The Design of VALDEMAR—An Artificial Head for Binaural Recording Purposes

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The design of VALDEMAR - an artificial head for binaural recording purposes

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Abstract **-** An artificial head was designed. The design is based on acoustical measurements on real people. The design method includes a special developed measurement technique separating the pinna from the body and head thus making it possible to adjust the shape of the body, head and pinna separately. This approach has led to a design for which the HRTFs are representative for a typical human subject for all directions. Furthermore the measurements reveals which parts of an HRTF are formed by the body, head and pinna respectively.

0. Introduction.
Artificial heads are widely used within the world of 3D audio. They are supposed to capture an acoustical event for playback later on, preserving spatial information. Also for measurement purposes e.g. noise measurements the artificial heads seem to gain more and more focus.

For whatever purpose used, the very basic idea of the artificial head is to represent the anatomical features of a typical human being. Investigations of human sound localisation performance on binaural recordings done with human and artificial heads has shown disappointing results for a range of artificial heads [1].
Compared to real life listening more localisation errors are seen when artificial head systems are used. The errors includes front/back confusions as well as confusions between sounds coming from up and down directions at the side of the listener.
The larger amount of errors using the dummy head systems seems strange since some of the heads are known to be designed as impressions of real human beings. This is an encouragement to trying out new design methods.

The objective of this work was to design an artificial head that represents the acoustical properties of a typical human being.

1. Method.
The nature of the acoustical properties of a human anatomy concerning the sound that reaches the eardrums is normally described by means of Head Related Transfer Functions (HRTFs). The HRTF is defined as the sound pressure at the eardrum divided by the sound pressure measured at the position of the centre of the head with the head absent [2].
The sound pressure at the eardrum is constituted by the sound being reflected by and scattered around the human anatomy and then reaching the ears. Thus when making an artificial head it seems natural to use HRTFs as a design tool because the characteristics of the different parts of the human external anatomy is reflected in the HRTF. Of course the goal of making a representation of a typical human being could also be reached by making an impression of a person that fulfills the demands including al external anatomical parts. It might though be the case, that not all parts of the anatomy is equally important for the sound reaching the eardrums. For instance it could be argued, that the sound bouncing of the feet probably is minor to influences from other anatomical parts e.g. the shoulders. This rises the question which parts to include in a design and which could be neglected. The final measure of this is the contribution from the specific body parts to the HRTF.
In order to design an artificial head by means of the eardrum measurements it is necessary to be able to identify contributions from different body parts in an HRTF in order to be able to tune the shapes separately. Since the HRTFs contains quite complicated structures arising from different parts of the human anatomy a special procedure was developed in which it is possible to measure the influence of the pinna separate from the head and torso. In this way he

HRTFs were decomposed into two separate parts, the Auriculum (Pinna) Transfer Function (ATF) and the Head and Torso Transfer Function (HTTF). This gives the possibility of designing the ear separate from the head and body. Which also leaves space for the possibility that the shape of each body part could be dominated by the anatomy of different people.

Measuring the head and body.

The HTTF is defined as the sound pressure on the surface of the head with no pinna at the point of the ear canal opening divided by the sound pressure at the centre of the head with the head absent.

The HTTFs were measured with a microphone positioned on the side of the head on the interaural axis with the pinna pressed flat to the head by an elastic bandage. See figure 1.

Figure 1:Figure 1: HTTF headband with microphone mounted at the ear canal position

In order to close off the cavity behind the microphone position the bandage was equipped with a piece of leather on the back side covering the ear.

A picture of the complete measurement setup is shown in figure 2, and a more thorough description of the loudspeaker setup and the placing of the test subjects can be found in [3].

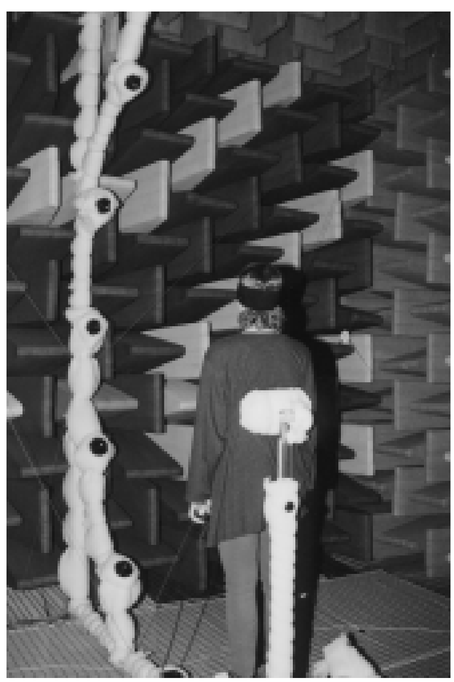

Figure 2:Figure 2: The HTTF measurement setup in the anechoic room.

HTTFs were measured in an anehoic room with a directional resolution of 45 degrees covering a sphere around the subjects.

An example of a measured HTTF is shown in figure 3. The general structure seen for all ipsilateral directions is a small amplification going towards 6 dB on the side of the head overlayed with a comb filter structure. The comb filters is most easily recognised on the linear frequency plot. Furthermore the figures show a dip around 12 kHz. This is because of a short delayed reflection from the surface behind the microphone.

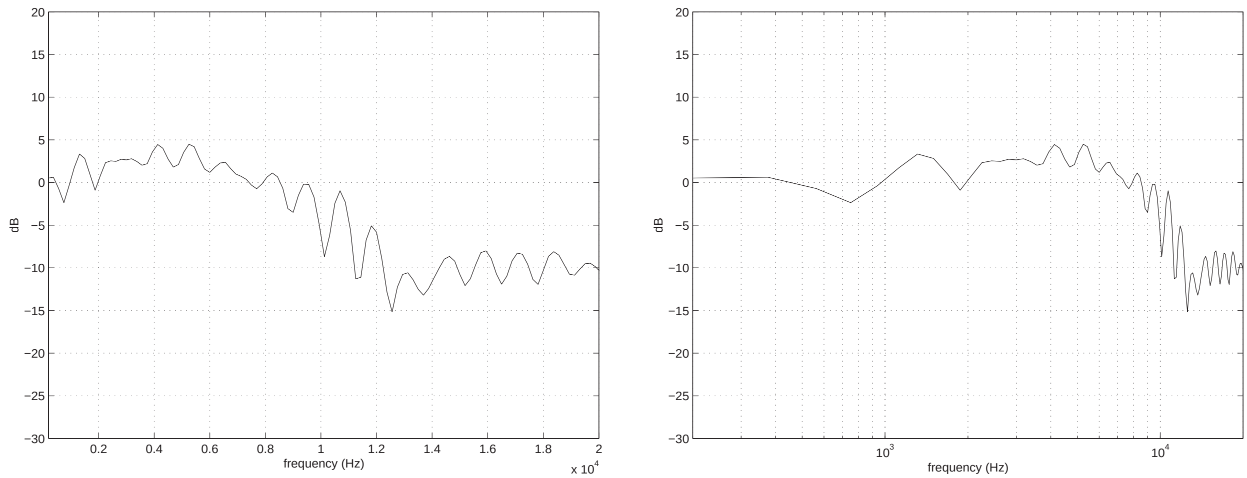

Figure 3:Figure 3: Example of an HTTF (frontal direction elevated 45 degrees). Linear frequency axis to the left, logarithmic to the right.

Measuring the ear.
Measurements on the pinna (ATFs) was done in a baffle setup where the ear was put through a centred hole in the baffle thus excluding the head and torso. A small microphone (Sennheiser KE 4-211-2) was positioned in the ear canal to capture the measurements.

The ATF is defined as the sound pressure at the blocked entrance to the ear canal divided by a reference measurement at the axis of the ear canal on the surface of the baffle.

The idea for the setup was inspired by Shaw [4,5] that measured characteristics of the human pinna by means of a small baffle mounted on the head. The baffle had a hole through which the ear could be put, thus separating the ear from the head.

The baffle is a 160 by 160 cm plate with a circular cutout with a diameter of 65mm in the centre. Through this hole test subjects can put their ear or a model ear can be mounted thus allowing the ears to be measured separate from the rest of the human anatomy. On one side of the baffle the test subject was seated, on the other side 25 small loudspeakers (Peerless ½ inch Cone Tweeter type 801771) was mounted allowing measurements from 25 different directions. The directions are indicated in figure 4. Transfer functions was measured using an MLSSA system (Maximum length sequence system analyser).

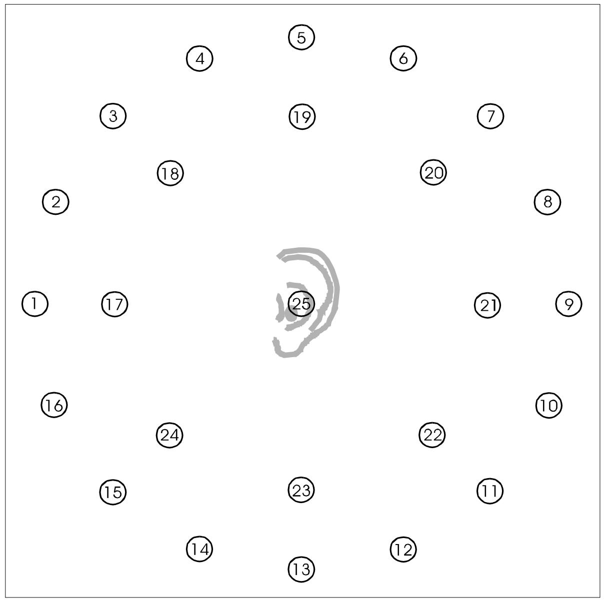

Figure 4:Figure 4: The positions of the loudspeakers on the baffle setup.

The loudspeakers numbered 1 through 16 is placed on the baffle surface. Number 17 to 24 is on a 45 degree angle to the baffle and loudspeaker number 25 is positioned on the ear canal axis perpendicular to the baffle surface. All loudspeaker are at a distance of 67 cm from the centre of the baffle and pointing towards the centre i.e. the position of the ear canal opening. A picture of the baffle, the loudspeakers and the ear in the centre is shown in figure 5.

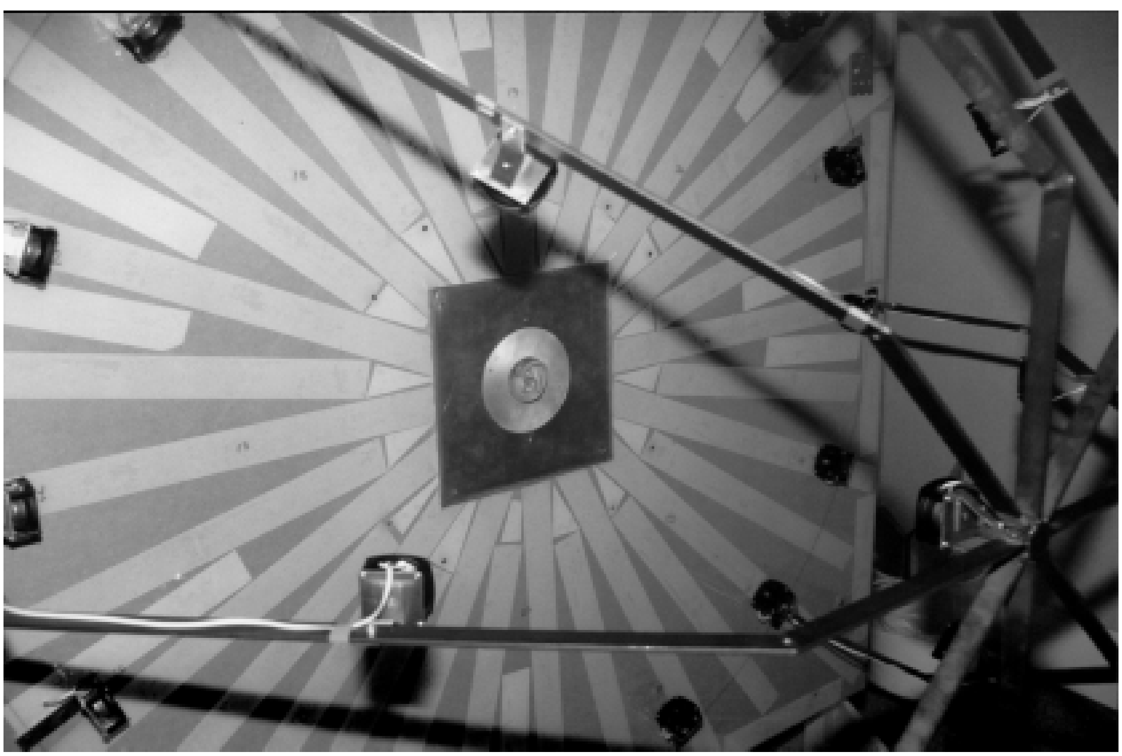

Figure 5:Figure 5: The baffle setup. The ear is seen sticking through the baffle in the centre. Acoustical absorption material is unwrapped from the loudspeaker support arcs in order to get a better view.

More information about the ATF setup can be found in [6]

In order to align the ears in the measurement setup an alignment line was defined for the ear going through the edge of the hard parts of the ear just in front of lobulus, tragus and helix see figure 6 .

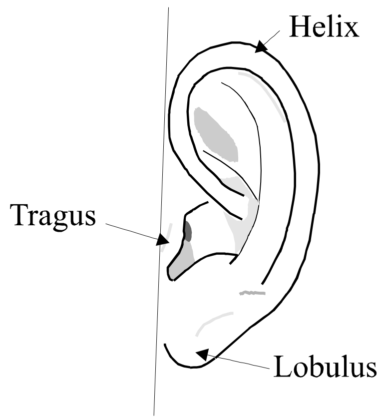

Figure 6:Figure 6: Alignment line of the ear.

This line was aligned with a reference line on the baffle. Repeatability measurements showed that this procedure lead to a deviation of less than ±2 dB up to 20kHz when removing a subject from the setup and redoing both microphone placement and positioning of the ear in the baffle. The subject was held in a stable position by an elastic band going from the baffle around the head.

The left ears of 40 people were measured from 25 directions. An example of an ATF is shown in figure 7.

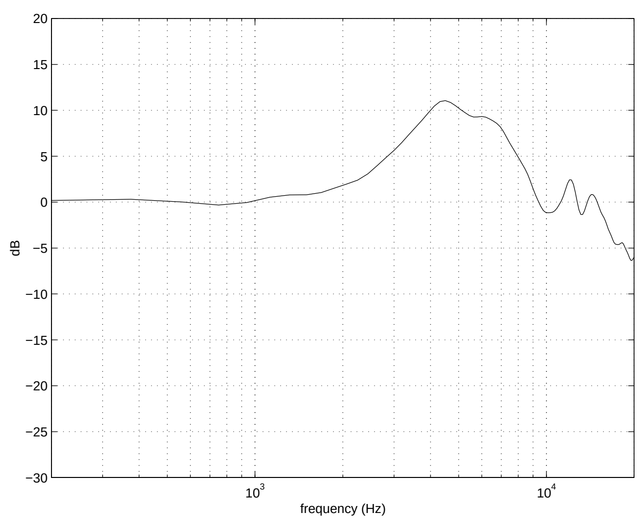

Figure 7:Figure 7: An ATF for one subjects left ear, loudspeaker no. 3.

2. Design procedure.
A group of 40 people was measured, and the artificial head was designed in an iterative process minimising the error between the measurements on the human subjects and the artificial head for all measured directions.

The body and head.
The design of the body and head was done in four basic steps. First a skeleton was made out of two wooden boxes for

the head and torso, and an adjustable iron skeleton neck. On this skeleton a rough shape of a human head and torso was modelled, the dimensions being those of an average human being. The measures was found from antropometrical literature, for instance [11,12,13], and own measurements on a group of people. The second step was to adjust the neck in order to get the right distance and relative position between the ear canal and the shoulders. This was done using the HTTFs as a reference focussing on the timing of the shoulder reflection from different directions.

When the neck was adjusted the third step was to do the precise shaping of the head. This was accomplished using data in the frequency domain (HTTFs) focussing mainly on measurements from the contralateral (shadow) side of the head. When the sound reaches the head it diffracts around the head reaching the measurement point on the opposite side. This is seen in time as different wavefronts arriving at different times. In the frequency domain this constitutes a structure of one or several comb filters. By adjusting the size and shape of the head this comb filter structure was tuned to fit a typical person.
The fourth step in the design was to do the final shaping of the body and especially the shoulders. Again the HTTFs was used as a tool for this. The shape of the shoulders could be tuned by looking at the frequency and depth of the first dip in the comb filter arising from the shoulder reflection.

The ear.
In order to parameterize the design, the ear was designed using the ATF measurements of the 40 people as a reference.

When considering the design goal a variety of strategies are relevant. The one that might occur as the obvious is to do a mean of for instance the amplitude response, and aiming for that as a goal. However, averaging of an amplitude response tends to ‘smear out’ the high frequency dips thus destroying a possible localisation cue [7]. Therefore it was chosen rather to make an attempt to parameterize the frequency response into peaks and dips with corresponding centre frequencies and bandwidth, thus focussing on typical structures of the frequency response.

For the design of the ear two approaches were made. The first approach was to do the shaping from scratch and then iteratively reshape the ear until measurements from all 25 directions fitted the design goal. This method turned out to be to complicated to perform by hand, since the different physical structures in the pinna interact strongly i.e. a simple connection between the frequency response features and the different physical structures couldn’t be found. Therefore a second approach was made, in which a typical ear was chosen from the set of 40. An impression of the ear was made, and slightly altered to fit the base in the dummy head as well as fitting with the microphone.

Because the dummy head is designed for binaural recording purposes only, no considerations has been done about making an earcanal. A microphone position at the entrance to the blocked ear canal is chosen as all directional information is included in the sound at that position [8,9].

For the choice of material measurements have shown no difference between rubber materials and hard burned modelling clay.

Assembling the dummy head
The final step in the design was to assemble the ears and the body. This step involves tuning one last parameter, the rotation of the ear around the ear canal axis. This was done on basis of antropometric data revealing an average tilt of the length axis of the ear of approximately 9 degrees.

For further details about the design, refer to [10].

3. Results.
The measurement and design process led to a prototype model of an artificial head build in wood and plaster. The artificial head can be seen in figure 8 together with a new more handy model made in plastic.

Figure 8:Figure 8: Left: The final prototype made in wood and plaster. Right: A new model made in plastic.

The final plastic version of the head are fitted with rubber ears and ½" microphone capsules from G.R.A.S. Sound & Vibration, and microphone preamplifiers from Danish Pro Audio.

The design was evaluated measuring the HRTFs of the prototype and comparing to HRTFs of a test group of 40 people different from the group used for the design. The prototype was seen to be positioned well inside the group of HRTFs. For further detail about the comparison see [10].

A psycho acoustical evaluation of the artificial head has been done showing better results in a localisation test than for other previous designs, the results of the test can be found in [14].

The artificial head was named VALDEMAR in honour of Valdemar Poulsen the Danish inventor of the tape recording principle.

4. Conclusion.

An artificial head **-** VALDEMAR **-** has been build and testet. The design is based on a strategy of measuring acoustical characteristics of different parts of the human anatomy separately. These measurements made it possible to make the design of the body, head and ears separate tasks.

5. Acknowledgements.

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