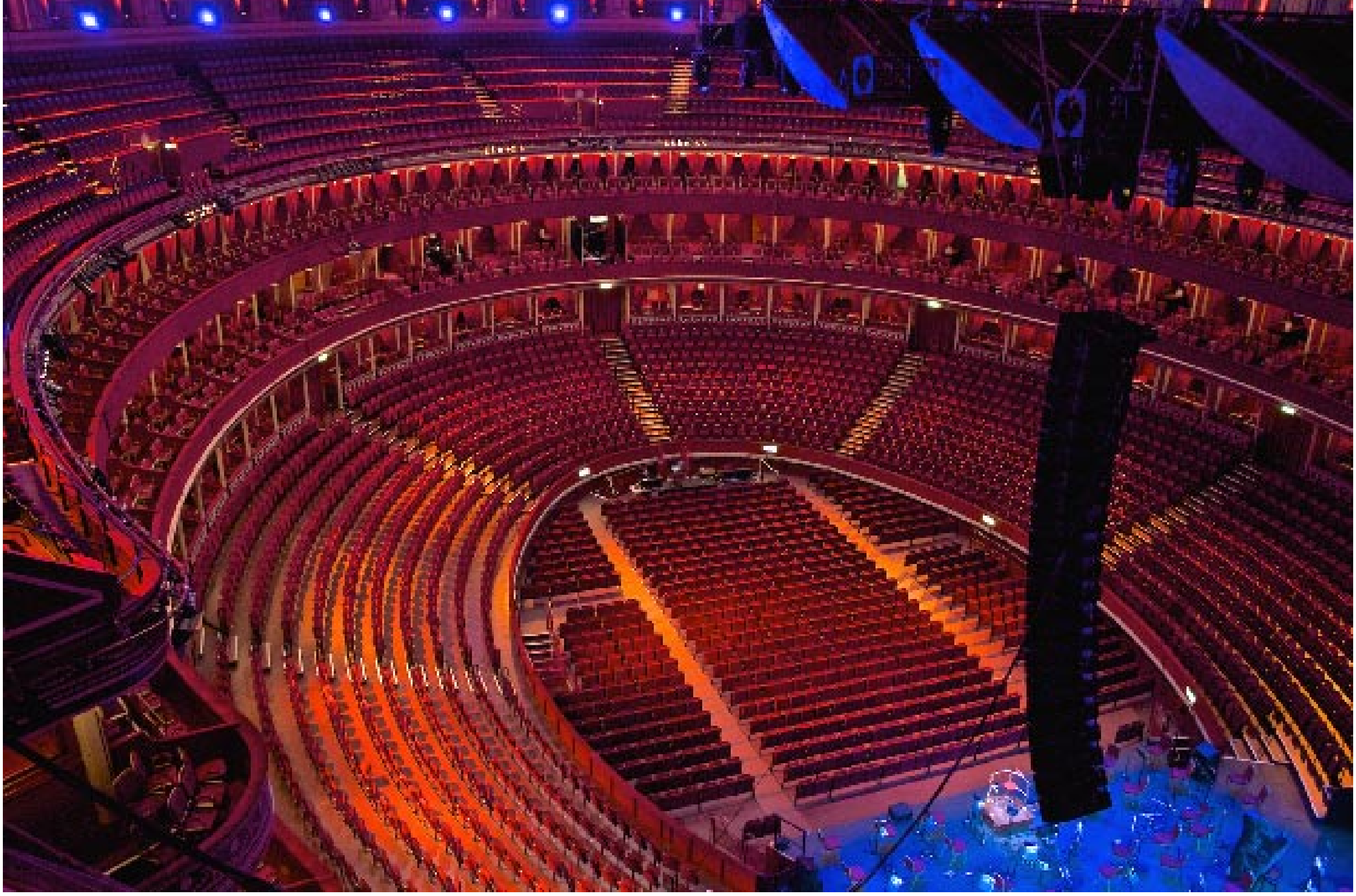


Natural Sound

Sound Reinforcement for the Royal Albert Hall with Mundorf ProAMT

Dieter Michel

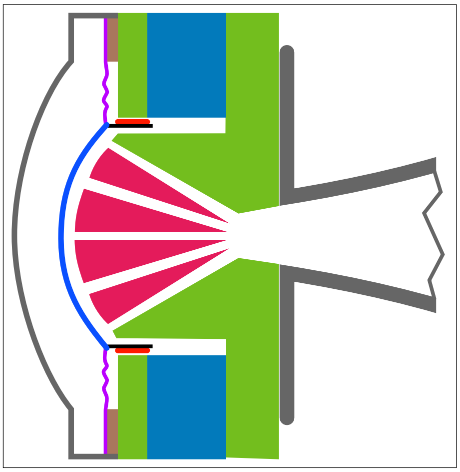
One of the greatest challenges for modern sound reinforcement technology is to make everything sound natural, even if the acoustic conditions of the venue conflict this objective more or less strongly. At its best, listeners asked about their impression of the sound will have found everything completely normal and inconspicuous and perhaps even be surprised about the question. Perhaps they will assign positive impressions about the sound to the artists involved, the orchestra or the choir - even though these would be virtually unheard without electro-acoustic support. In addition, there are of course also concert venues, which live on the characteristic sound of the sound system - for example, rock concerts, where, apart from the voice, acoustic instruments are virtually unused and from which a real large-scale PA sound is expected. However, this article deals with a sound system concept for venues of the aforementioned type, for which the priority is to provide support that is as natural and undistorted as possible for human voices, acoustic instruments and orchestras. The trigger for the following report was a visit to the ProLight+Sound trade fair stand of Mundorf and the opportunity to gain a personal impression of the sound quality of the professional version of the Mundorf Air Motion Transformer (ProAMT) at a performance of "Swan Lake" with the English National Ballet and its orchestra.

A natural reproduction of the human voice and acoustic musical instruments with loudspeakers is absolutely feasible. Manufacturers of studio monitors are happy to confirm that while the development and construction of loudspeakers that sound really neutral is not a walk in the park, neither is it impossible. Users will also agree, at least as long as the tasks is to provide that sound for a only a handful of people in a control room with carefully planned acoustics. But if it is 5000 people, not five, and the room is not actually built to provide electro-acoustic support, then things look very different. Firstly, the loudspeakers used for such a purpose must provide enough acoustic power to be able to sufficiently serve the public. Secondly, they must radiate the sound in a defined way to avoid any undesired stimulation of acoustically unfavourable room structures.

As a minimum standard, most professional sound systems use horn systems for the mid and high ranges and are often used nowadays in the form of line arrays. While these are not universal tools, they have proven their worth in many theatres and venue halls.

Modern horn/driver combinations have the advantage of both a high degree of efficiency and a defined radiation pattern, which can be designed to meet the requirements of the application using modern horn constructions. So, everything's ok then?

The problem is that even with a good horn system, you can sometimes hear that a loudspeaker is being used during the reproduction of voices and acoustic instruments. That is in no way to say that the sound is poor in any way, or that anything can be criticised really. On the contrary, the sound can actually be considered good it is only that you can hear that a loudspeaker is being used.



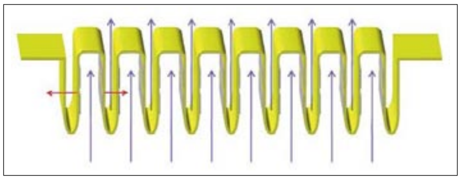
Cross-section of a typical compression driver with flange-mounted horn

For a lot of venues even very demanding ones this is ok. It's also not like that sound designers and sound engineers would complain continually about the imperfect quality of the loudspeaker system. However, there are events, for which the natural sound of voices and acoustic musical instruments is very important, during which you would not want to hear that a loudspeaker is being used.

Among others, critical events include classical concerts with large orchestras or a lower number of individual acoustic instruments. In a classical concert hall or opera house, electro-acoustic support would naturally be unnecessary because the built-in acoustics will provide a good sound. But when the concert is taking place in a room, which is too large or unsuitable for a purely acoustic orchestra, there is often no way round using a loudspeaker. However, when the demand for naturalness is very high, it can be difficult to avoid a to put it bluntly "loudspeaker sound" with conventional PA equipment. This can be partly down to the fact that modern sound systems work with compression drivers, which have part of the set of promlems discussed here virtually built-in in principle.

Compression Driver

A normal compression driver gains its high degree of efficiency from the said "compression". It has a diaphragm with a diameter of perhaps 10cm, which is comparably large for a tweeter, but does not radiate the sound directly. Instead, it works into



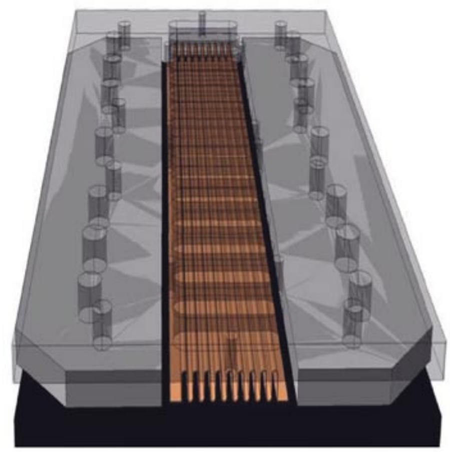
Cross-sectional view of the folded membrane of an AMT: the Lorentz force caused by the current flow (here vertical to the paper level) and the (vertical in this top view) effective magnetic field moves the membrane folds in a horizontal direction the flanks are pressed together and away from each other alternately (red arrows) thus creating an air movement (black arrows).

a pressure chamber, which has a significantly smaller sound exit opening, typically 1" (25.4mm) but often now also 1.4" (35.6mm) because this is far more suitable for shaping the radiation pattern properly together with the adjoining horn than a large diaphragm radiating directly into the horn. As the diaphragm in the high frequency range is no longer small in comparison with the wavelength, the pressure chamber is filled with a phase plug, which only enables defined sound paths to the sound exit opening, for example in the form of circular channels. The diaphragm is almost in direct contact to the phase plug the air gap may be only 1 mm. The channels in the phase plug have a considerably smaller opening than the surface of the diaphragm. This means that a given diaphragm velocity leads to a higher sound particle velocity in the phase plug (velocity transformer). It is higher by a factor, which corresponds to the area ratio of the membrane surface to the opening of the channel in the phase plug and is termed "compression ratio". With a 1.4" driver, the compression ratio is normally in the range of 7:1.

The advantage of this compression is that the driver membrane "sees" a considerably higher radiation resistance as compared to direct radiation into a horn which in turn means a high degree of efficiency. In theory, this can amount to up to 50% - in practice, the achievable efficiency is lower, more around 30%.

No Light without Shadows?
No Light without Shadows!

Unfortunately, this operating principle is not completely without problems. One of



Structure of the Mundorf ProAMT the top pole plate is drawn transparent to make the installation of the membrane clearer.

the potential problems is extremely fundamental and is caused by thermodynamics. In the compression chamber, the air is very rapidly compressed and expanded by the diaphragm this is known as an adiabatic change of state. Now, the fact is one has to say: unfortunately that the relationship between pressure p and volume V in the case of adiabatic change of state is not linear. Instead, the following relationship is valid:

$$p \cdot V^{\kappa} = \text{const.}$$

Even a sinusoidal change in volume, created by the membrane in the compression chamber, does not lead to a sinusoidal pressure course at the sound exit opening, because the air itself is not linear.

In the case of small pressure deviations, the effect is a lot smaller than with large deviations, meaning that other non-linearities come to the fore with a loudspeaker which radiates directly. In the compression chamber of a compression driver, very high acoustic pressures occur, meaning the non-linearity of the air is practically the main source of non-linear distortions. With drivers with lower compression ratios and horns with a greater flare rate, the zone of high acoustic pressure is smaller and the distortions are lower.

However, there is a conflict of objectives when it comes to system design, as a low compression ratio and high lower limit frequency naturally collide with the aim of

covering the largest possible range of frequencies with a high level of efficiency. So a compromise must always be found.
Speaking of a large frequency range: another potential problem in compression drivers, which can sometimes be dealt with using suitable materials and constructions, is the fact that it is actually a mid range speaker.
The diaphragm of a compression driver is normally low tuned. This means the resonance frequency is below the operating frequency range. This means that the vibration characteristics of the diaphragm are predominantly defined by the membrane mass known as mass control or mass breakup. With a loudspeaker, that emits directly, this means the diaphragm can decreasingly follow the driving force due to its mass inertia the higher the frequency is - this results in a decreasing membrane excursion with increasing frequency. With a direct radiator, this effect is compensated by the radiation resistance increasing in reverse with the frequency, so that the frequency response remains more or less constant in the frequency range of operation.

However, due to the flange-mounted horn, a compression driver works onto a more or less constant radiation resistance, which no longer compensates the frequency-dependent influence of the diaphragm mass. Due to the strong damping effect caused by the high radiation resistance, the frequency response in the mid range is reasonably flat. However, in principle, a 1st order low pass is created. Its cut-off frequency is defined by the diaphragm mass and the strength of the drive and will be located around 3.5 kHz in the case of modern drivers. You can either use electronic equalisation here or devise measures to at least alleviate the effect of mass breakup. Expanding the frequency response is part of the high art of driver development. Normally, developers move towards using at least an overtone of the driver diaphragm and/or suspension to expand the frequency response. Another solution is to divide the frequency range and emit the sound from two membranes in a co-axial driver configuration.
The bottom line is that with compression drivers, you will always have to deal with

Mundorf ProAMT with backward chamber and without horn

non-linear distortions in the compression chamber due to the principal non-linearity of the air and with bandwidth limitation. Unfortunately, there is another effect of driver diaphragm size: the sound emitted by the diaphragm does not pass completely through the nearest channel of the phase plug. Instead, it propagates in the gap between the phase-plug and the diaphragm. As a result, sound propagation paths of different lengths are created, which express themselves in a certain smearing of the impulse response and cannot be completely removed by an equalising filter (also FIR) [1].
All these effects can be alleviated by a sophisticated construction, but not completely eliminated. This is the point at which other concepts for high frequency sound production take up which claim not to have these previously mentioned potential problem zones and can, for this reason, supply a natural high frequency reproduction.
One such concept is the Air Motion Transformer (AMT). Its operating principle is similar to that of a magnetostat, while having special construction characteristics which should provide the AMT with a high degree of efficiency and power handling capability.
As a matter of fact, a presentation by Cologne-based company Mundorf at the

Diaphragm assembly of a ProAMT - the folded film can be seen clearly.

ProLight+Sound provided the incentive for this article. With the ProAMT, Mundorf presented an Air Motion Transformer for professional use and proved a power handling capacity of 60W during a live exhibit before the trade public.

Air Motion Transformer

The diagram shows the structure of an Air Motion Transformer. The core is a Kapton film, on which a thin aluminium conductor path is laminated in a winding pattern. The film is placed in S-shaped creases during installation, so that the conductor paths are on the edges of the folds (see diagram) when installed. The magnetic structure of an AMT consists of two pole plates, of which at least the front one has sound exit openings. The magnetic flow causes the folded membrane to be permeated vertically by an almost homogeneous magnetic field.
A current flow through the laminated conductor path now causes a force to be effected on the membrane, which stands vertically to the magnetic flux lines and to the direction of current flow. As the magnetic field is parallel to the main direction of radiation and the current flows in a vertical direction the force acts in a horizontal direction. The membrane does not move forwards and backwards. Instead neighbouring edges of the creases are pressed to-

Raymond Gubbay and the Royal Albert Hall 2013 Production von "Swan Lake", June 2013

Raimund Mundorf and Ed Kinsella in front of the Royal Albert Hall

gether and away from each other through the Lorentz force. Sound is created when the folded membrane of the AMT, following the electrical excitation signal, presses and sucks in the air from the creases. The principle is similar to that of a magnetostat, but has the advantage that the effective sound radiating area is greater than the front of the diaphragm construction.

So, this is a loudspeaker which has a comparatively high effective radiating area , but which is very light and is driven directly and in comparison with a driver diaphragm - in an equiphase manner by the magnetic field at all points of the moving surface. For this reason, it is possible to assume that a coherent acoustic wave is created in the sound exit plane. In turn, these are very favourable starting conditions for use as a tweeter in a line array, as the small wave lengths in the high frequency range cause the greatest problems in ensuring a coherent coupling between the array elements. With the AMT, there is automatically a rectangular sound exit plane and in-phase sound production over the entire membrane caused by the direct drive.

In comparison with a compression driver, the AMT principle has the advantage of working without a compression chamber, meaning the thermodynamic non-linearities due to the high acoustic pressures play no noteworthy role. In addition, the AMT membrane is very light and does not have to move piston-like in one piece. This means the AMT can work up to the limits of the operationg frequency range and exhibit a very good impulse response behaviour.

Because there is no compression chamber in the AMT principle, the level of efficiency is naturally not as high as with a compression driver. However, the conductor paths on the AMT diaphragm have a considerably larger surface than the voice coil of a driver diaphragm, meaning that heat can be better be dissipated. You can even use a ventilator to do this, which is fed from the audio signal. This means it only operates when it is really loud.

There are constructive differences among the various AMT designs, e.g. in the design of the area behind the membrane. If the rear pole plate is closed, there is a higher power handling capacity and a higher lower cut-off frequency. If you open the pole plate into a more or less large chamber, then the frequency range expands to include lower frequencies. However, the maximum sound pressure level falls as a result.

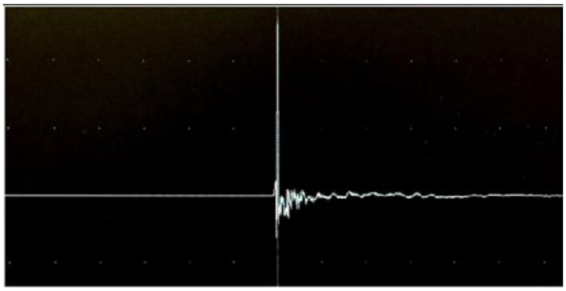
As interesting as a single component such as the ProAMT is in technical terms, complete systems are naturally of more practical significance for the professional PA market, as these can be easily purchased and used by an event technology service provider.

Among the ProAMT customers a manufacturer in the professional PA market could relatively easily be found, the British company EM Acoustics, whose range includes a line array system (the Halo Compact) with a special constructive approach which stands for a particularly natural sounding reproduction.

At the time of this contact, the sound reinforcement for "Swan Lake" at the Royal Albert Hall with the English National Ballet and its orchestra was provided with the Halo Compact system by EM Acoustics. This meant there was a last-minute opportunity to hear the Mundorf ProAMT in use in a very typical, but very demanding application.

But first to the Halo Compact: it is a compact line array system, whose elements are equipped with an 8" mid/bass unit and a 19.7cm high ProAMT both with a Neodymium drive unit. The frequency response ranges from 75Hz to 20kHz. The Halo CS Subbass is responsible for frequencies below 75Hz and can be flown in the array as well. The array elements offer two special features: firstly, the high frequency range is covered up to the upper cut-off frequency without compression distortions and secondly, the system is designed in a purely passive way.

Ed Kinsella, R&D Director at EM Acoustics, naturally had something to say about this somewhat unusual concept at our meeting in London. The core component is, of course, the Air Motion Transformer, because it does not have the potential problems of a compression driver. According to Kinsella, it goes without saying that you



Impulse response of a HALO Compact array element Diagram: EM Acoustics

HALO Compact Arrayelement

can get more sound pressure from a compression driver but it doesn't sound as good at high output levels. The AMT principle means the impulse response is better than that of a compression driver, so that your sense of hearing does not become fatigued during longer periods of listening and it is also seemingly easier to evaluate the information on offer. The audience no longer notices the loudspeaker. Instead, they can concentrate better on the music. Unfortunately, it is difficult to record such properties in a data sheet.

Royal Albert Hall

The Royal Albert Hall in London is a world-class venue, which opened back in 1871 and is not just a performance venue for classical music concerts. Architecturally, the Royal Albert Hall is based on the design of a Roman amphitheatre and has an oval layout. At the northern end of the oval, there is the orchestra podium, the large organ and the seating area for the choir. The central performance area is used as a dance floor for ballet (as is the case for Swan Lake) or other performances. Seats can also be placed here. On the parquet flooring, the public is seated almost 270ø around the central performance area. Three rows of boxes surround the parquet and are complemented by a three-quarter circle of seating on the top tier. In this way, the Royal Albert Hall offers space for up to 5,272 visitors on regular seating. This is normal for an arena or multi-purpose hall, but actually considerably too large for a classic concert hall. In fact, the Royal Albert Hall is constructed more as a large ballroom than a classic concert hall singly by the basic room geometry. A large orchestra can no longer fill this large room purely acoustically, especially as its acoustic conditions are not designed so that the sound from the podium is distributed to all public spaces in such a way that the audience receives a good impression of the sound. During classical concerts, opera and ballet, electro-acoustic support is required. In a hall of international reputation, it goes without saying that the sound system must not only be loud enough but also fulfil the highest demands on the naturalness of the sound. Ideally, the public should forget that electro-acoustic support is being used at all.

The Royal Albert Hall offers a requirement profile that can be fulfilled with a ProAMT-based sound system. For this reason, EM Acoustics sound systems have already been used for various productions in the Royal Albert Hall, including the production of "Swan Lake" I saw. For this production, Ed Kinsella planned a sound system consisting of a total of four line arrays based on the Halo Compact System, which is suspended above and somewhat in front of the orchestra podium. The arrays are each equipped with 15 Halo Compact elements. The wide emission range of the line arrays supports the even coverage of the relatively large angle range of almost 270°. The central area is naturally used as a dance floor for Swan Lake and does not need to be provided with sound. The curving of the arrays was designed in such a way that the systems cover all the public spaces from the parquet flooring to the top tiers. It is interesting that it is very easy to control the entire sound system due to the passive construction of the array elements including system equalisation. All the electronics for the sound system are in a really tiny rack unit. AQ-10 four-channel amplifiers are used for the power unit, which were designed by MC2 and supply four array elements per channel (3.2kW@2Ohm). For each array, only one amplifier is needed, and a further one for the sub-basses i.e. just five amplifiers for the entire system plus an XTA controller to control the amplifiers. In total, this is just 11(!) rack units for the entire Royal Albert Hall!

Sound

In terms of a personal impression of the sound during the performance, all that can actually be said is that the sound system described here is not noticed either in terms of its appearance or it's sound. This is not only meant in the sense that it is not acoustically at the forefront this would be absolutely undesirable during this performance. It is also unnoticeable in that you do not have the impression of a loudspeaker system being used at all it is simply just loud enough and sounds naturally and this has definitely been the aim of using this very system.

In the case of the Royal Albert Hall, the acoustic result is very natural and harmonious inconspicuous in the most positive sense of the word. With some experience in the field, you would perhaps wonder how the sound could be so normal and natural in such a large hall, which was not designed as a concert hall. However, this would be a conclusion arrived at through explicit reflection when you are simply listening, this insight does not arise. Even during the solo of a single violin, the acoustic impression was normal, although it must rationally be clear that a single violin cannot naturally fill a 5000-person hall with the sufficient volume.

To this extent, I am able to draw an extremely positive conclusion from this first contact with the ProAMT during a very demanding event. Definitely reason enough to look more closely at the Halo compact systems in one of the next editions.

[1] David W. Gunness, Improving Loudspeaker Transient Response with Digital Signal Processing, 2005, 119. AES Convention, NY