

AES San Francisco 2008
Exhibitor Seminar ES11
Saturday, October 4, 1:00 pm — 2:00 pm

**Automated
Loudspeaker Balloon
Response Measurement**

Audiomatica SRL

3D Polar Measurements

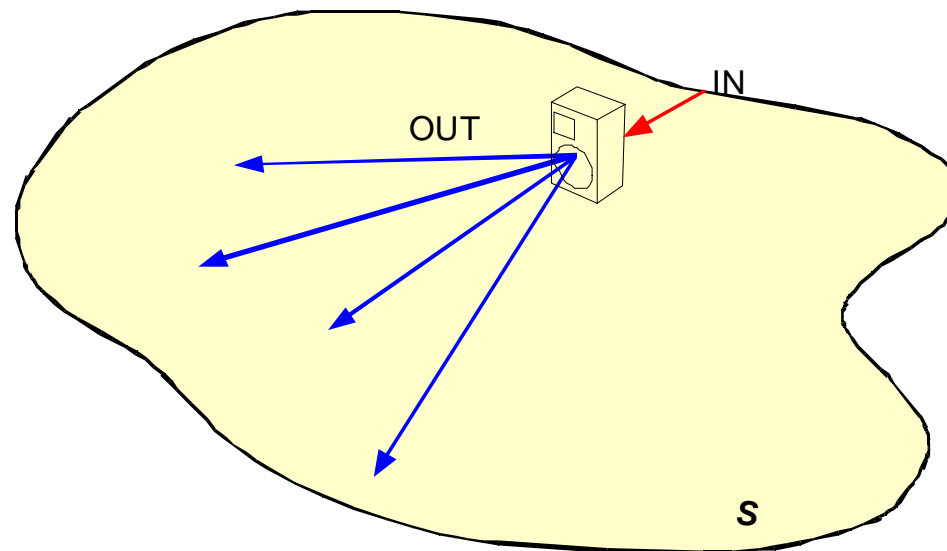
- In this seminar we will analyze the *whys* and the *how* of loudspeaker polar measurements
- Every aspect of the measurement process will be treated in detail (but in fact more questions than answers will be raised...)
- The CLIO + Outline ET250-3D automatic measurement process will be showed
- Exportation of sets of polar data to most used simulation softwares formats will be showed

Polar Measurements Aim

- Polar measurement sets are used for (contexts):
 - Laboratory use:
 - design and validation
 - input for design simulation softwares
 - technical documentation
 - Public use:
 - data sheets and catalogs
 - technical publications
 - models for commercial simulation softwares (EASE, CLF, ...)

Loudspeaker Radiation Model

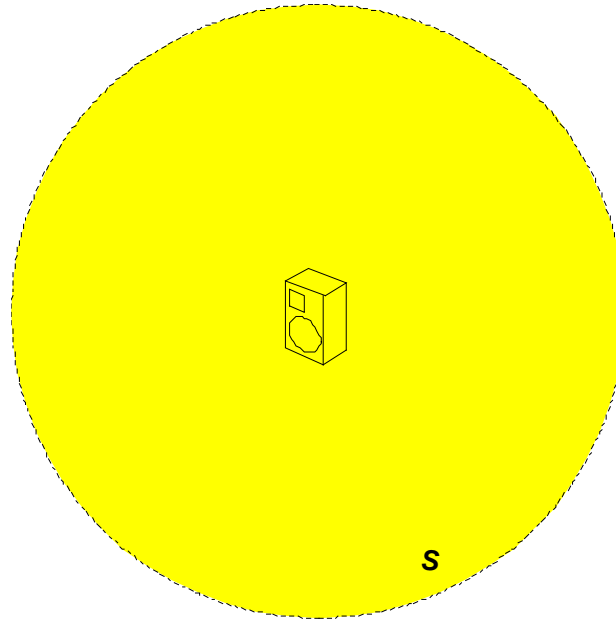
- A loudspeaker source can be seen as a single input multiple output system and modeled as a point source:



with a given transfer function (linear model) for every point in the surrounding space \mathbf{S} . In order to model the system it is necessary to sample the response into the \mathbf{S} space.

Point Source Model

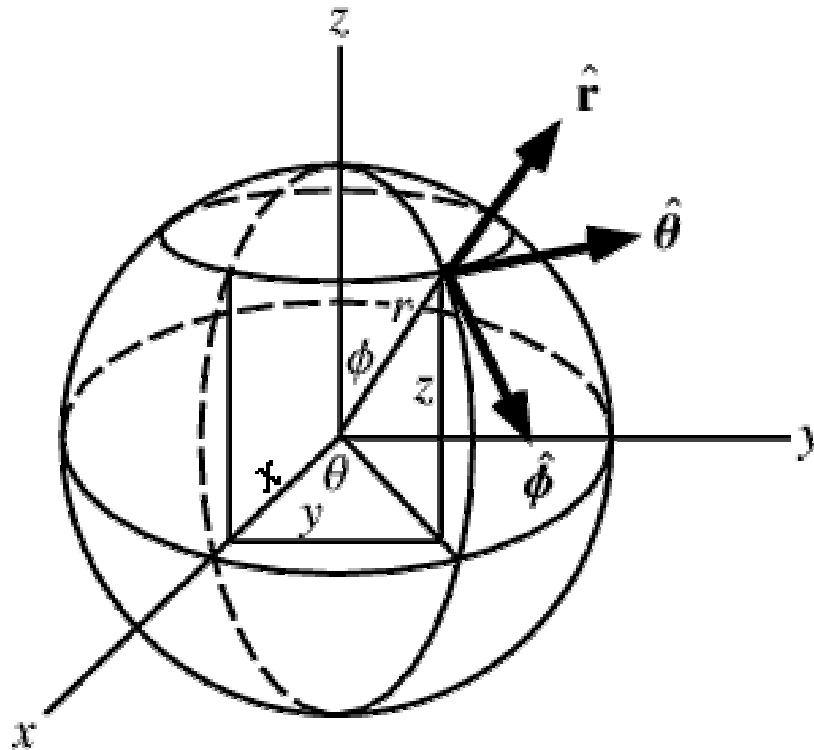
- If the loudspeaker can be modeled as a point source it is possible to sample the response over a sphere centered in the source position.



How To Sample?

- How to sample over a sphere?
 - Which spherical coordinate system?
 - How many “meridians” (aka polars)?
- Use regular sampling or adaptive?
 - Which resolution if regular?
 - It seems also reasonable to use a finer resolution where the energy content is high (can be seen also as a coarse resolution where the energy content is low, i.e. back emission)
 - Spherical harmonics?

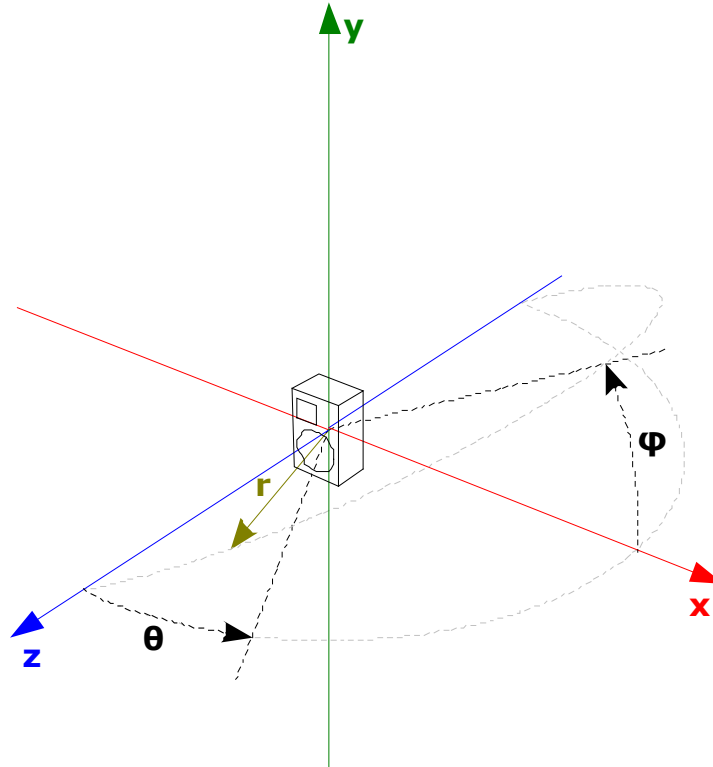
Spherical Coordinate System



Weisstein, Eric W. "Spherical Coordinates." From MathWorld - A Wolfram Web Resource. <http://mathworld.wolfram.com/SphericalCoordinates.html>

Spherical Coordinate System

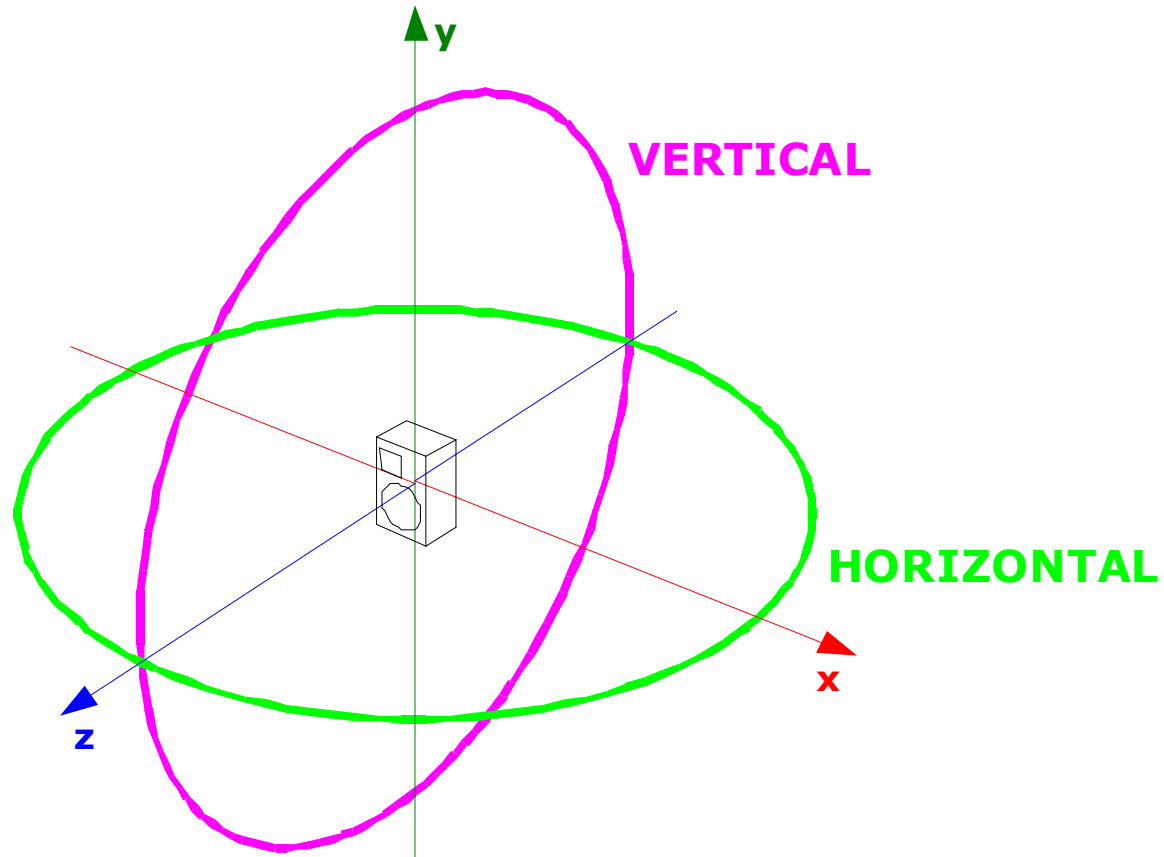
- We adopt *this* spherical coordinate system:



Is it possible to think at the source pointing its on-axis direction towards the north pole. In this way the polars (meridians) are effectively passing thru the poles.

Simplest Method H+V

- Simple and FAST



Simplest Method H+V

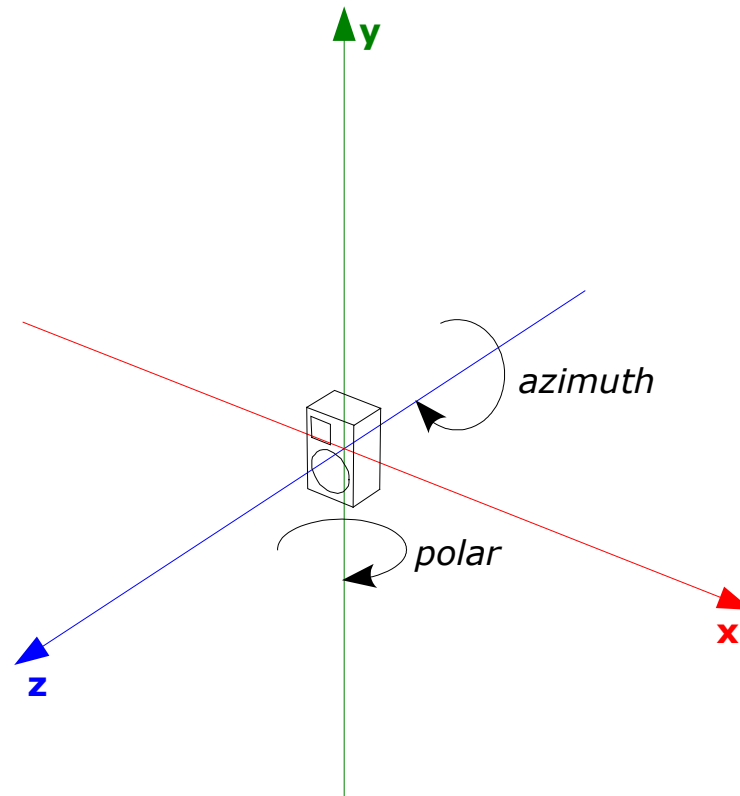
- Sample the response over only two polars, the Horizontal and Vertical polar with a given angular resolution
 - common values for theta (polar angle) resolution are 5 degrees
 - phi resolution is 90 degrees
- Then the missing polars are interpolated mathematically
 - how to interpolate?
 - Elliptical interpolation
 - Smoothness of the balloon shape
 - Is it the interpolation meaningful?
 - Only in very simple cases
 - Works only for magnitude data AFAIK

Why H+V is simple?

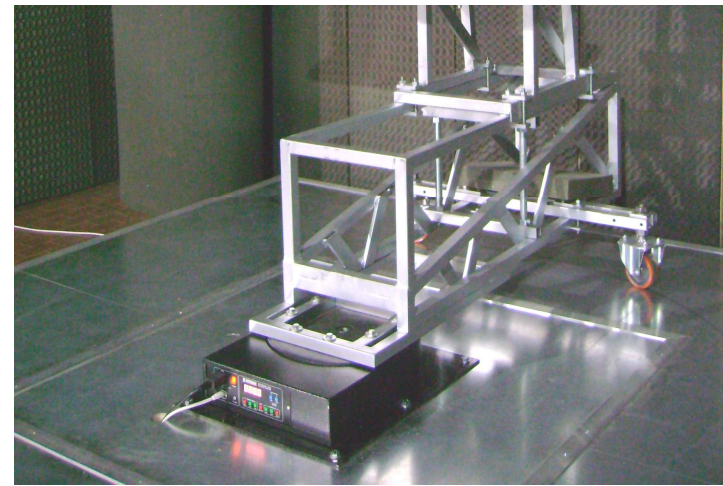
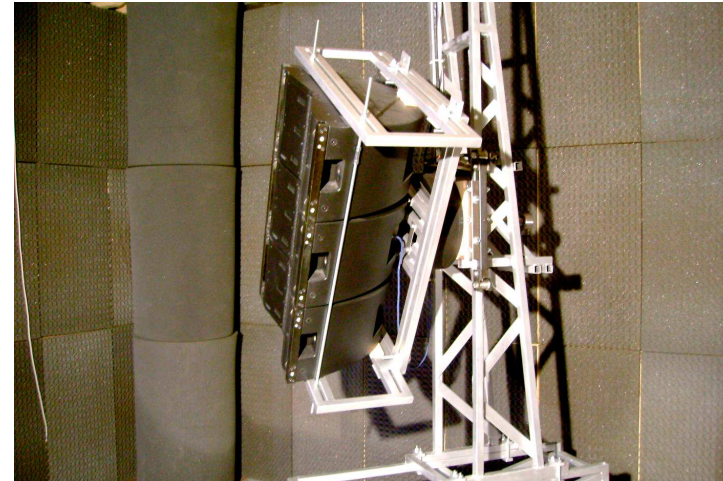
- The measurement setup involve a single PC controlled turntable
 - the PC control can be quite basic, just sending pulses to the turntable
- The loudspeaker can be easily put on the turntable in vertical and horizontal position and only two polars need to be sampled
- For a regular sampling angle of 5 degrees only 144 points are needed, the procedure can be completed in less than 10 mins

Adding Complexity

- If we want to collect other polars, a single turntable is not sufficient : we need to rotate the loudspeaker over another axis
- In fact this is exactly what we do with the H+V by placing the loudspeaker on the turntable in two positions
- The second rotation axis can be realized using a second turntable or manually rotating the device



Big Setup Example



Small Setup Example



Full 3D - different approaches

- There are some different approaches that we need to mention apart from our 2 turntables setup:
 - Arc of microphones and multichannel data acquisition
 - very fast
 - complex
 - needs an anechoic chamber
 - fixed angular resolution
 - Rotating microphone
 - not faster
 - bit complex to get working in non-anechoic spaces
 - mechanical oscillations of the long microphone boom arm

How Complex do we get?

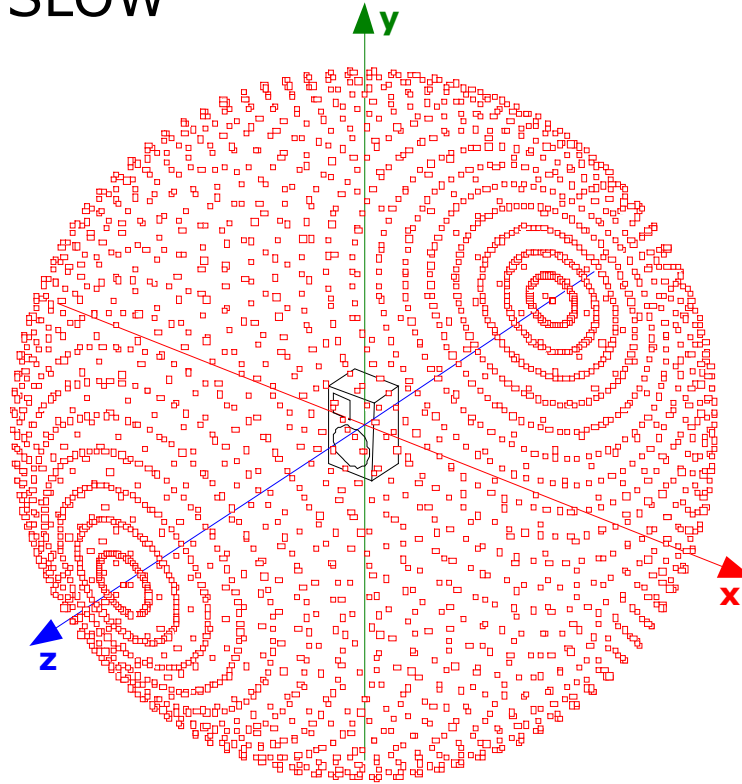
- With two axis of rotation is it possible to sample the loudspeaker response at every point of the surrounding spherical surface
- Regularly sampling over polars leave us the possibility to choose two different resolutions for the theta and phi angles
 - as an example it is possibile to sample theta at 5 degrees and phi at 30 degrees
 - is it better to choose the same resolution for the theta and phi angles?
 - The AES standard currently under discussion recommends a 5 degree resolution for both angles

Interpolation, again?

- At this point it must be noted that some degree of interpolation must be carried out at a certain point of the modeling process.
- If the response of the source is known over a given number of point over the space:
 - from the point of view of the measurement process we need to decide which is the correct angular sampling angle
 - it is possible here to follow the recommendations and use a 5 degree angle and leave the interpolation issue to the users of the measured data (simulation softwares)
 - It has been showed by Ahnert and Feistel that the angular resolution is related to the simulation accuracy, and that given a resolution the simulation error is bounded below a certain frequency (The Significance of Phase Data for the Acoustic Prediction of Combinations of Sound Sources, AES preprint no. 6632)

Full 3D

- Complex and SLOW



in the worst case (no symmetry) at 5 degree resolution
2664 impulse responses needs to be measured

Practical considerations

- At this point we are quite confident on the fact that “high resolution” polar measurements must be carried out in 3D with a resolution of 5 degrees...
- There is still a couple of practical problems to take into account before starting to make measurements:
 - Distance source-to-microphone
 - Anechoic or non-anechoic space (closely related to the distance)?

Source to Microphone distance

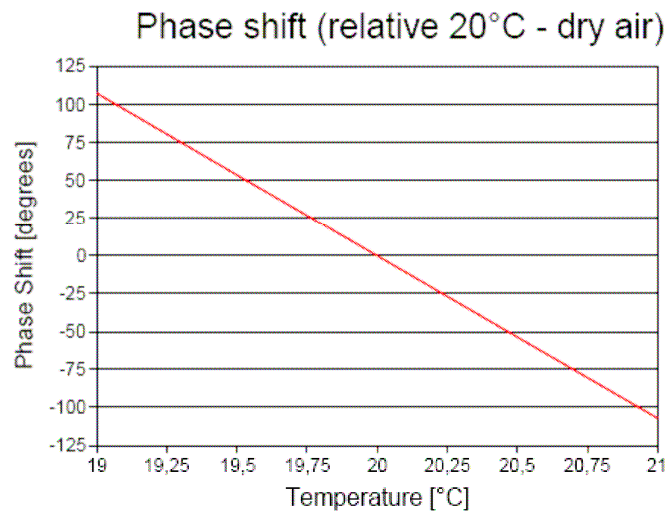
- It is known that the distance must be sufficiently high to measure the far field response. Commonly used distance for arrayable loudspeaker ranges from 4 to 8 meters.
- A greater distance reduce also the error related to apex, due to the fact that we model the source as a point and that we rotate the source around another point that can be non coincident with the "acoustical center"
- This can lead to measuring distances as high as 6-8 meters.

Anechoic or not?

- In theory a big anechoic room is the solution. But it is difficult to get distances greater than 4m in common sized anechoic chambers
- Also the measurement setup can be quite heavy and need to be very stable, which is hard to achieve over a cable floor
- A solution can be the use of semi-anechoic chambers or low reverberation spaces (large spaces with sufficiently low reverberation)
- A non-anechoic or semi-anechoic chamber can cut the costs dramatically

Please, NO Outdoors!

- The temptation to perform 3D polar measurements outdoors is high, but the uncontrolled environment together with long duration of the measurement process can lead to big errors!
- Discarding the effect of the wind and the noise, a change in temperature will cause a phase shift:



distance 6m
frequency 10kHz

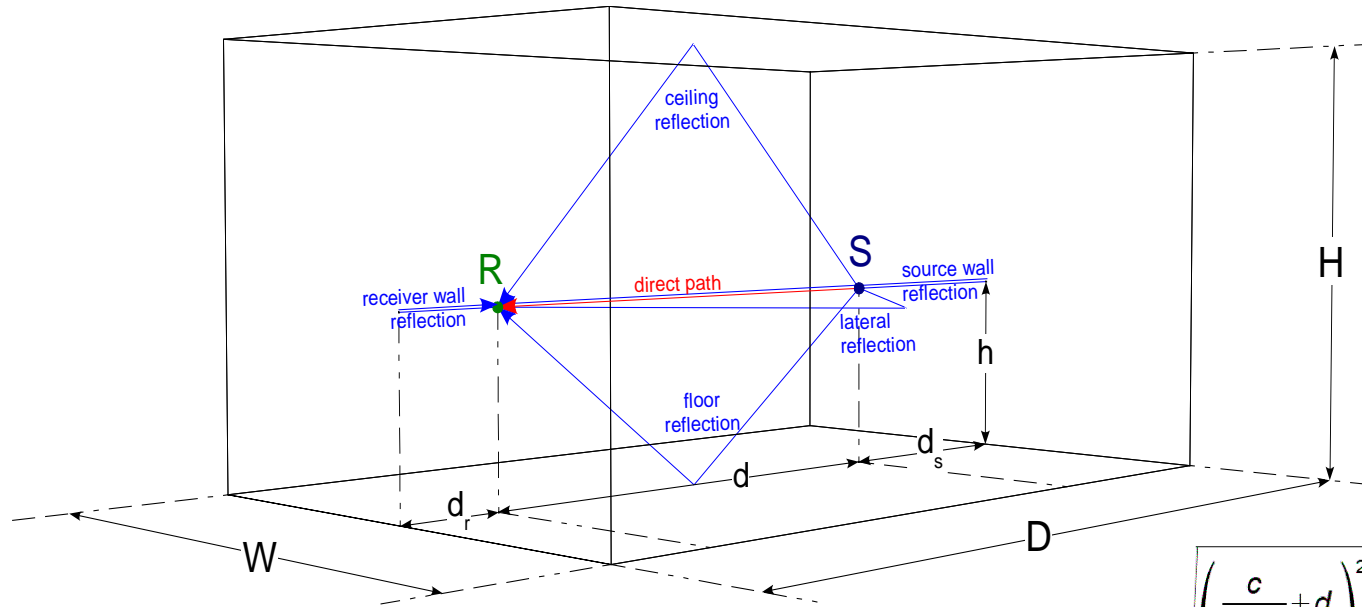
Not or Semi-Anechoic

- There are two issues to take into account.
 - Reflections (can be eliminated by impulse windowing)
 - Reverberation (can cause time alias between different measurements)

Managing Reflections

- Is it possible to use time windowing to get rid of the room reflections
 - The IR must be reflection free for at least $T=1/f$, where f is the lowest frequency we want to measure
 - In order to get this the source must be sufficiently far away from reflective boundaries, or the boundaries must be treated (in the frequency range) to be absorbing.
- C.Struck, S.Temme, "Simulated Free Field Measurements", JAES, Vol. 42, No. 6, 1994 June.

Room Reflections



Given the minimum frequency to be measured it is possible to calculate the needed room dimensions

$$H = \sqrt{\left(\frac{c}{f_{LOW}} + d\right)^2 - \left(\frac{d}{2}\right)^2} + h$$

$$W = 2 \cdot \sqrt{\left(\frac{c}{f_{LOW}} + d\right)^2 - \left(\frac{d}{2}\right)^2}$$

$$d_s = \frac{c}{2 \cdot f_{LOW}}$$

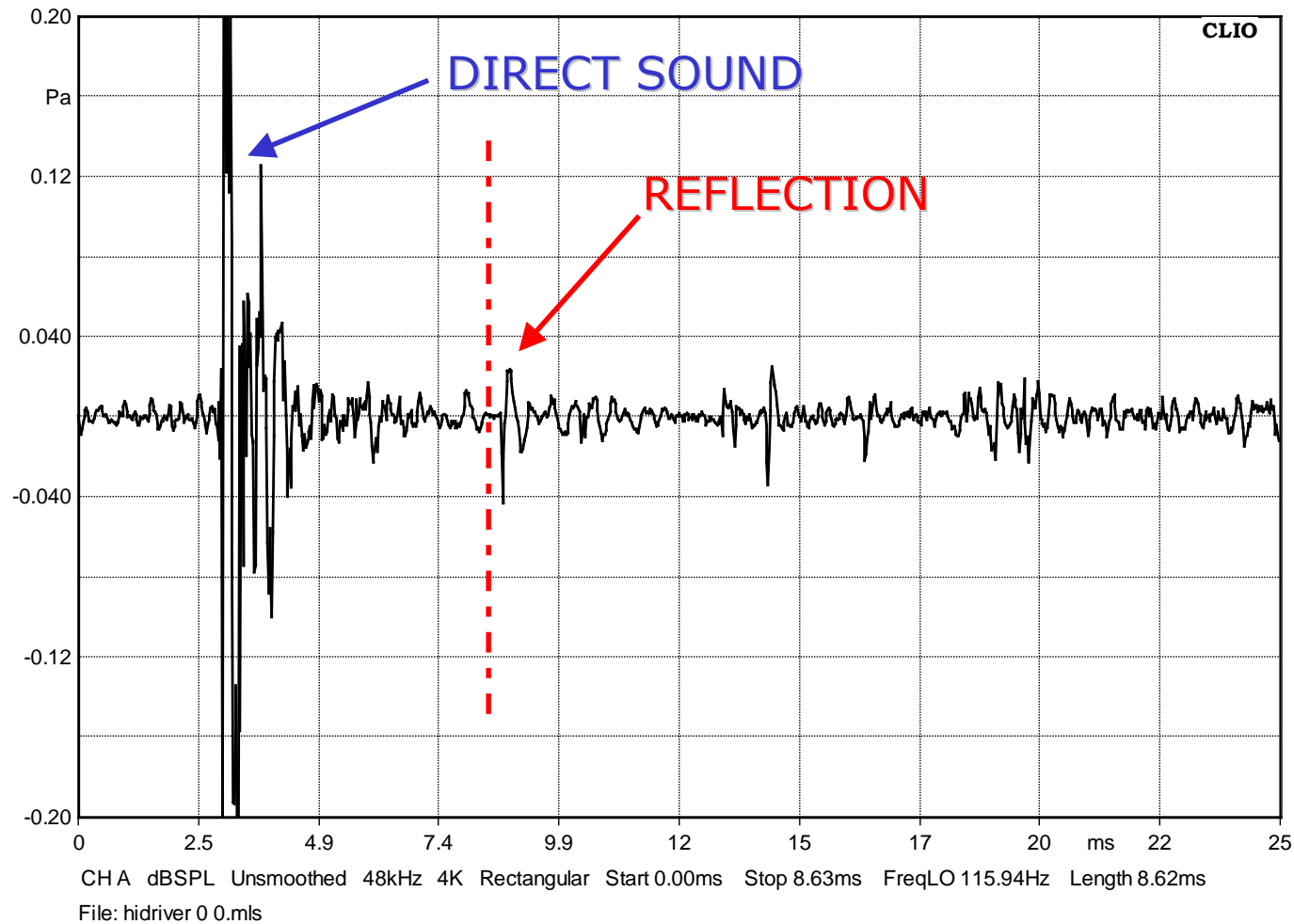
$$D = d + 2 \cdot d_s$$

Room Reflections

Audiomatica Srl

LogChirp - Impulse Response

9-20-2008 12.59.27 PM



Managing Reverberation

- The reverberation time can cause time aliasing between measurement
- There is the need to let the energy decay sufficiently before taking another measurement
- The RT60 must be low at least for the frequency range we are measuring
- An anechoic chamber is the perfect choice, but a so called “low reverberation chamber” can work good also

CLIO and 3D

- CLIO can control two turntables and automatically perform a set of 3D measurements
- What's new?
 - turntable control dialog*
 - 3D autosave procedure*
 - 3D analysis menu**
 - data export in various ASCII formats**
- New turntables commercially available:
 - Outline ET250-3D
 - LinearX LT360

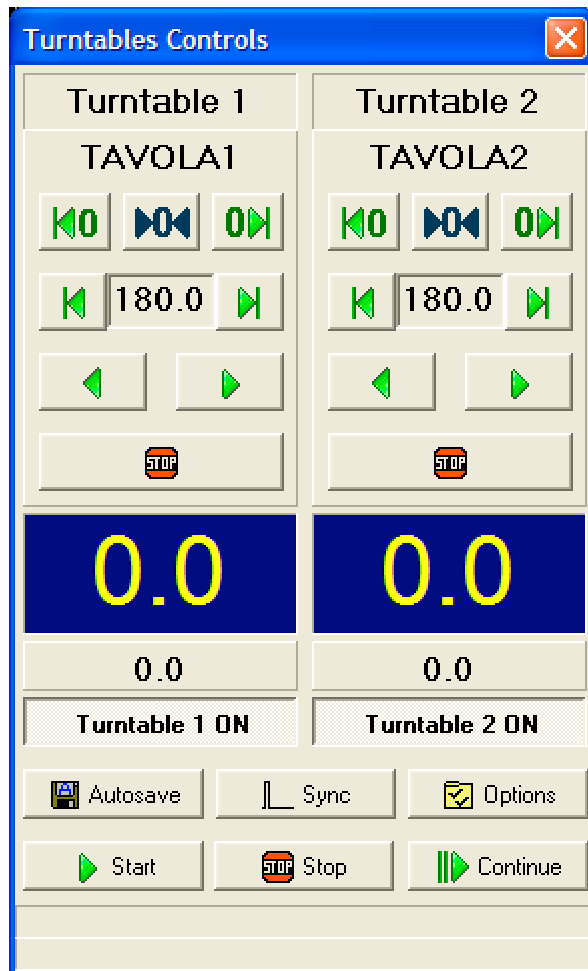
*in production **beta

The new Outline ET250-3D turntable

- Outline recently released the new ET250-3D turntable:



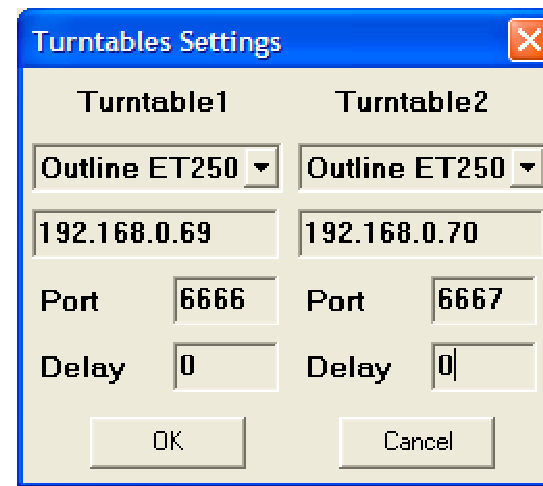
Turntables Dialog



- With this dialog it is possible to connect and send commands to the turntables
- Start, stop and resume an autosave procedure

Turntables Options

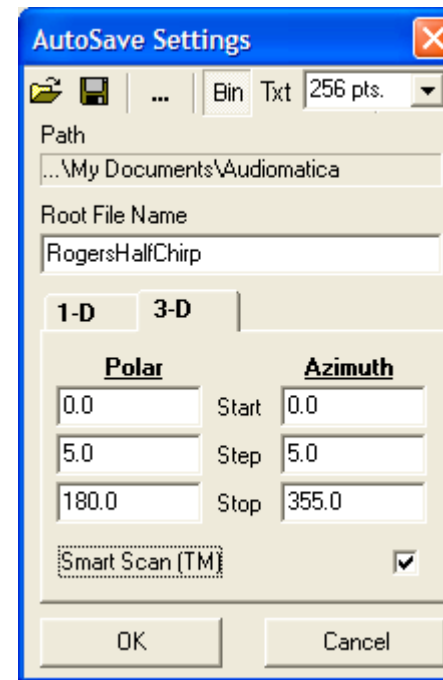
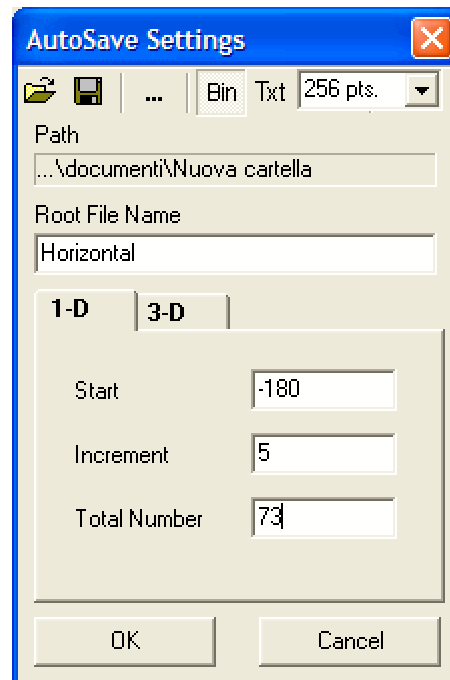
- Specify which turntables is used for the polar (1) and azimuth (2) axis and communication setup
- Turntable 1 choice:
 - Outline ET250-3D
 - LinearX LT360
 - TTL Pulse (legacy mode*)
- Turntable 2 choice:
 - Outline ET250-3D
 - LinearX LT360
 - Manual



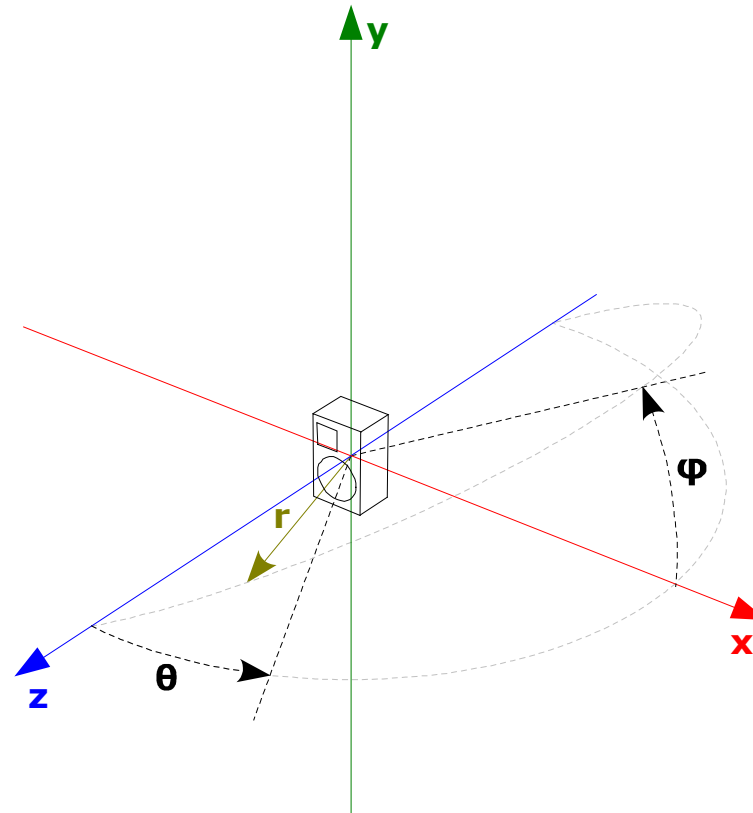
*If a parallel port is not present on the PC it is possible to use the CLIO QC BOX model V to generate the pulses (i.e. how to drive an old Outline ET2 without a parallel port)

New CLIO Autosave

- Two autosave methods are available:
 - 1D: Basically the old CLIO method, to be used as a legacy mode
 - 3D: Can perform either single polar or full sphere measurements using two turntables



New CLIO Autosave



<filename> <phi*100> <theta*100> .mls

New CLIO Autosave

- Polar and Azimuth angular resolution is independent
 - Example only horizontal and vertical polar with 5 degree resolution:
 - phi resolution = 90
 - theta resolution = 5
 - Example polar every 15 degrees and 5 degrees resolution:
 - phi resolution = 15
 - theta resolution = 5 degrees
- The SmartScan algorithm reduces polar data set measurement time and avoid cabling problems scanning the polar angle back and forth

CLIO Automation

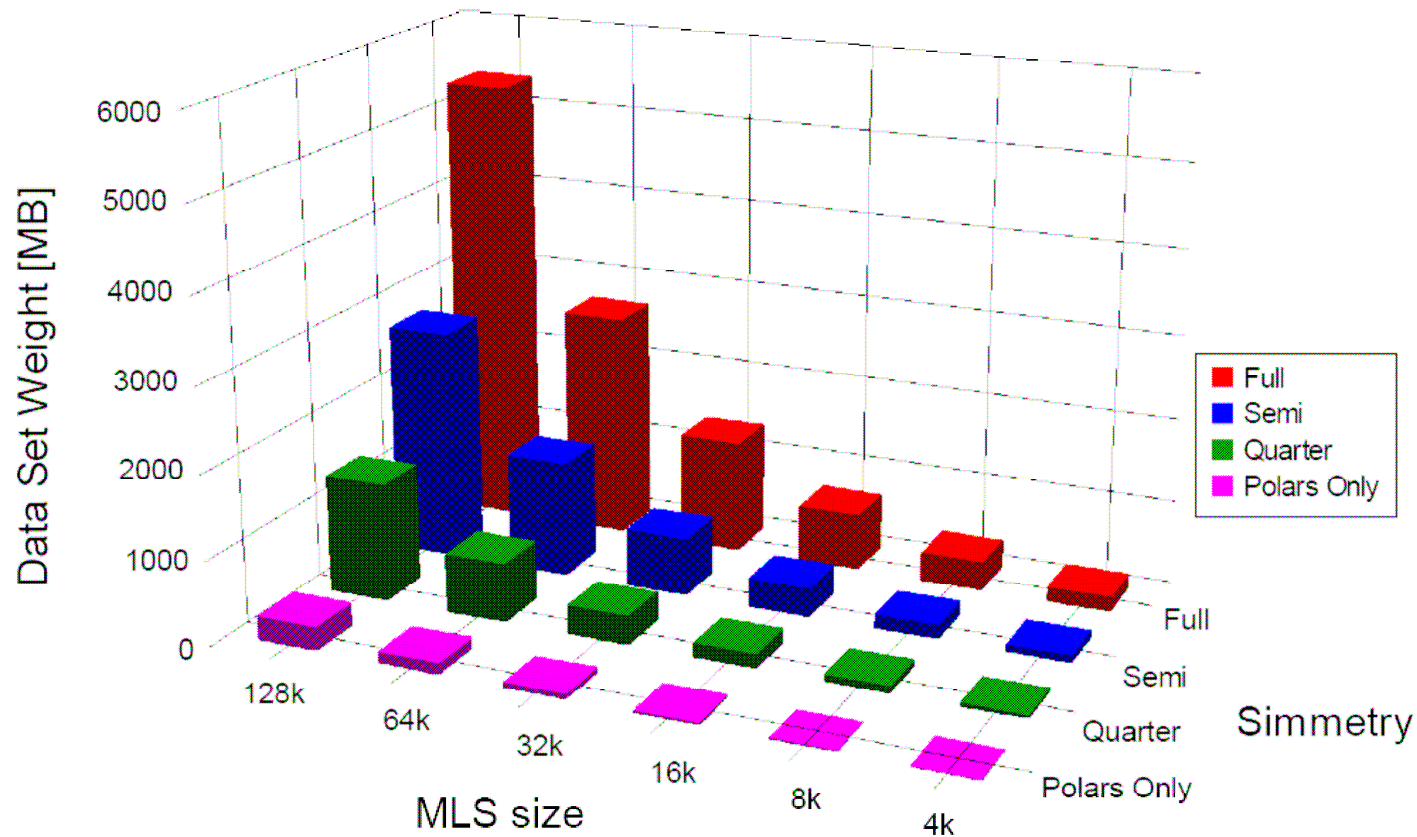
- Once the turntables are connected, and the autosave setup is done... just press GO!
- CLIO will take care of controlling the turntables, getting the measurements, saving the files with the naming scheme.
- It is also possible to halt the measurement process and to resume it in a later time

Before to GO!

- To avoid the unwanted reflections it is necessary to setup the time windowing, this can be done doing an mls measurement on-axis and carefully setting the stop window.
- In theory it is possible to apply this windowing after collecting the measurement set, but to avoid to reprocess during the analysis a great number of responses the windowing has to be done in advance.
- It is also necessary that the disk where we want to save the measurements has a sufficient disk space...

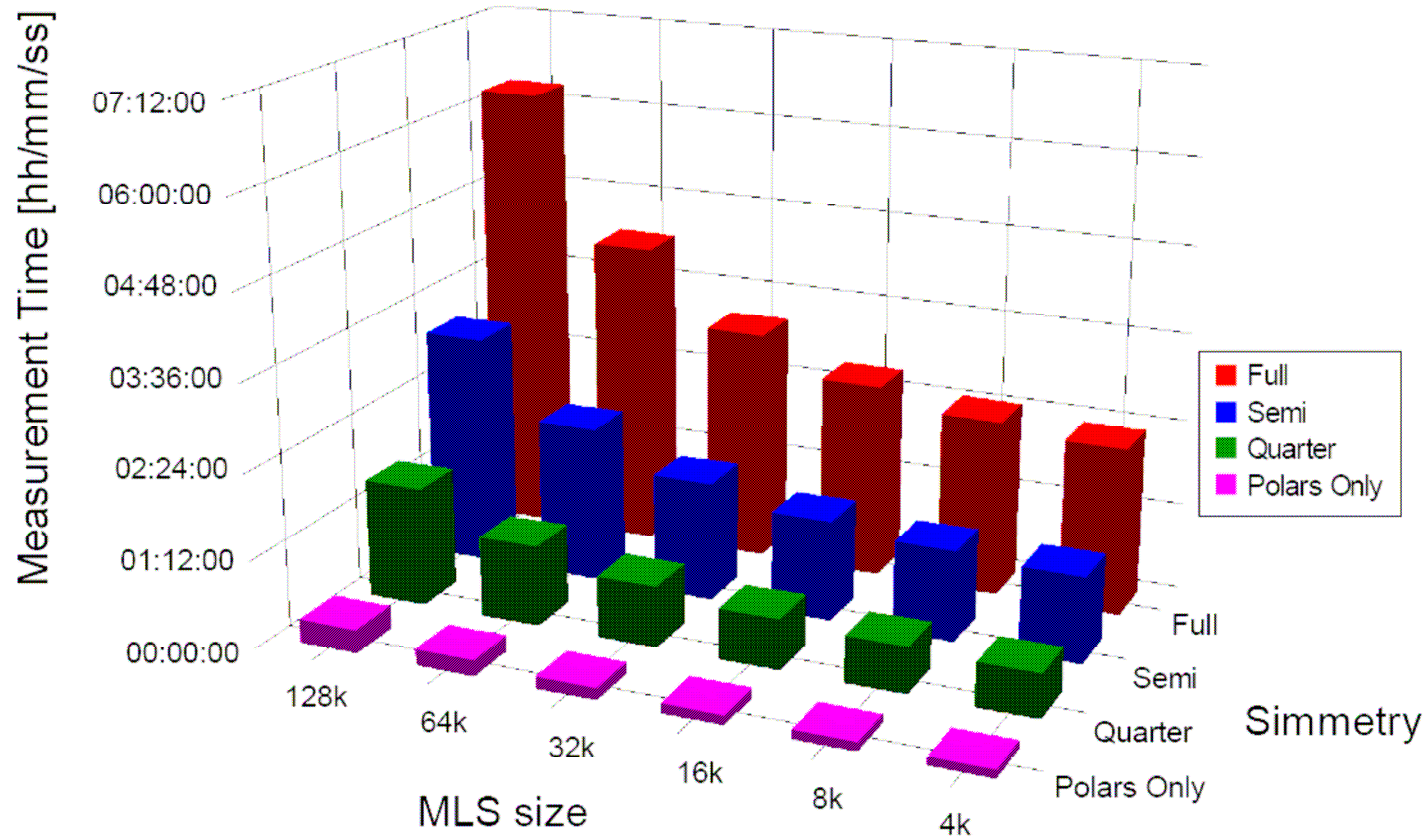
Data Set Size

- The Data Set size depends on the MLS size and the number of measurements to be performed:



Press GO! ...and Wait...

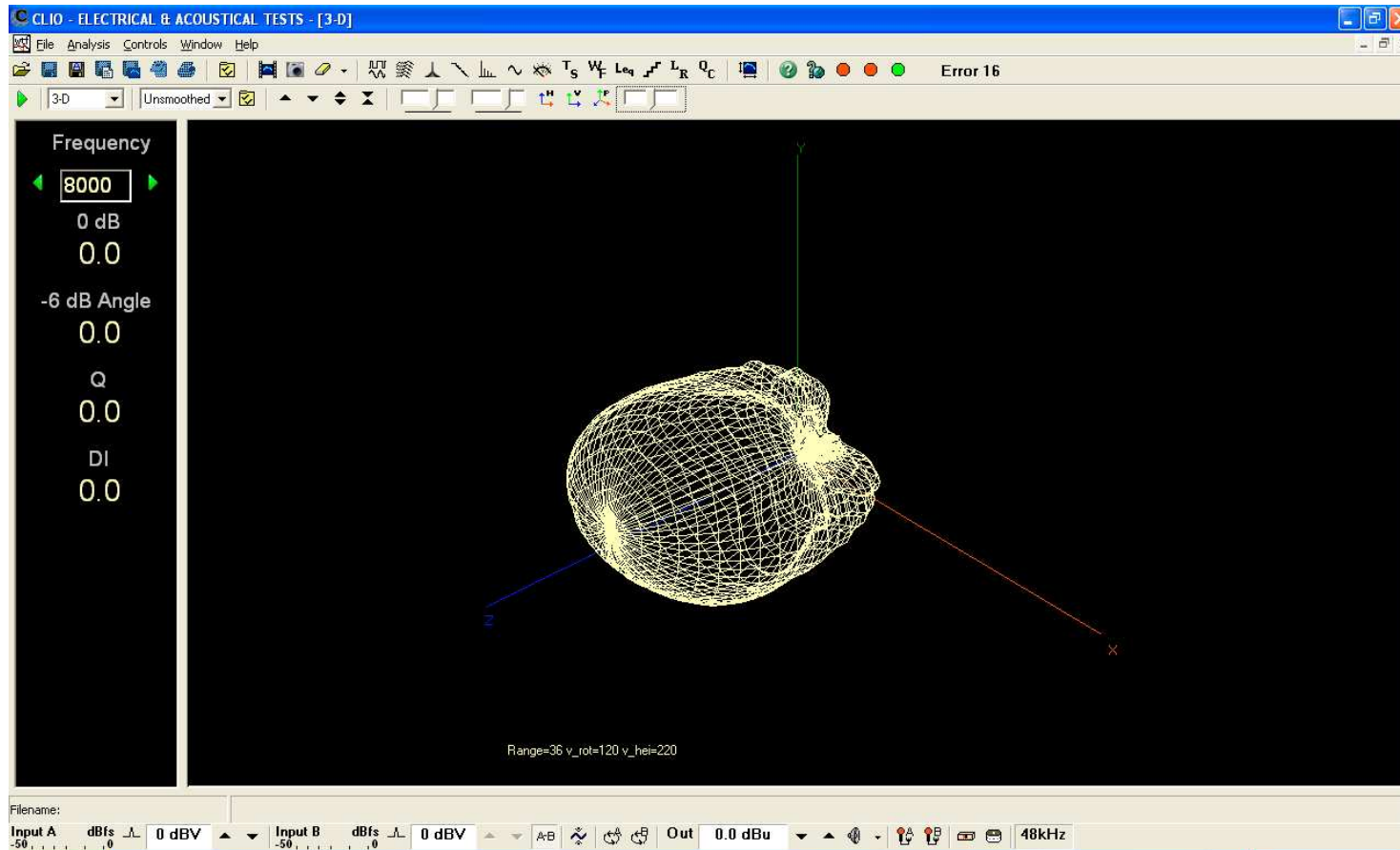
- The measurement time depends on many factors. Here is reported an example using two Outline turntables:



3D Analysis

- This is a beta version of the upgraded Waterfall and Directivity module, basically it is a tool to check that the 3D measurements has let to meaningful results
- An enhanced version with better graphics support is already on the wish-list, at the moment it is a basic wireframe view of the magnitude balloon with controls to rotate the balloon and to zoom in and out the balloon range (inflate/deflate?)

3D Analysis



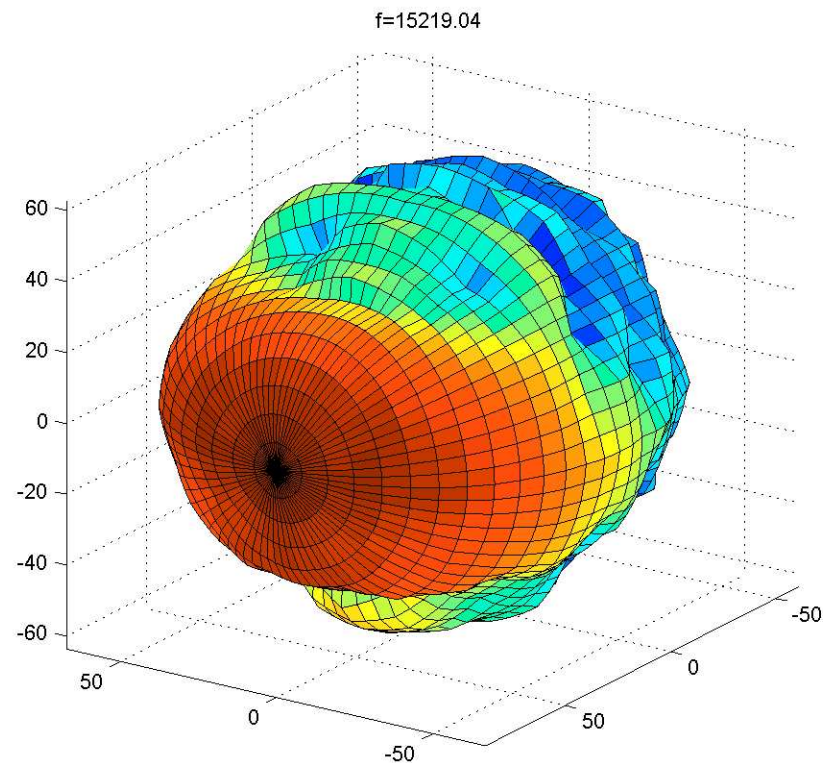
Export Data

- There are some ways to use the measured data sets, some implemented into the 3D Analysis menu:
 - Export to a single .xhn EASE (only magnitude) *
 - Export to a single CLF v2 .tab *
 - Export a single responses as time data .txt (to be imported with EASE SpeakerLab)
- It is also possible to import the data sets into Matlab or Scilab where the processing and visualization options are countless

* regular sampling of 5 degrees for both phi and theta angle is needed

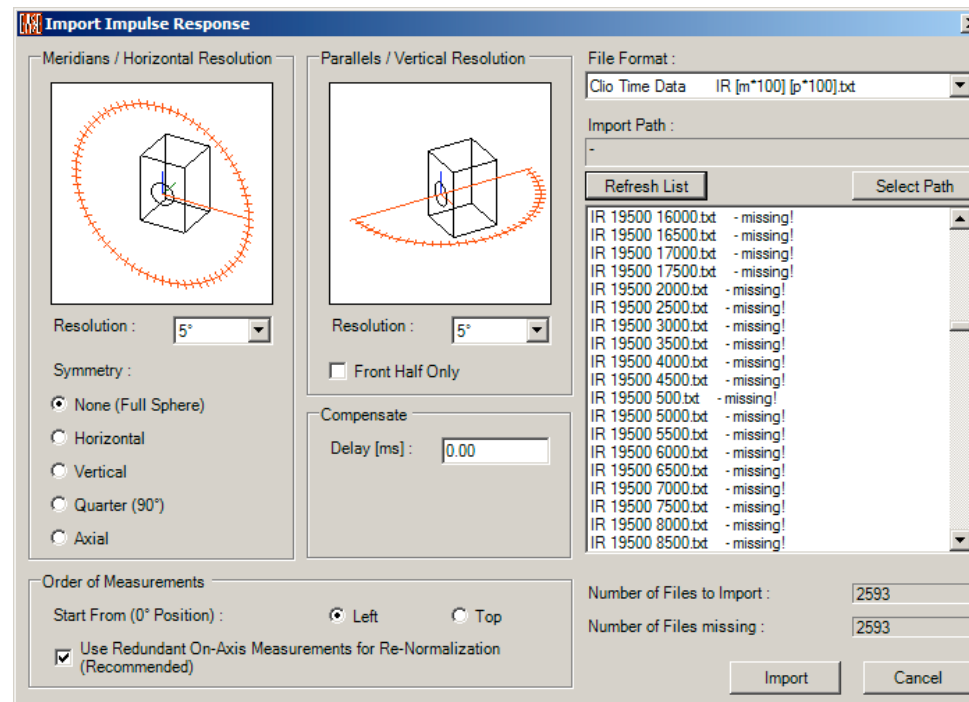
MATLAB (or Scilab)

- Here is an example of a 3D data set measured with CLIO and visualized using MATLAB



Import with EASE SpeakerLab

- EASE SpeakerLab can import CLIO time data in .txt format, the CLIO export routine formats the file with the name requested by the SpeakerLab.



Conclusions

- CLIO + 2 x Outline ET250-3D can automatically measure the loudspeaker 3D polar response
- The setup is very easy to manage, and measurements can be carried out in non-anechoic spaces
- From a single measured data set it is possible to create EASE and CLF models, technical documentation and polar plots

Thank you!

For more info:

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