unit. DE Patent 102007062424, 2007.

[9] R. Mundorf: Membrane or membrane configuration for an electrodynamic sound transducer, and loudspeaker comprising such a membrane or membrane configuration. US8208678, 2009.

[10] K. Heinz: Air motion transformer principle loudspeaker drives. Audio Engineering Society Convention 106, Munich, 1999.