outlinearray butterfly System

White Paper

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Introduction

In the Sound Reinforcement world in recent years, a great deal has been said and written about vertical line arrays. All manufacturers, from the smallest to the largest, have brought out in a more or less efficient and objective manner these particular sound systems, each trying to influence listeners or readers as to how his construction choices were the right ones.
The proliferation of “comments" which certainly informed the members of the public, educating them on this particular issue, has avoided people like myself, are among the latest to speak about them, to have to dedicated endless pages to an accurate description of the theory behind vertical line arrays.
This also eliminated any temptation I might have had to criticize other manufacturers’ products, because a lot of others have already done so in the “comments” circulating in the audio community for some time.
On the contrary, I’ll offer as examples the products of some manufacturers, dedicating some space to them, because their particular products in this field give indispensable help in understanding the work and results achieved by Outline, described in this publication. A great deal of what is written in this white paper is taken directly from the text and designs contained in some patents for the “Butterfly” system, applied for in 2002.

Preliminary remarks

Before Christian Heil (*Ref.1*), “Vertical Line Array” was simply the definition used to appropriately describe a particular type of enclosure: a speaker column. An enclosure still used today several decades after its demise, for the speech reproduction in reverberant environments and all those places in which it’s necessary to project speech over a considerable distance with good intelligibility.
To date, these columns haven’t undergone any further technical development to make them suitable for wider more demanding use, such as the wide range reproduction of the whole audio spectrum in the pro audio reinforcement field.

The reason for this and its intrinsic characteristics, which made it and still makes it an enclosure able to reproduce with a virtual dispersion of a cylindrical nature, with an adequate sound level and quality, a rather small portion of the audio spectrum, i.e. the frequency range normally described as “Vocal or Telephone Band”.

Fig.1 Example of spherical wavefront with a single sound source and circular sound wavefront with a vertical speaker column.

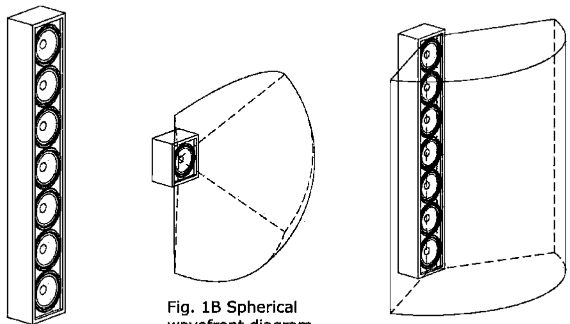


Fig. 1A Vertical speaker column

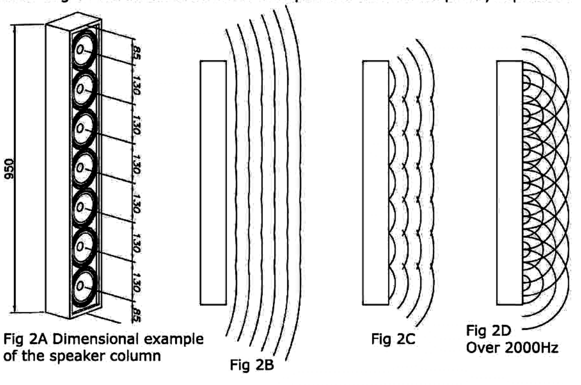
Fig. 1B Spherical wavefront diagram

Fig. 1C Cylindrical wavefront diagram

This is also the case with the “columns” called “Intellivox“ designed during recent years by Duran Audio (*Ref.2*), for which a sophisticated DPS controller was implemented enabling to achieve very high directivity values on the vertical plane, even if in a narrow band of the audio spectrum, nevertheless more than sufficient for solving speech intelligibility problems in environments with high reverb levels.
Going back to the field which interests us, in spite of all his denigrators and the sceptics who attacked him in every way, everybody has to attribute to Heil, the inventor of the V-DOSC, the rediscovery and modern profitable application from the acoustic point of view, of the principles which are at the basis of vertical line arrays, thanks to which they can be used in wide-range applications, in sound reinforcement in general and in particular in the high performance high quality market.

Nowadays, the term vertical line array is used to describe a particular sound reproduction system, which has nothing to do with the classic vocal speaker column, apart from construction similarities, which consist the column's use of a number of normally small loudspeakers, mounted alongside and one above each other and, in the case of the modern line array, the use of a number of complete enclosures, also mounted alongside and one above each other and able to reproduce the entire audio band or, more generally speaking, a very wide part of it (normally without the low frequencies).
In this configuration, the system has a virtual "cylindrical" acoustic emission caused by the effect of the vertical coupling of the multi-way enclosure elements forming the array.
In fact, the use of several channels, with each loudspeaker dedicated to a specific audio range, for the construction of vertical line arrays isn't a idea recently introduced by Heil, but had already been experimented and used for many years in various models of speaker columns.
0ne good example is described in *Ref.3*
Merit therefore shouldn't go to Heil for having introduced the use of multi-way systems forming vertical sound line arrays, but rather the fact of having clearly described and demonstrated the criteria that govern these configurations, arriving at the formulation of a complete theory, based on the similarities between acoustics and optics with reference to the Fresnel and Fraunhofer diffraction. (*Ref.4 and 5***).**
This is the acknowledgment that the international audio community must rightly and objectively give Heil and this, at the same time, is the contribution of knowledge he made to this sector and can now be used by everybody.
In fact, like others in the past, such as Olson and Beranek, to mention the most famous (*Ref. 6 and 7***), his work once again clarifies how difficult or impossible it is, using orthodox methods, to build a vertical line array which works well over the entire audio band, up to high frequencies of the order of 15/20 kHz.**

Fig. 2 Schematic sequence of the wavefront of a vertical speaker column according to the distance between the speakers and the frequency reproduce



So didn't Heil's work give anything new, just a better knowledge of what was the state of the art?

From the point of view of theory, there's certainly nothing new that (even if in a different less stylish way perhaps) hadn't already been explained fifty years ago in the books quoted.
From the point of view of practical realizations however, Heil introduced a new element, for which he deposited the patent in France in far-off 1988 and later in Europe and America (*Ref. 8***), the importance of which was such as to relaunch the "vertical line array" as a highly effective constructive solution for professional high-powered enclosures; the same one that had been abandoned after the first attempts many year before in the pro audio world and limited, as we've seen, to a more restricted use in the aforementioned speaker columns.**
The new element is a special wave guide - the "DOSC wave guide", which resolves a problem which up until then had been insurmountable, of obtaining from a high frequency loudspeaker a high sound level emission, suited to building vertical sound columns for use at concerts and in general for sound reinforcement in large areas".
Before describing Heil's invention and its peculiarity, it's necessary to outline, at least briefly (the books mentioned can be consulted for the details), the most important features of a line array, worthy of being defined as such with reference to the elements that form it.

Vertical Line Arrays work

Since vertical line arrays for sound reinforcement are formed by a certain number of elements/enclosures assembled one above the other but operating individually, it's clear that the operation of a system like that is closely linked with the acoustic coupling achieved between all the elements with reference to the audio range to be reproduced.
In short, one can talk of acoustic coupling when the emission of the elements forming the line array (comparable to the emission typical of point sources, with reference to the highest frequency to be reproduced) interact, summing the energy emitted individually.
In order for this to occur, which is at the basis of the system's efficient operation, two fundamental criteria must be respected (Heil cites three more, which in this context it's superfluous to mention and of which, those of you who wish can easily find the description in his publications):

a) ***The surface occupied by the active sources forming the array elements mustn't be less than 80% of the total surface of the array.***

b) ***The sources must therefore be closely coupled and separated by a distance of no more than half a wavelength referred to the highest frequency they have to reproduce.***

These two requisites, if satisfied simultaneously, mean that a certain number of sources (comparable with the point sources at the frequencies they have to reproduce) generate in the coupling plane a sound wave similar or equal to the planar wave, as happens in a sound source which is effectively planar with the

same dimensions, a fundamental condition for obtaining a virtually cylindrical wavefront.
When the second of these condition can't be achieved for geometrical reasons illustrated further ahead, as it's impossible to obtain the necessary coupling which makes the group of emissions comparable with the emission of a planar wave source, at least among the emission of the single elements forming the array, it's necessary that no destructive interference is generated in the band of frequencies for which the aforementioned coupling couldn't be achieved.
If the requisites listed so far are easily achieved for low frequencies, it's more difficult for mid frequencies, to avoid destructive interference at 1000Hz, for example (1/2 wavelength = approximately 17cm.), this would imply the use of sources that don't exceed the dimensions of 17cm (a 6.5" speaker), with all the results in terms of poor efficiency.
Then, for frequencies above 1000Hz, the dimensions of the sources must gradually diminish to values that are only theoretical and materially impossible to achieve with real sources such as loudspeakers.

Vertical line arrays' weak point

It can be seen from all this that the formation of a vertical line array has its weakest point in the "high frequencies" or rather in how the active component, loudspeaker or other item that has to reproduce them is made and used.
In fact, for example, to reproduce frequencies up to 10000Hz (1/2 wavelength = 1.7 cm), sources that don't physically exceed this dimension would have to be coupled closely.
Even supposing that such small loudspeakers (magnetic circuitry included) can be built, it's easy to imagine that it would be a waste of time, due to the practically non-existent efficiency of loudspeakers of that type.
Creating vertical line arrays that operate well at high frequencies therefore becomes a practically insurmountable physical question if one wants to use traditional loudspeakers such as for example cone or dome units.

Refer again to Fig. 2A, 2B, 2C, 2D.

And also all kinds of horns are by their very nature flared ducts whose sides are divergent according to the required sound dispersion, and whose mouth surface dimensions aren't negligible as they're suited to the lowest frequency that has to pass through them.
This means that even reducing the distance between the horns, the emission centres (the throats) can still be a considerable distance apart, so for all these reasons can't be built with dimensions and type of dispersion more suited to forming a line array operating correctly according to the requisites listed.

Fig 3 Diagram of the geometry and wavefront of a vertical line array with high frequencies reproduced by horns

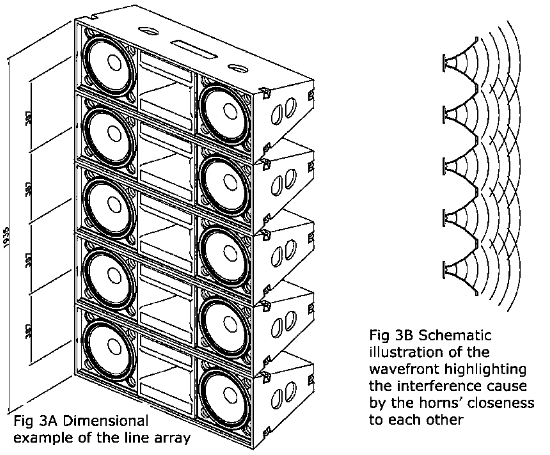


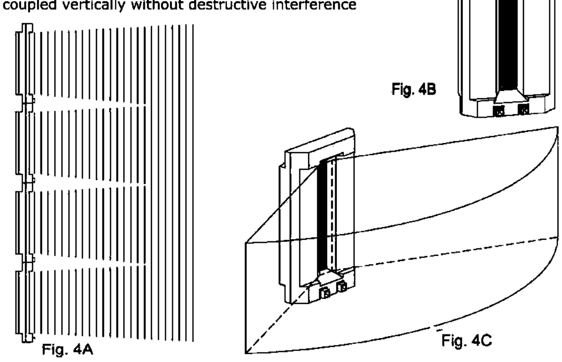
Fig 3A Dimensional example of the line array

Fig 3B Schematic illustration of the wavefront highlighting the interference cause by the horns' closeness to each other

Flat diaphragm loudspeakers in vertical line arrays

If however one decides to use loudspeaker that are slightly less traditional, such as those with a flat diaphragm, in one of the versions manufactured today (electrostatic, isodynamic, etc.), it wouldn't be difficult to obtain correct behaviour even at high frequencies.
In fact, it's easy to imagine how the behaviour of these loudspeakers, with reference to their sound emission, is the best that could be imagined for forming a line of vertical sound emission. In fact, these loudspeakers, being made up of flat diaphragms that move in phase with all the frequencies they reproduce, are comparable to small line array, and the installation of one small line array on another small line array can only result in the formation of a higher line array with emission of planar sound waves on the coupling plane. Unfortunately, due to the current state of this technique, their intrinsic construction means that this type of loudspeaker doesn't have sufficient power handling capacity for the high sound pressure levels required from pro line arrays able to cover large areas as far as both width and depth are concerned.
For this reason they're not widely used, and can generally only be seen in models with lower performance.

Fig. 4
Design of a flat diaphragm loudspeaker and a diagram of its cylindrical wavefront, which enables this type of unit to be coupled vertically without destructive interference



Compression drivers in vertical line arrays

So, what can be used to reproduce high frequencies that meets the necessary requisites?
Since the most important requisite, as has been seen, is the capacity to reproduce sound pressure, of all today's known components the most efficient and that which is most suited to obtaining it are compression driver. However, like other traditional loudspeakers, it doesn't have negligible dimensions, or sound emission comparable with that of a rectangular flat diaphragm.
Therefore, many manufacturers tried their skill at making special wave guides or particular acoustic adaptors that enabled the easily available compression drivers in multiples to reproduce the high frequencies in line array systems.

Fig. 5 Example of use of multiple compression drivers with horns or wave guides coupled to minimize destructive interference in vertical line arrays

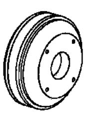


Fig. 5A Typical compression driver with circular throat

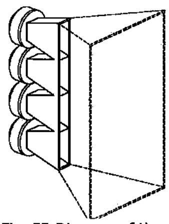


Fig. 5B Diagram of the use of a driver with its circular throat transformed into a vertical slot to form a line array

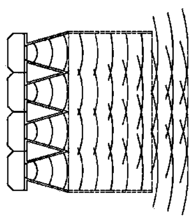


Fig. 5C Diagram of the imperfect wavefront of the solution shown in fig. 5B

But as can be easily deduced from the schematic examples on these pages, apart from the more or less good acoustic results obtained, no device inspired by them fully achieves what is required by the line array theory: *sound emission by a rectangular flat diaphragm.* **The simplest most efficient solution for generating planar waves.**

Is the "DOSC" wave guide the only possible solution?

The techniques illustrated up to now or similar ones simply enable to reduce the effect of interference that occurs between the elements, taking them to the highest possible frequencies their physical dimensions will allow.
Heil's wave guide on the other hand offers an innovative valid way of achieving the aim described:

"Simulating the behaviour of a rectangular flat diaphragm using a classic compression driver".

The system foresees a wave guide that receives the compression driver's emission via a "phasing plug" element, which in turn creates with the sides of the wave guide a narrow circular duct at the throat plane where the sound is emitted, transforming it gradually into a rectangular annular duct finishing in the sound output slot.

This emission slot can in turn become the throat of a further coupled horn or wave guide, in order to control dispersion on the horizontal plane.
The aim of the "phasing plug" is to get the emission of every point of the circular throat plane of the driver to reach the new rectangular throat plane at the end of the wave guide, the diffraction slot, covering the same distance, in such as way as to reproduce the same planar wave found at the throat of a compression driver in rectangular rather than circular form.
The dimensions of the annular duct are very small and therefore avoid creating destructive interference due to internal reflections between the walls of the wave guide and the "phasing plug". Fig. 6A, 6B, 6C and 6D schematize Heil's innovation. It's obvious that this element simulates the cylindrical wavefront of a rectangular flat diaphragm very closely.
In particular, *Fig. 6A* shows a horizontal cross section of a driver with phasing plug; *Fig. 6B* shows a vertical section of the same driver with phasing plus; *Fig. 6C* is an axonometric view showing the driver with phasing plug with the output slot coupled to a front horn or wave guide; *Fig. 6D* is the diagram of two units with phasing plug aligned one above the other to give a cylindrical wavefront.
It seems clear that Heil's system is geometrically exemplary and essentially correct for achieving the result, compared to those less correct ones based on coupling various wave guides, horns, etc. And in fact, the performance of this system, in my opinion is at the basis of the success achieved by the product on which it's used.

Fig. 6 Schematic illustration of Heil's invention, able to perfectly simulate a flat diaphragm's cylindrical wavefront

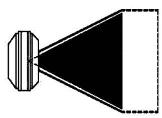


Fig. 6A Horizontal cross-section

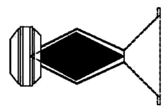


Fig. 6B Vertical cross-section

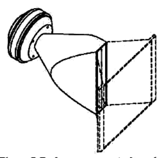


Fig. 6C Axonometric view of a unit with sound output slot coupled with a horn or wave guide

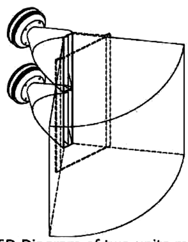


Fig. 6D Diagram of two units mounted one above the other in a line array with a cylindrical wavefront

Other valid solutions? The Reflective Wave Guide

Only recently, a new solution was found. After several years during which there was firstly confusion in the pro audio sound reinforcement market on behalf of the majority of the world's manufacturers regarding the use of line arrays and later their mobilisation in the search for new more or less valid products to be put on the market, following up on the success that Heil's products continued to have year after year.

Perhaps this new solution isn't as totally irreprehensible from a geometrical point of view as Heil's invention, but anyway in my opinion it's more valid than the others that have been put forward up until now since, based on a completely different principle, it enables to realize a high frequency section which performs very similarly to a source with a rectangular flat diaphragm, which I wish to repeat, is the solution most suited to use in a vertical line array.

In fact, if one looks closely, the solution found allows the formation of sound emission not only for planar waves, but also convergent and divergent waves according to construction needs.

At this point, I'd like to state that this innovation was the almost simultaneous subject, unbeknown to its inventors, of two patent applications, both valid for patent law, as the most recent was presented before the publication of the previous one, during the so-called latency period which, unless expressly requested by the inventor, normally lasts for 18 months.

One application is Italian, ***N° BS2001A000073 dated 03/10/2001***, deposited by Outline, which I represent, the other is the French ***N°001149 of 08/09/2000***, deposited by Eric Vincenot and Francois Deffarges, two names that don't require any introduction.

The operating principle of this wave guide, which can generally be defined as "reflective", suited to be used to advantage not only in vertical line arrays, is schematized respectively in the group of diagrams from 7A to 7E, as far as the designs illustrating the application for an Italian patent are concerned,

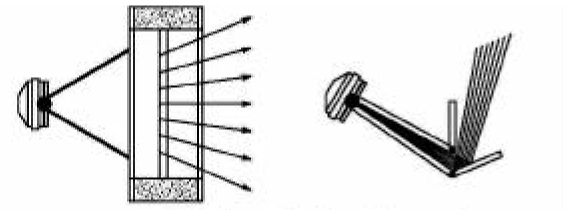


Fig. 7A Diagram of reflection by a flat surface, seen from above and in cross-section

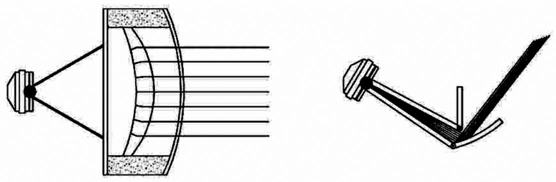


Fig. 7B Diagram of reflection by a parabolic surface before the second throat plane, seen from above and in cross-section

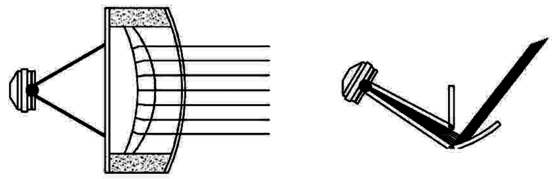


Fig. 7C Diagram of reflection by a parabolic surface after the second throat plane, seen from above and in cross-section

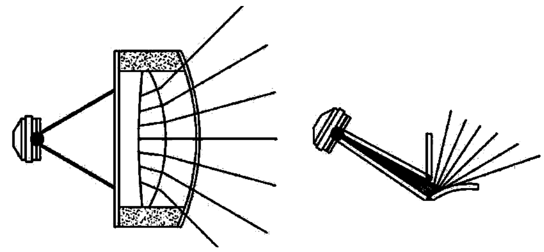


Fig. 7D Diagram of reflection by a hyperbolic surface, seen from above and in cross-section

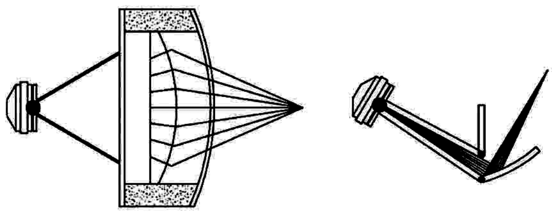


Fig. 7E Diagram of reflection by an elliptical surface, seen from above and in cross-section

in the Fig. 8 group, as far as the designs illustratiing the French patent application are concerned,

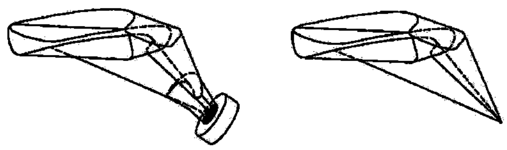


Fig. 8A Diagram of a wave guide with real and theoretical parabolic reflecting surfaces

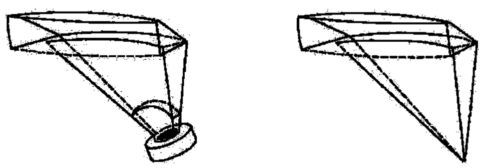


Fig. 8B Diagram of a wave guide with real and theoretical hyperbolic reflecting surfaces

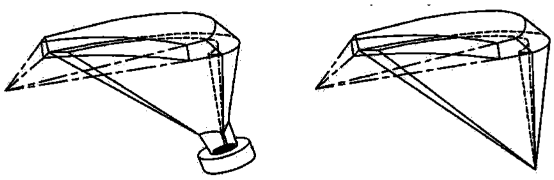


Fig. 8C Diagram of a wave guide with real and theoretical elliptical reflecting surface

The operating principle is based on the reflection of the sound emitted by the compression driver's throat by means of a flat, parabolic, hyperbolic or elliptical surface, according to the type of dispersion required.
Before being reflected, the sound emitted by the driver's circular throat passes through a wave guide formed on one side by parallel, convergent or divergent walls and on the other by walls which diverge conically or with another geometric flair, in order to form (at a given distance from the initial throat) another so-called diffraction throat with a rectangular shape (a slot), positioned just before or just after the reflecting surface portion, creating planar, divergent or convergent sound waves.
As well as advantages which can be easily imagined by looking at these illustrations, this solution offers doubtless advantages of a geometric nature, because folding the high frequency wave guide (normally straight to avoid creating destructive internal interference) close to the reflecting surface facilitates reduction of the dimensions of the enclosure in which its fitted.
What's more, its acoustic operation, at least in the case of the parabolic reflecting surface, resembles that of the flat diaphragm it tries to imitate. In fact, a parabola works according to the diagram shown here,

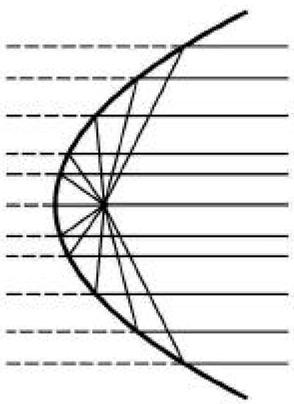


Fig. 9A1 Cross-section of a parabola

and is able to concentrate planar sound waves cutting its surface in its focus and/or emit planar waves starting from a point source put in the same focus, maintaining an identical signal path from the source to the emission plane in question –

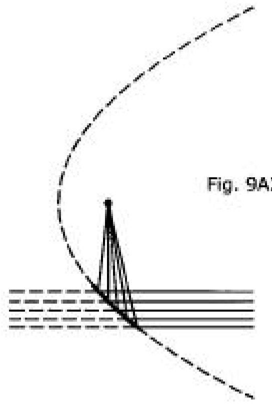


Fig. 9A2 The effect of a point source on a segment

However, closely analysing the geometry of the device proposed in the aforesaid patent applications, one realizes that the imitation of flat diaphragm emission isn't completely successful and doesn't achieve the degree of perfection that on the contrary the geometry used by Heil enables his device to achieve.
In fact, the reflecting parabolic surface, described as being able to transform the spherical planar sound wave emitted by the compression driver into a rectangular planar sound wave, which is the prerequisite for forming "vertical line arrays" performing well at high frequencies, needs, for this to take place, a source which is effectively a point source and doesn't have dimensions such as that of a driver's throat.
In fact, analysing the parabola by means of the schematic designs, it can be noticed that, due to its shape, it can't reflect in parallel beams the sound emitted by any source other than a point source positioned in its focus and therefore, in this case, can't come close to flat diaphragms' operation for planar waves.
It also seems clear that the paths from every point of the source to the emission surface (shown with a darker line in the illustrations) can't remain the same, as is necessary to avoid the occurrence of the typical interference caused by different arrival times of the signal reproduced by the device.

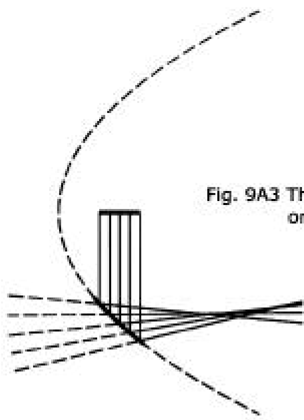


Fig. 9A3 The effect of a real source on a segment

This also happens in the case of the reflecting wave guide in the aforementioned patent applications.

In fact, since the real sound emission is not point source emission, virtual point source emission can't be formed outside the wave guide for any of the possible reflecting surfaces, including parabolic.

A glance at *Fig. 9B1, 9B2, 9B3,* regarding a hyperbola, will clarify the concept better than any more written explanations.

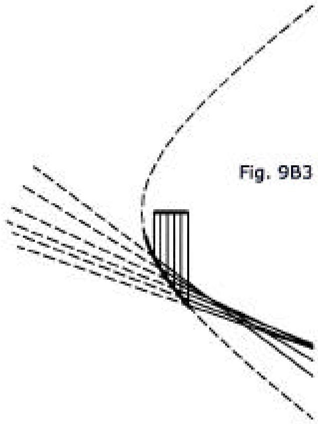


Fig. 9B3 The effect of a real source on a segment

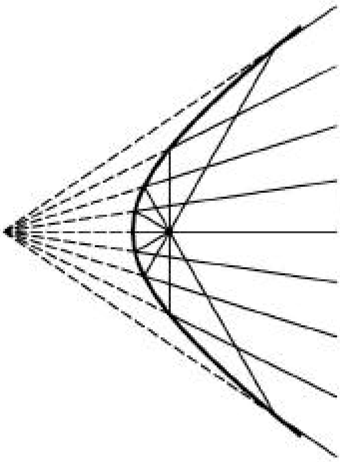
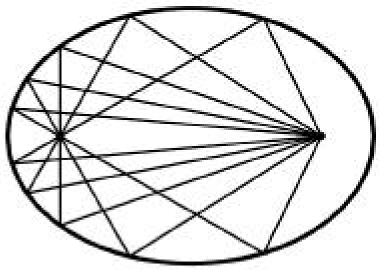


Fig. 9B1 Cross-section of a hyperbola

Then, with reference to the ellipse, see *Fig. 9C1, 9C2, 9C3.*

Fig. 9C1 Cross-section of an ellipse



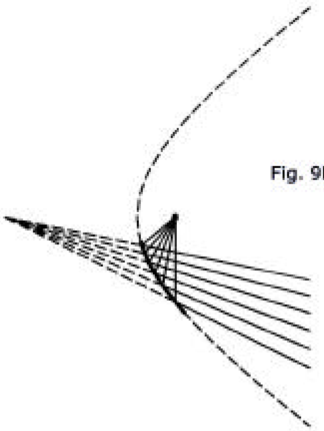


Fig. 9B2 Effect of a point source on a segment

Fig. 9C2 Effect of a point source on a segment

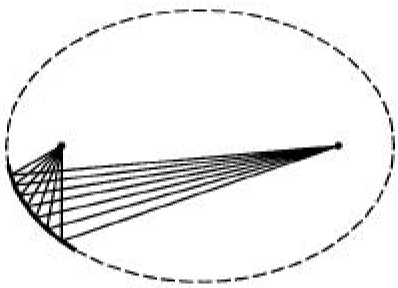
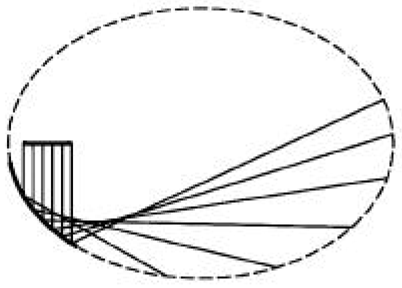


Fig. 9C3 The effect of a real source on a segment



In short, the conditions for optimum sound reflection, those strictly comparable with theoretical conditions, particularly those allowed by a parabola, which is the reflecting surface by means of which it's possible to approach the emission conditions of a flat diaphragm, are only effectively and totally achieved if the source is a point source.

When the real source has dimensions can't be overlooked (in the professional sound reinforcement sector, these dimension can't be reduced below a certain limit for reasons of power), the sound emission obtained using the reflection method gets further and further from achieving the emission characteristics of a flat diaphragm the larger the source's dimension and the higher the frequency band to be reproduced by reflection.
It can be deduced that from a theoretical and practical point of view, this method doesn't have the geometric precision of Heil's wave guide and therefore its use in multiples for HF sections in vertical line arrays will increase the imperfections which occur in the system for physical reasons which can't be overcome, even if the result is still potentially better that that which can be achieved adopting other "classic" solutions found up until now, as they're also conditioned to a greater extent by unavoidable geometric/physical questions.
In my opinion, the solution described to far, based on folding the wave guide to achieve the required type of reflection having a real source like the throat of a driver, can be better exploited to build "particular" single enclosures which don't necessarily have to be coupled in multiples, such as for example very low profile "wedge monitors", in which it's important to keep the physical dimensions within necessary limits.
I personally used this system for our H.A.R.D. 212, "no compromise" wedge monitors with a very low profile and with ideal acoustic/directive characteristics for short/medium throw applications.
After these observations, if I've managed to explain myself sufficiently clearly, it's obvious that in spite of the latest (nevertheless valid) solutions to the problem of reproducing high frequencies in "vertical line arrays", the "DOSC" wave guide offers greater precision and its performance is much closer to that of a flat diaphragm.
Is there therefore absolutely no possibility of building a device that performs in the same way as Heil's without using the same construction logic safeguarded by its patent?
In recent years, the search for this device has been the object of research and constant work at Outline with countless prototypes being built, of both very complicated individual devices and equally complex complete units containing these devices, as the latter were necessary for carrying out measurements which are really indicative of the acoustic results obtained using them in line arrays.
This intense work led to the discovery of a new solution to the problem, with the invention of a device whose patent application, registered in Italy some time ago, has been extended to international level (PCT).
The device's operation is extremely similar to that of a flat diaphragm, at least to the same extent as Heil's wave guide, with which it has no principles in common.
In fact, the new device combines operation similar to that of a flat diaphragm with the much wider versatility and potential of the reflecting wave guide already described, as it exceeds it in precision, emission coherence and overall performance.

Noselli's "DPRWG, Double Parabolic Reflective Wave Guide" as an alternative solution to Heil's "DOSC" wave guide.

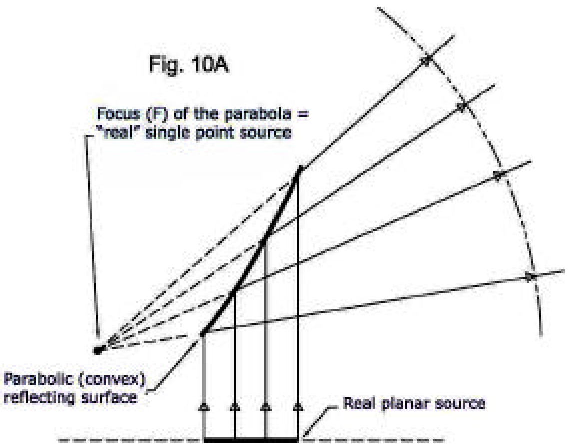
The solution, which had been sought for so long and has at last been found, like all valid solutions, is of disarming simplicity.
Its application allows loudspeaker system designers wide working margins from the construction point of view and much greater creativity regarding enclosures' shapes, up until now based on the classic solution imposed by well-known techniques.
In short, this device, built on the basis of the invention, allows to overcome the intrinsic limits of a geometrical and dimension nature of traditional cone speakers, dome tweeters and compression drivers also and above all used to build line arrays, or those systems in which the correct acoustic coupling of multiple sources is indispensable to achieve the result.

The invention is based on the transformation of a source with the typical dimensions of real loudspeakers, firstly into a virtual point source with characteristics identical to a real point source and later, in a second stage, obtaining from this "real" point source the required sound dispersion by means of reflection with various types of surfaces with different shapes, keeping the sound paths exactly the same from any point of the active source to the measurement or listening position via the reflecting surface.
This reflecting surface can be flat, parabolic, hyperbolic or elliptical, or more generally speaking, flat, concave or convex.

It's much harder to describe the device in words than with the following diagrams.
Fig. 10A, 10B, 10C, 10D and 10E schematize the transformation of a real flat source (represented in

all the diagrams by a continuous segment on a dotted straight line) into a "real" point source by means of a parabolic concave reflecting surface and also schematize the sound diffusion in the direction of the arrows by means of the same parabolic (convex) surface (Fig. 10A), a flat surface (Fig.10B), a hyperbolic (concave) surface (Fig. 10C), a parabolic (concave) surface (Fig.10D) and an elliptical (concave) surface (Fig. 10E);

Fig. 10A



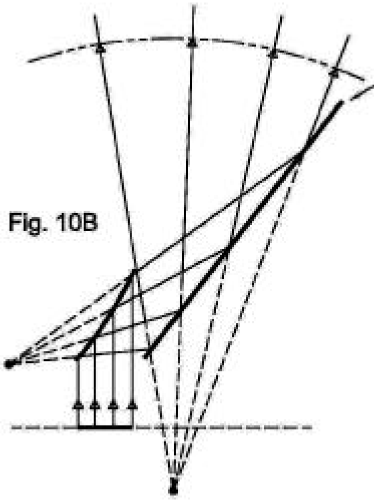


Fig. 10B

Fig. 10C

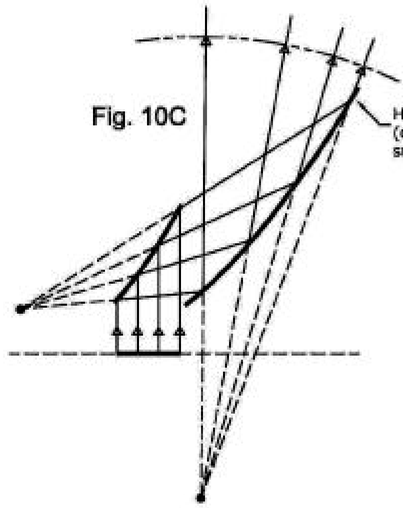
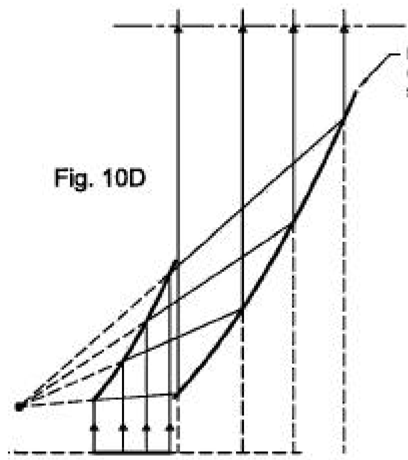
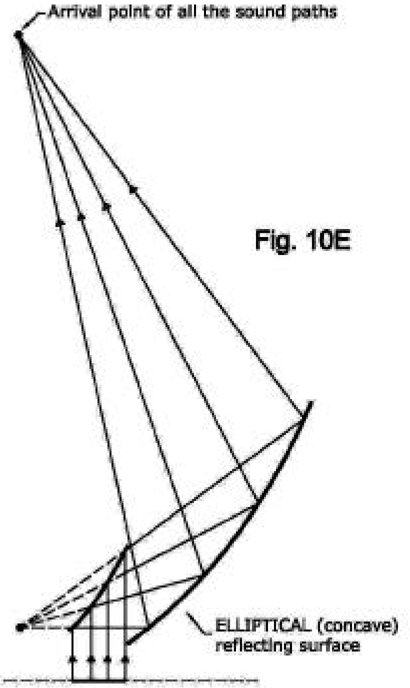
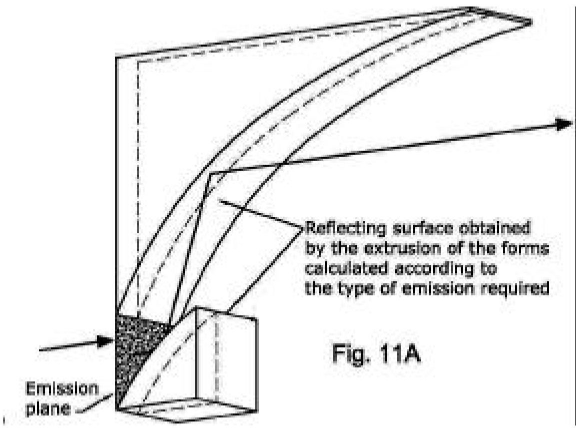


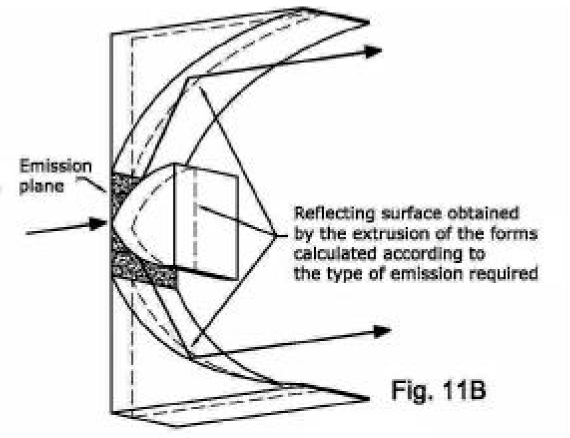
Fig. 10D





From a graphic point of view, the behaviour of the device can be seen in the following diagrams. 11A, 11B schematize axonometric diagrams of some examples of acoustic reflectors which reproduce the various aspects of the invention.





La Fig. 11C shows the cross-section of a practical example of the double reflective wave guide in which separators have also been mounted in the duct to eliminate any possible internal interference at high frequencies.

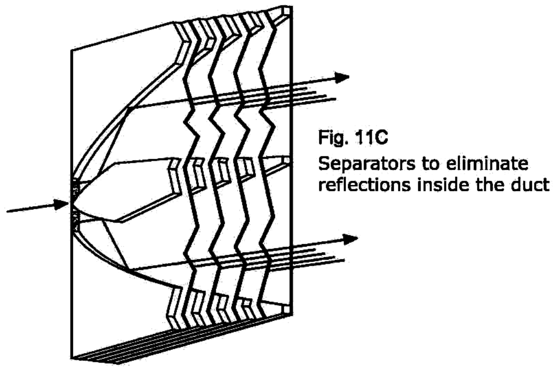


Fig. 11D shows yet another example, which can be achieved by the revolution of the section of the wave guide shown in Fig. 11A

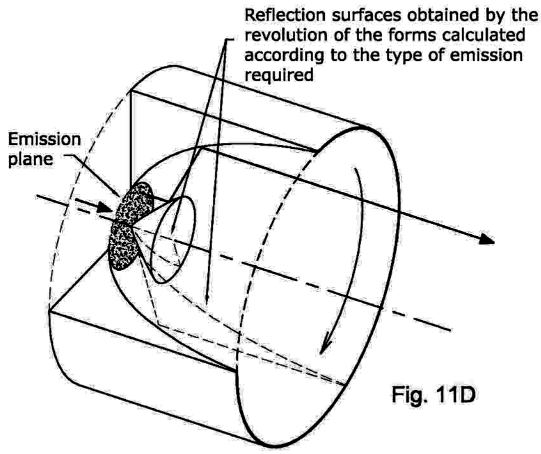
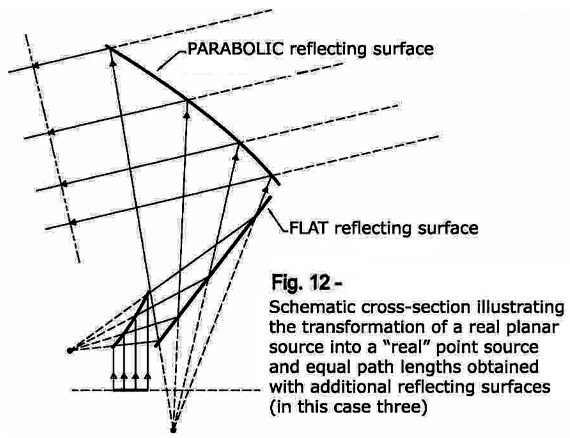


Fig. 12 schematizes another possibility offered by the invented system, showing its great potential: the transformation of a real signal source into a "real" point source which, by means of other two combined reflecting surfaces, is transformed into a source which is planar or of another type, but nevertheless keeping the signal paths the same length.



There are a lot more possible combinations which, in order to increase the sound pressure level, use several real sources simultaneously, whose emission, using the same mechanism, is "directed" and reflected outwards with the required dispersion.
But, after what has been described up until this point, I'll leave it to you to imagine the numerous possible configurations this technique offers.
The first practical application of the device described, the DPRWG-Double Parabolic Reflective Wave Guide, in one of its possible variations, is found in the C.D.H. 483 Butterfly Hi-Pack.
Here below there is a picture of partially disassembled one.

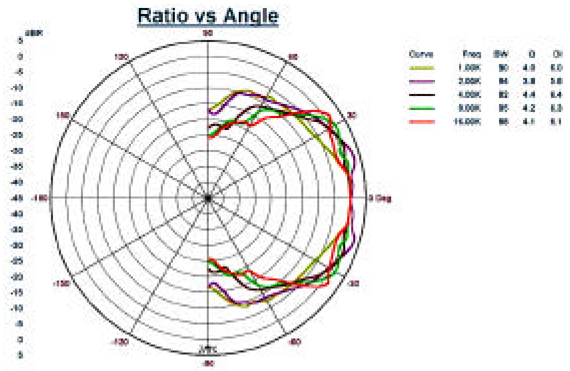
Definitely the most interesting part to be found in this element/enclosure, built by Outline for multiple use in vertical line arrays, because, as I think I've clearly shown, it's a good solution to the problem of reproducing high frequencies in this type of system.
However, with the Butterfly Hi-Pack all the necessary geometric and mechanical solutions have obviously also been adopted to ensure that the rest of the audio spectrum, not entrusted to the high frequency section, is reproduced with the same quality and precision.
So all the construction stratagems were chosen and applied in order to meet the requisites imposed by line array theory, even exceeding them wherever possible.

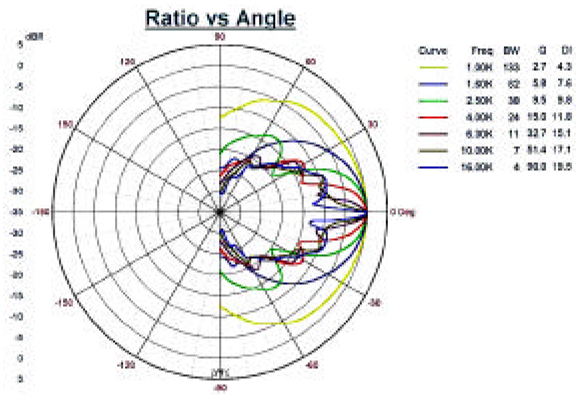
The following designs show the definitive single and array versions of the Butterfly C.D.H. 483.

The first thing one notices looking a the above design is the external shape of the Hi-Pack, for which application has been made for an international industrial design patent, resulting in the product being called Butterfly for two reasons; firstly, because the shape brings to mind that of a butterfly and secondly because it is also very light weight: in fact, considering the fact that it's equipped with no less than five loudspeakers, it's weight is approximately 33kg, including flying hardware fitted as standard.
The second innovative fact, also the subject of an industrial design patent application and also an application for an invention patent along with the DPRWG wave guide, consists in the total lack of top and bottom panel defining the horn "cavity" in front of the diffraction slot.
The aim of this was clearly to facilitate the coupling of the arrays' components up to the highest frequencies, keeping the smallest possible distance between the sources and at the same time offering them a loading baffle with appropriate uninterrupted lines, an effective stratagem for minimizing diffraction and alteration of the response in the mid/high range due to gaps which can't be overlooked.
The horn itself, or rather the sides of the horn, which establish the system's horizontal dispersion, finish with smooth curves meeting up with the box's external sides, which are also rounded and raked

towards the rear of the cabinet and another innovation from a design and technical point of view. In fact, these geometric and construction features have two aims: minimizing any diffraction at the mouth of the horn and at the same time greatly strengthening the side walls of the box, which (as well as all the rest) also contains a bass section with bandpass configuration and two dedicated speakers.
The box is built in composite plywood, obtained almost entirely via moulding and high frequency gluing. The panels' thickness has been limited to 14mm. to reduce the enclosures' weight, but at the same time improve overall rigidity and eliminate any resonance that might be caused by the low frequency section.
The flying hardware allows to vary the angle between the elements with minimum steps of as little as 0.1 degrees if necessary; the minimum standard step is 0.25 degrees.
The dimensions and the materials used have enabled the units to be certified, according to the strictest international norms, for flying up to 32 Hi-Pack systems in a Vertical Line Array reaching a height of almost 8 metres.
From the acoustic point of view, as well as the groundbreaking DPRWG-Double Parabolic Reflective Wave Guide, it's worth mentioning that it's a 3-way system, but only requires active biamping.
One channel for the compression driver with 3" diaphragm and 1.41" throat, the other for the mid/low and mid sections, connected in parallel to passive components without any kind of crossover.
By means of a mechanical break, achieved by means of the precise restricting geometry of the resonance chambers and the respective tuning of the mid/low and mid sections, the emissions' phase was shifted in order to obtain a coherent sum over the entire reproduced bandwidth the two sections have in common.
This technique, which required fine adjustment of the cabinet's volumes and tuning, has a great advantage, above all regarding the array element's compact dimensions (240mm. high, 700mm. wide and 600mm. deep): in fact, it's able to produce great energy between 80 and 400Hz, which is often very poor in other systems with comparable dimensions. An advantage which is even more effective because as it's been achieved with a minimum increase in overall cost and weight.
In fact, two extremely light 8" neodymium speakers are use in the mid/low section in a rather unusual position and with the magnet facing out into the tuned chamber to ensure efficient magnetic circuitry cooling by means of the ventilation created by the movement of the cone itself.
The sound emission of these speakers, which are in bandpass configuration, has been fed into two large front slots at the extremities of the box, in such a way as to be summed evenly and perfectly with the emission of the mid section, which in turn faces out from the sides of the horn in a position which is symmetric with the sides of the diffraction slot.
The section comprises two more 8" speakers, in this case in ferrite for better heat dissipation, since they've to move less than those already described, as they're damped by a small rear loading volume tuned to raise their resonance, in order to obtain greater efficiency in the mid range reproduced by the two cones.

Horizontal dispersion is 90° in the definitive system, while the prototypes were built with a slightly narrower angle.
The horn used for this has rather enviable dispersion behaviour: for one thing, it's constant over the entire frequency range reproduced and the off-axis level remains high up to nominal dispersion, indicated in the case of the prototypes as approximately 80°, after which it drops decidedly; this indicates its efficiency as far as directivity is concerned.
There again, the mouth has ample dimensions (approximately 50cm. before it curves round to join the rear panel, which means that at 700Hz the horn already has a suitable dimension for the control of dispersion and at 1400 (1/2 ë), control is completely achieved. Vertical dispersion is obviously established by the height and aperture of the array element.
I've included a polar plot measured on the horizontal and vertical plane on a prototype, to highlight behaviour at some significant band-centre frequencies.





The preliminary characteristics for a single element in its standard version are as follows:

Operating frequency range
80÷18000 Hz

Nominal dispersion
90° horizontal

Loudspeakers

low range	2) 8" Neodymium
mid range	2) 8" Ferrite
high range	1) 3" compression driver - 1.41" throat

Sensitivity 1W/1 m

low	98 dB
mid	103 dB
high	110 dB

Continuous power handling - Hi-pass enabled

low	400WAES
mid	400WAES
high	120WAES

Continuous spl calculated - 1m

Low/mid	132 dB SPL
High	131 dB SPL

Peak spl calculated - 1m

Low/mid	138 dB SPL
High	137 dB SPL

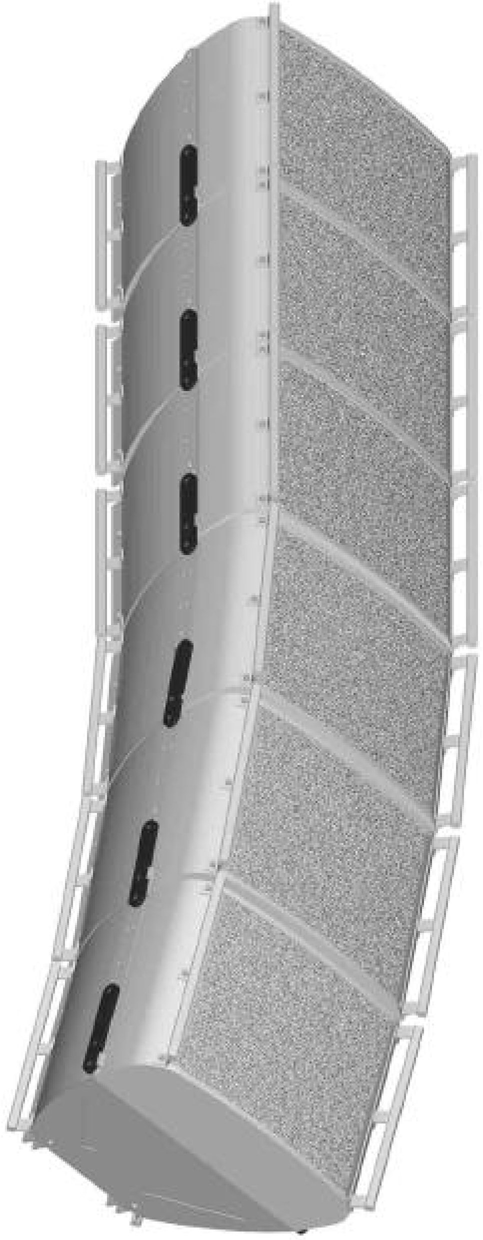
Up until this point, I've illustrated as simply as possible and with the most understandable images the innovative original technology that Outline uses for this new product.

“Butterfly Low-Pack C.D.L. 1815”

From the preliminary characteristics given for the Hi-Pack, it's obvious that the system must be used with a bass system matching its characteristics.
The Outline range has at least two products that could excellently complement the system, with performance definitely up to the same standard; they're Victor Live and TopSub Plus. Both are fitted with two 18” woofers in classic reflex configuration in enclosures that are very compact in spite of the reproduction high level of very low frequencies; if necessary, Victor Live can be flown for greater versatility.
Performance specs can be found in Outline's technical documentation.
In spite of this, it was decided to include in the Butterfly series a new low frequency system for use along with the Hi-Pack, sharing its functionalities. I
n fact, the new system's box is designed and built with multiple dimensions as far as height is concerned and it has the same footprint although it obviously doesn't have the Hi-Pack's horn “cavity”.
It has the same flying hardware, which makes it perfectly compatible and enables it to also be included in main line arrays. In multiple arrays, up to 16 can be flown one above the other (if there's sufficient space even 24!!!!!) for a height of approximately 8 metres and a total weight of approximately 700kg, which can be handled by the flying system without any difficulty.
To all effects, it's an element built with the criteria necessary for forming a real vertical line array suited to reproducing low frequencies.
In actual fact, since the system was designed with some special features which facilitate replacement of the speakers with others with a smaller diameter than 18” (the size fitted as standard), such as for example 15” or even 12” speakers, and since the box has truly compact dimensions which occupy just the space of two Hi-Packs one on top of the other, (480mm. high, 700mm. wide and 600mm. deep), with a net weight of 43.5kg including its flying hardware, the Butterfly C.D.L. 1815 (the code number of the basic version), can be easily configured to better reproduce the required band, from the deepest low frequencies to the highest mid/lows, and adapt it to the most varied sound reinforcement requirements, highlighting the versatility of the entire vertical line array.
These characteristics alone would be sufficient to make it a worthy match for a product such as the HI-Pack C.D.H. 483, but Outline, thanks to the intense activity in recent years and the results of on-going experimentation, decided to added a further useful detail to the product: Cardioid or Hypercardioid dispersion.
Designing this type of enclosure for low frequencies certainly isn't exactly something new, even if generally speaking the technology necessary for obtaining this dispersion has been widely applied for many years to microphones.
In fact, obtaining this dispersion pattern from low frequency enclosures isn't exactly an easy job (on this topic, I suggest some interesting reading - Ref. 9).
The dimensions involved, linked with large loudspeakers and the relative boxes to contain and “load” them with an adequate volume for reproducing low frequencies, don't allow immediate compact solutions, so through time there haven't been products with any real commercial success.
Construction difficulties resulting from the reasons mentioned in fact inevitably lead to high costs, worsened by the fact that for this type system it's also necessary to use sophisticated electronics, normally digital.
As far as I know, to this day on the professional market, there are only two brands whose product ranges include low frequency enclosures with cardioid dispersion or similar: one is US firm Meyer Sound Laboratory, which manufactures a couple of self-powered models; the best known and first on the pro market a few years ago was the PSW-6, in which no less than six large loudspeakers are used in reflex configuration: four for front radiation (two 18” and two 15”), other two 15” speakers facing backwards to annul rear emission.
Declared performance is considerable, as usual with this brand, with a 143dB maximum peak spl in half-space at 1 metre, a 30÷125Hz operating frequency range, and net weight of 200kg. its dimensions are 1083mm. (W), 1089mm. (H) and 794mm (D): all this with a front-to-back ratio which is on average 15dB for the stated range.
The second model, also of the cardioid type, designed and built expressly as a line array element, has four speakers (two 18” for front radiation and two 15” to annul rear radiation) and, even if more compact and lighter (1372mm. wide, 508mm. high, 775mm deep and a net weight of 180kg.), it also has a considerable declared performance, with 140dB of maximum peak spl and similar operating frequency range (28÷100Hz).
The technology used for these two products is relatively simple from a physical point of view; in fact, the loading system used in both the loudspeaker sections, front and rear, is the classic phase shift set-up, commonly known as “bass reflex”, while the electronic control applied to ensure the system's cardioid dispersion is complicated.
The Meyer Sound unit was recently joined by another brand's system with low frequency cardioid dispersion - Nexo.

In fact, this French firm's product range already has a couple of models: the CD 12, which is fitted with two 12" and the brand new CD 18, which has two 18".
Rather than choosing a classic method from the point of view of the configuration (bass reflex), the French manufacturer obtained good results, considering the declared characteristics, from the application of what to an outsider appears to be a complicated "twin reflex" configuration, also called "high-order bandpass", whose operation regarding cardioid dispersion is necessarily controlled by digital electronics which are complex and sophisticated.
In fact, a glance at the systems shows the presence on the front of the tuning and sound emission ports of the two chambers foreseen by twin reflex configuration, stressing that this particular enclosure's directivity is somehow obtained exclusively using digital electronics; in short, electronic delay and phase shift of the two individual loudspeakers' emission. This same configuration is also used for the CD 18.
The declared specs for the CD 12 are 102dB (+/-3dB) sensitivity and 134 dB (+/-3dB) maximum peak at 1m in half-space, to obtain the which, making a quick calculation, peak power of no less than 1,700W is required, an operating frequency range from 39 to 250Hz, a weight of 36kg, including flying hardware and a box which is 600mm. wide, 400mm high and 754mm. deep.
Figures declared for the CD 18 on the other hand are: maximum sensitivity 105dB (+/-3dB) and maximum peak spl in half-space of no less than 145dB (+/-3dB), to obtain which an amplifier able to feed out no less than 10,000W Peak will be required!!!!!!
Having seen that the market's supply of cardioid systems was rather limited, Outline decided to design its own Cardioid system for the reproduction of low frequencies.
What better opportunity to design and build it than to match it with a vertical line array system, with which it has very high directivity in common?

Here's the design of the definitive version of the Butterfly C.D.L. 1815.



The box is built in composite plywood, mainly manufactured via moulding and high frequency gluing. The thickness, in spite of what one might expect for a low frequency box, is decidedly limited (14mm.), to keep the weight down.
The "egg" shape of the sides and the "split" layout of the top and bottom give the box great sturdiness, taking residue resonance out of the system's operating range and therefore not excitable even at the highest sound emission levels.
The flying system enables to vary the reciprocal angle between elements and is completely compatible with that of the Hi-Pack, with which it has many mechanical parts in common.
Up to now I've explained the physical and mechanical characteristics which make it a technically advanced product, but these favourable features are combined with its cardioid or hypercardioid sound dispersion.

Like all Outline products, the technique used to obtain it is essentially based on the application of physical and geometrical principles to acoustics rather than intensive use of electronic correction.
I personally believe that the acoustic phenomenon is a completely physical phenomenon and therefore before using electronics, every possible configuration which could lead to the achievement of the required performance is patiently and generally successfully tried out for each project.
The same criterion was also used for the Low-Pack and after numerous prototypes, assessments and measurement on the field, a new type of hybrid acoustic loading was found, of which (following in-depth search) no trace has been found in international technical literature regarding speaker enclosures, in particular the special type of enclosure for low frequencies with cardioid o similar dispersion.
For this new configuration, a hybrid from the physical point of view using a complex combination of interacting "mechanical" bandpass and high-pass to load the two loudspeakers, which are in a common air space, Italian and an International patents (PCT) have been applied for, supported by frequency response polar plots and an equivalent electric circuit diagram which, as well as specifying the type patented, makes its operating principle comprehensible, otherwise difficult to explain due to the lack of specific publications.
To highlight the versatility that the technology used by the system offers, regarding possible variations, in the passband reproduced with the replacement of the speakers, and in the dispersion pattern, without any particular electronic processing apart from the use of a normal "delay", a function included in the standard GENIUS 6 controller, the following acronym has been coined:

"ADLS" Adjustment Directivity Loudspeaker System.

Important diagrams and designs are shown below, including a very detailed concept diagram.

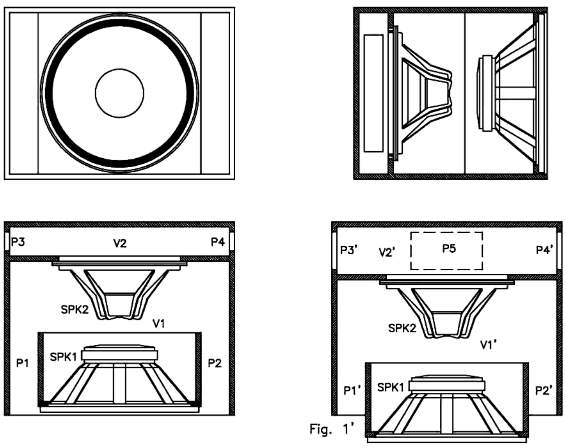


Fig. 1 - Narrow dispersion Low frequencies design example louspeaker system. **International Patent pending (PCT)**

The substantial complexity from the point of view of the electroacoustic circuit used is expressed with extreme semplicity from the construction point of view.

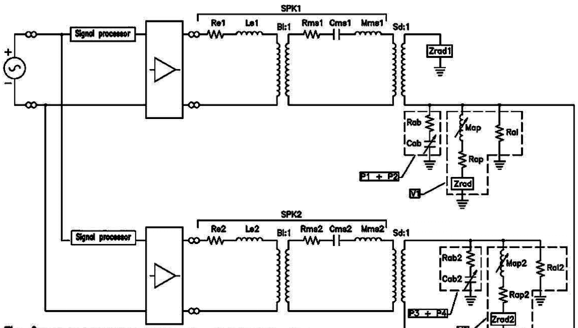
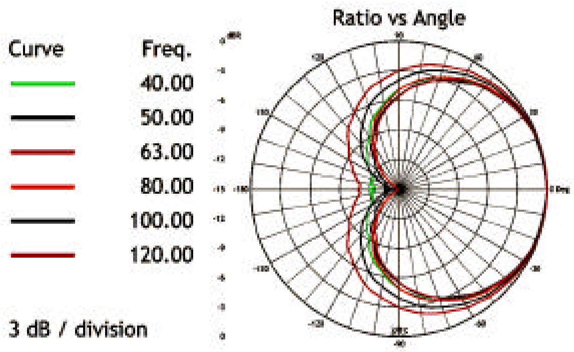


Fig. 2 - **Butterfly C.D.L. 1815 - Cardioid LF System**
Equivalent electroacoustic circuit.

In its standard configuration, the system uses an 18" speaker for front emission and the speaker inside the box, whose emission is used to recreate the required cardioid or hypercardioid dispersion in the system, is a 15" speaker. Normalized polar response in half-space obtained from the system are shown below (valid for the horizontal plane.
On the vertical plane, the system has a dispersion of approximately 90°, extending from the plane the box is standing on to an imaginary vertical plane which intersects it perpendicularly behind the enclosure (in this case, the cardioid dispersion is modified by the plane the box is standing on, which in fact eliminates emission in the bottom left quadrant of the polar pattern).
It's worth noting the uniform reduction of rear emission for all frequency bands involved and the remarkable "front-to-back" ratio which, from a minimum of 12 dB at 120Hz (the top cut-off frequency suggested) attenuates the rear emission by over 15dB for all other frequency bands.



The preliminary characteristics for a single element in its standard version are as follows:

Operating frequency range
35÷180Hz

Nominal dispersion – Free-field
180° horizontal/vertical

Nominal dispersion - Half-space
180° horizontal
90° vertical

Loudspeakers

front	1) 18" Ferrite
rear	1) 15" Neodymium

Sensitivity 1W / 1 m

Half-space	102 dB

Continuous power handling capacity – Hi-Pass enabled

front 18"	1000WAES
rear 15"	500WAES

Continuous spl calculated - 1m
Microphone in front at 4 metres

Half-space	132 dB SPL

Peak spl calculated - 1m

Half-space	138 dB SPL

Front-to-back dB SPL ratio – 1m
Rear microphone at 4 metres

Average	15 dB SPL
Passband	40÷100Hz

What else can be said about the Butterfly Series?

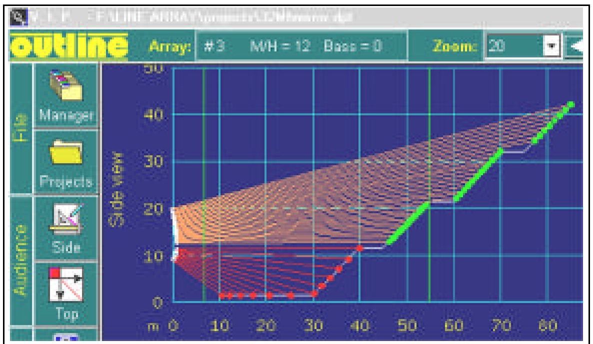
We could probably list endless other important "details" to illustrate its design philosophy and the results obtained, but I think the contents of this white paper are more than sufficient.
It is however worthwhile giving a mention to the aiming and acoustic/mechanical calculation software supplied with the system.
Everybody agrees that current requirements as far as performance and sound quality of a sound reinforcement systems are concerned have increased logarithmically compared to those of just ten years ago, when they would have seemed unattainable. Material technology, new ideas and (why not?) old ideas that have been updated to match present-day construction possibilities, have enabled this jump in quality and performance.
There hasn't unfortunately also been a similar jump in "performance" in the behaviour of those in charge of audio systems, whether they're the sound engineers who use them or those in charge of rigging and flying. When this rift occurs and isn't solved, it leads to mediocre or even pitiful results regarding the sole aim for which a sound reinforcement system should be used:

Ensuring audiences the maximum sound quality that the environmental conditions allow, without overlooking the achievement of an adequate sound level.

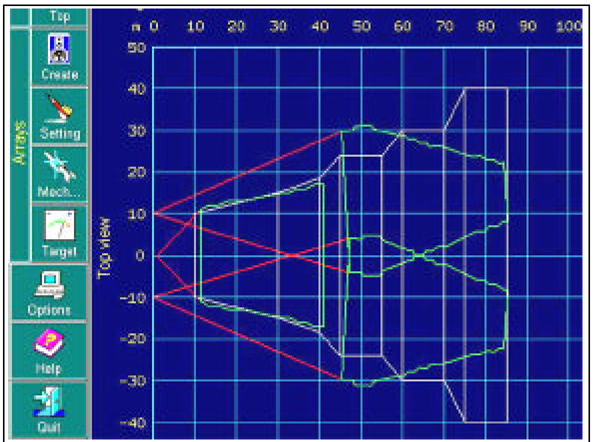
To avoid one of these environmental conditions being left to chance and subjected to mistakes or lack of experience, often the aspects with the greatest effect on results, manufacturers of sophisticated systems which are therefore "difficult" to set, such as vertical line arrays, have all developed so-called "tools" which, by means of relatively use-friendly software dedicated to a specific product, guides the person in charge of installing the system through the correct procedure, from the point of view of aiming, mechanical aspects and problems which occur for safe array flying, thus reducing the risk of bad results.
The "tools" offered by the various manufacturers of line arrays are generally developed by using classic spreadsheet such as Microsoft's Excel.
This greatly limits the programs' graphic precision, not so much as far as the actual resolution is concerned, but rather for the level of logic/visual correlation that "languages" born for calculation and at the most for statistic graphs allow to achieve.
For this reason, but also considering the development of these "tools" in perspective, Outline's R&D team put a great deal of effort and work into developing and designing:

V.I.P. *"Vector Implementation Protocol"*

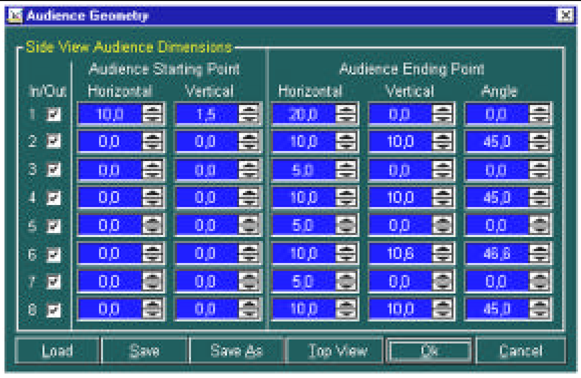
The first software dedicated to a determinate product developed completely with a cutting edge programming language using powerful "Open GL" graphic libraries.
Listing all the functions found in the software's "Beta Version" and those forecast for future development would be a hard job here. so I'll just list a few of the most important and include a few screen shots:



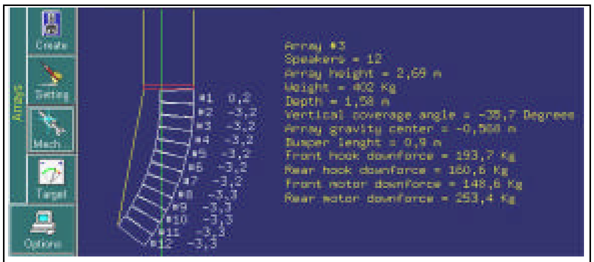
Creation, setting and manual/automatic aiming of eight vertical line arrays simultaneously, with two different types of Hi-Pack or Low-Pack enclosures or a third type which is a combination of the two.



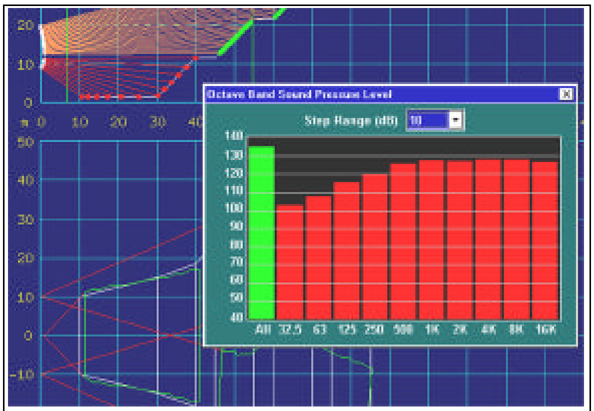
Creation and free positioning of eight different simultaneous listening areas on which the arrays created are to be aimed. The cross-section and designed listening area can be seen simultaneously.



Keying in dimension parameters of the middle section of the surface at which each individual element of an array or several arrays installed has to be aimed.



A graph is enclosed with each Array supplied, with all the parameters for flying according to the limits set by international norms on suspended load safety.



Among many acoustic parameters represented in reports of various types, it's interesting to see the display, in all the positions of the plane intercepted by the aiming axis of an Array element, of the spl with an octave bargraph taking into consideration the contribution of all the array elements at that point.

That's all!

I hope I've managed to give a summary that suitably reflects and rewards the recent years' hard work carried out with great enthusiasm and determination by Outline's R&D team.

January 2003
BRESCIA
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