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AUDIO ENGINEERING SOCIETY

# *Effects of the Background Noise on the Perceived Quality of Car Audio Systems*

Fabio Bozzoli, Enrico Armelloni, Emanuele Ugolotti,

Angelo Farina

**farina@unipr.it**
**University of Parma, ITALY**

ASK Automotive Industries Group
zendar Telecommunication Systems
SIPE ELECTROACOUSTICS
Automotive Sound & Communication

# Goals

- Assess the quality of an automotive sound system by subjective listening test
- Analyze the effect of the background noise on the performances of the sound system
- Avoid the problems encountered when attempting to collect questionnaires from subjects during on-the-road tests

# Proposed solution :

- The sound is recorded inside the car running on the road, by means of sophisticated microphonic probes capable of capturing the whole spatial and timbric information.
- Listening tests inside a special listening room, fitted with a multichannel, audiophile-quality sound reproduction system

# Methods

- Two kinds of recordings are employed:
  BINAURAL (dummy head and torso)
  B-FORMAT (Soundfield ST-250 microphone)
- 6 channels are recorded for each seat position
- ~~The binaural recording is actually NOT synchronous with the B-format recording (2 separate DAT employed)~~

In the future, this problem will be circumvented thanks to a single multichannel A/D interface linked to a notebook by means of a Firewire cable

# Binaural recordings

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Bruel & Kjaer type 4100
Head and Torso Simulator


advantages:

- Battery operated
- Microphones without ear ducts
- No analog equalization
- Easily calibrated

disadvantages:

- Expensive
- The support frame does not fits in all seats

# B-Format recordings

Soundfield ST-250


advantages:

- Battery operated
- Simple electronics
- No gain knobs
- Can be calibrated, but not so easily….

disadvantages:

- Expensive
- Phase mismatch problems in highly reactive fields

# Binaural reproduction system

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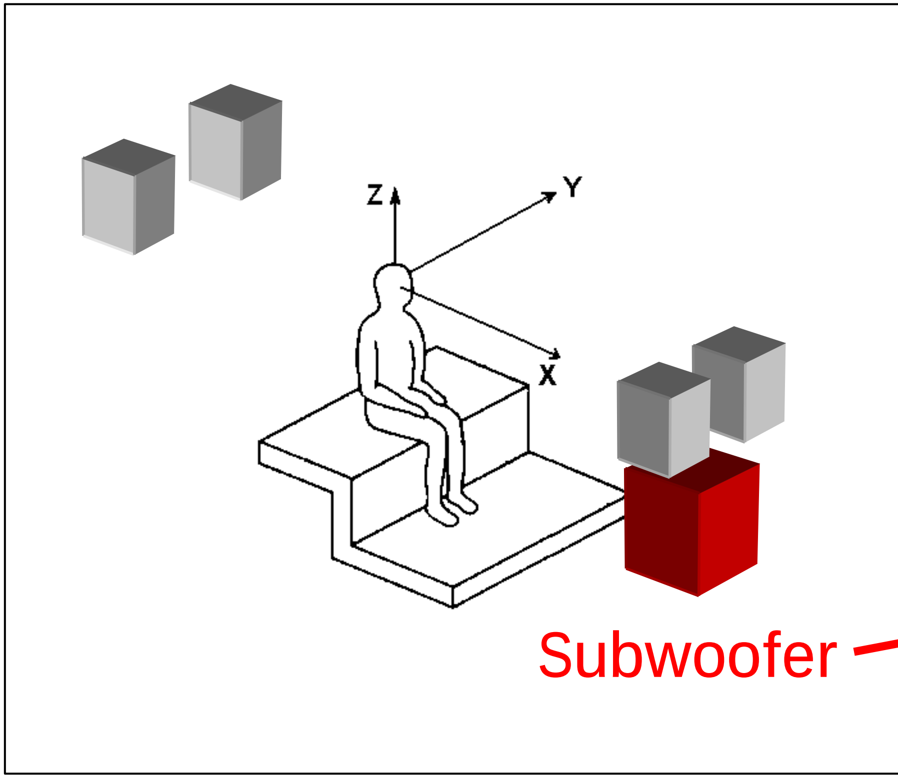
## Dual Stereo Dipole




advantages:

- Complete periphony
- Robust to head rotation
- The cross-talk cancelling filters also compensate for transducer's response

disadvantages:

- ~~Cannot manage very low frequencies~~
- Colouration outside the sweet spot

# Dual-Stereo-Dipole vs. PanAmbio

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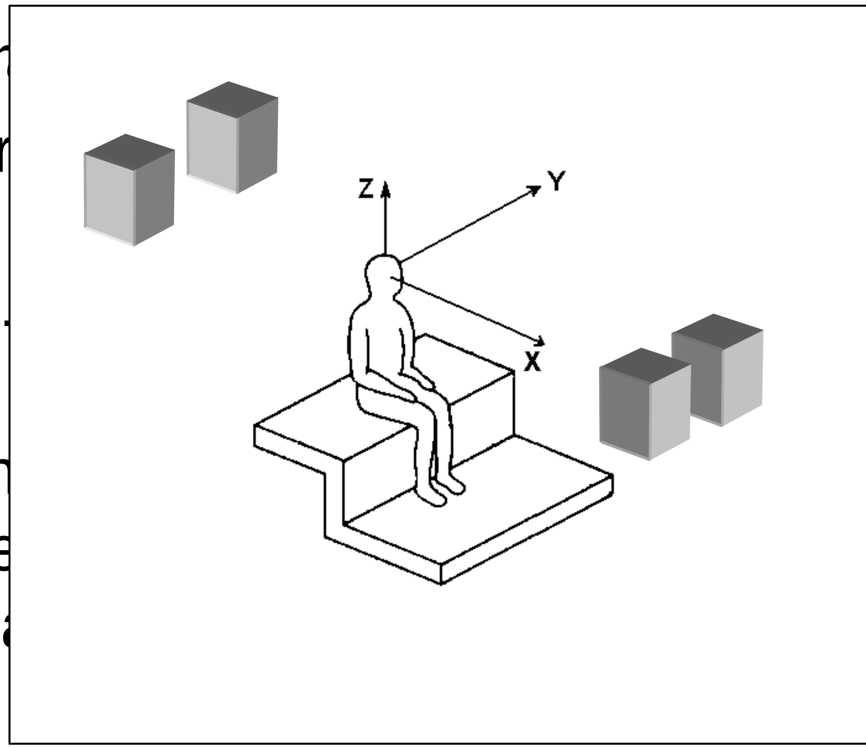
Both systems appear to be similar, because in both of them the listener is between two Stereo Dipole pairs of loudspeakers, driven with cross-talk cancelling filters.

*Dual Ster*

- 1 Binaural micr (with pinnae)
- Different cross- filters for front Dipoles, design actual measure the dummy hea listening room




*rambiophonics*

microphones
pinnae), with a baffle
n

, generic cross-talk
filters are employed
the front and rear
poles

# Dual Stereo Dipole

Frontal

Rear

Quested 2108 monitors

Quested F11P monitors

# DSP board for cross-talk cancellation

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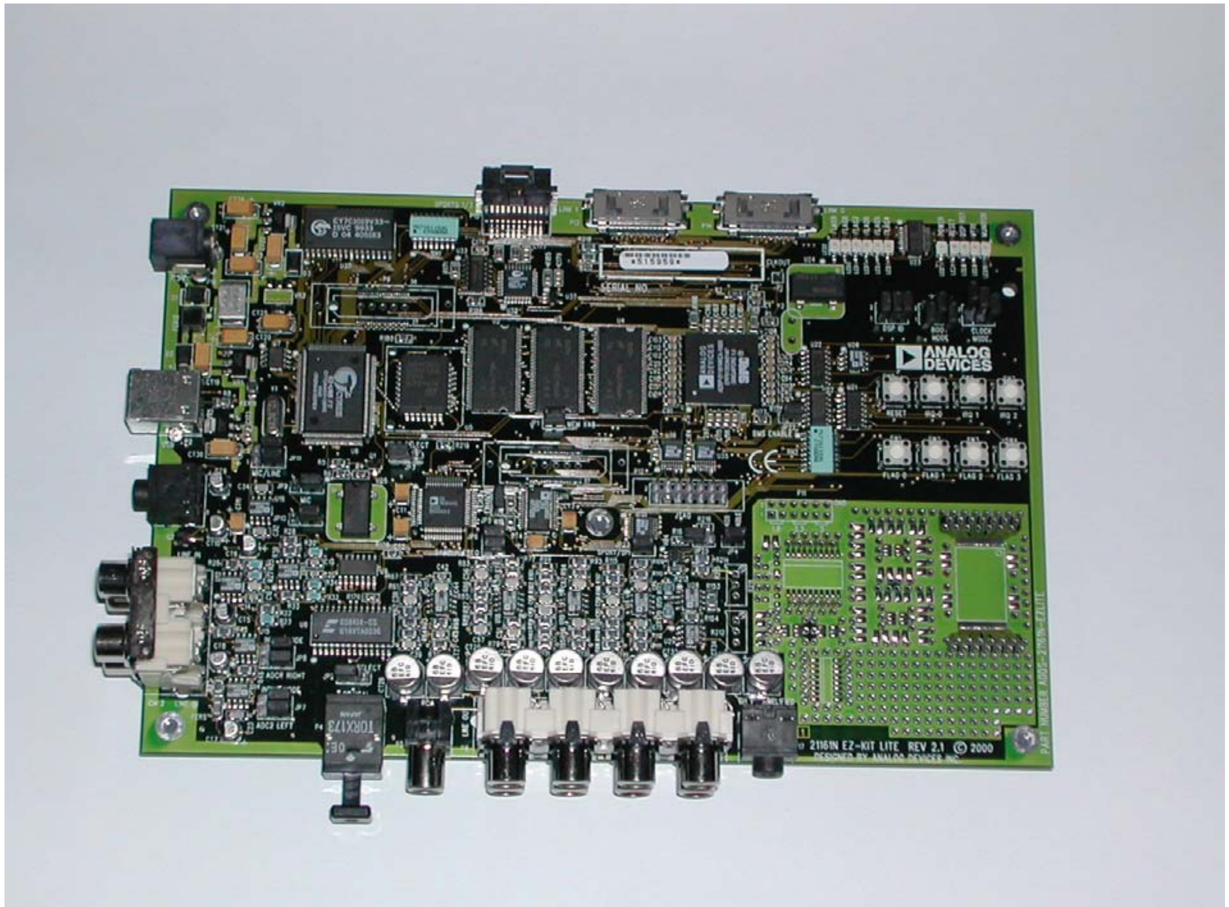
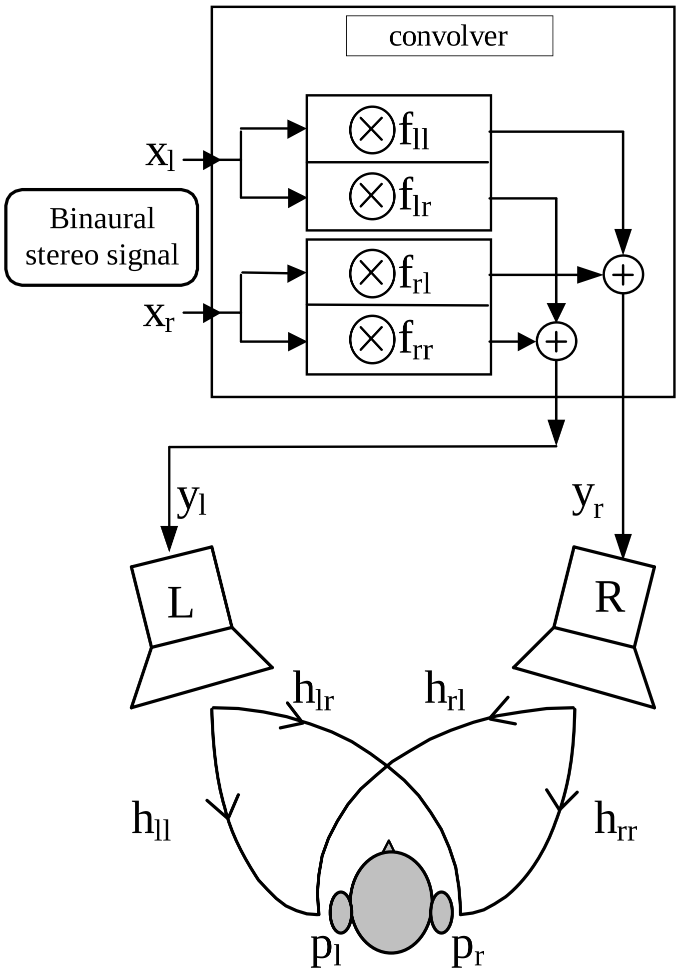
## *Analog Devices EZ-Kit board (Sharc 21161N)*



# Algorithm for cross-talk cancellation




- The DSP board is simply used as a 2x2 convolver (FIR or WFIR filters)
- Thanks to the SIMD capabilities of the SHARC21161N processor, a single board can simultaneously perform the same processing (with different filtering coefficients) for the second Stereo Dipole
- The sets of filtering coefficients are computed by means of a modified version of the method developed by Nelson, Hamada and Kirkeby

# Computation of the inverse filters

$$\begin{cases} f_{ll} = (h_{rr}) \otimes InvDen \\ f_{lr} = (-h_{lr}) \otimes InvDen \\ f_{rl} = (-h_{rl}) \otimes InvDen \\ f_{rr} = (h_{ll}) \otimes InvDen \\ InvDen = InvFilter(h_{ll} \otimes h_{rr} - h_{lr} \otimes h_{rl}) \end{cases}$$

$$C(\omega) = FFT(h_{ll}) \cdot FFT(h_{rr}) - FFT(h_{lr}) \cdot FFT(h_{rl})$$

$$InvDen(\omega) = \frac{Conj[C(\omega)]}{Conj[C(\omega)] \cdot C(\omega) + \varepsilon(\omega)}$$

- The four inverse filters f are computed in the frequency domain, based on the measured head-related transfer functions h.
- The denominator, common to all the 4 filters, is a mixed-phase function
- Its inversion is possible introducing a small regularisation parameter ε
- Making ε variable with frequency, the inverse filters make optimal use of the limited number of taps available

# Example of inverse filters

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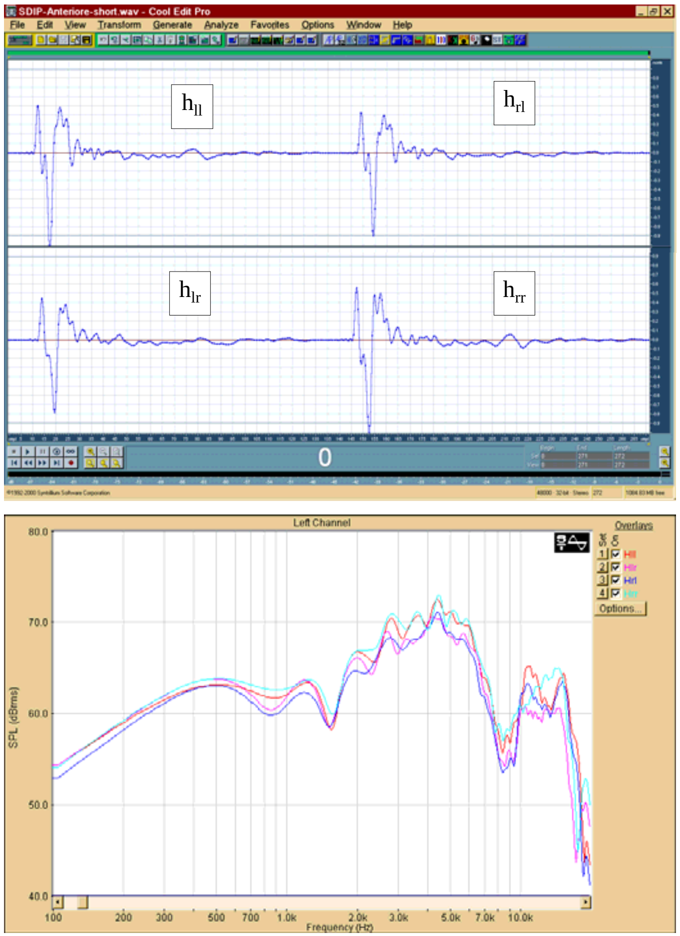
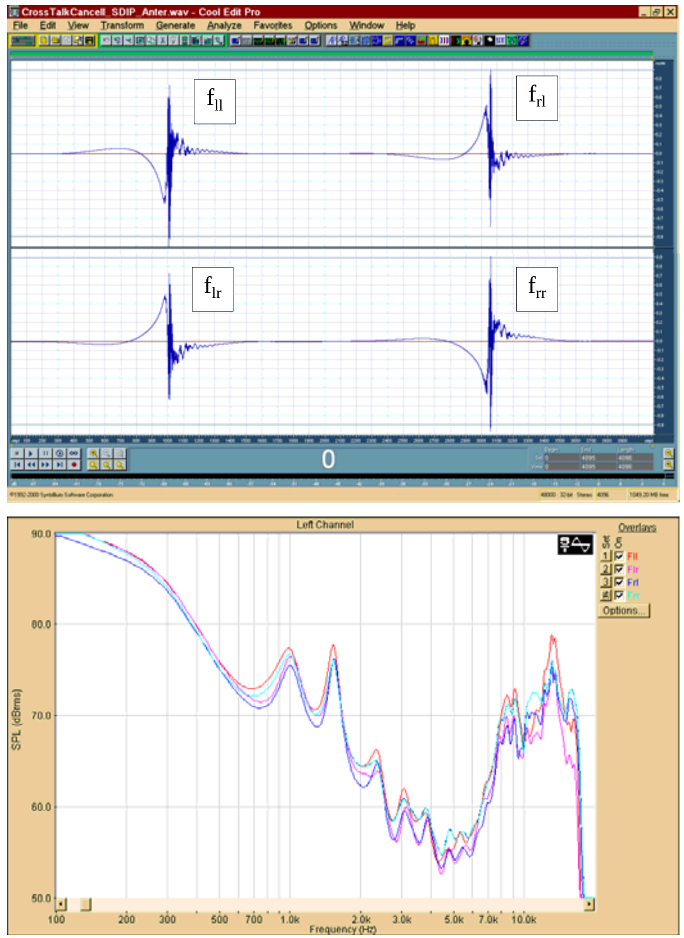
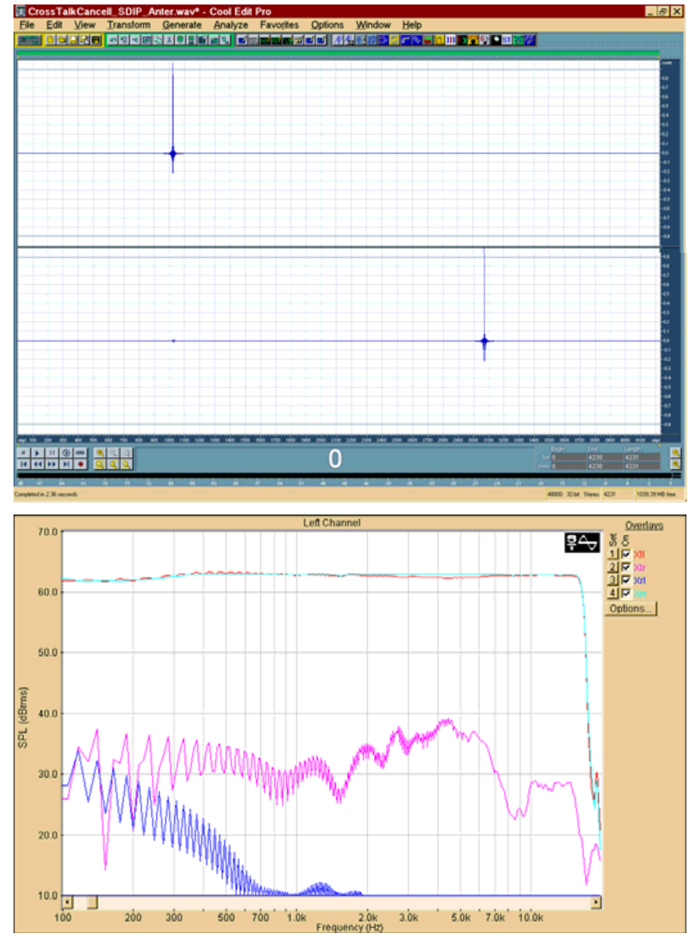



Measured transfer functions



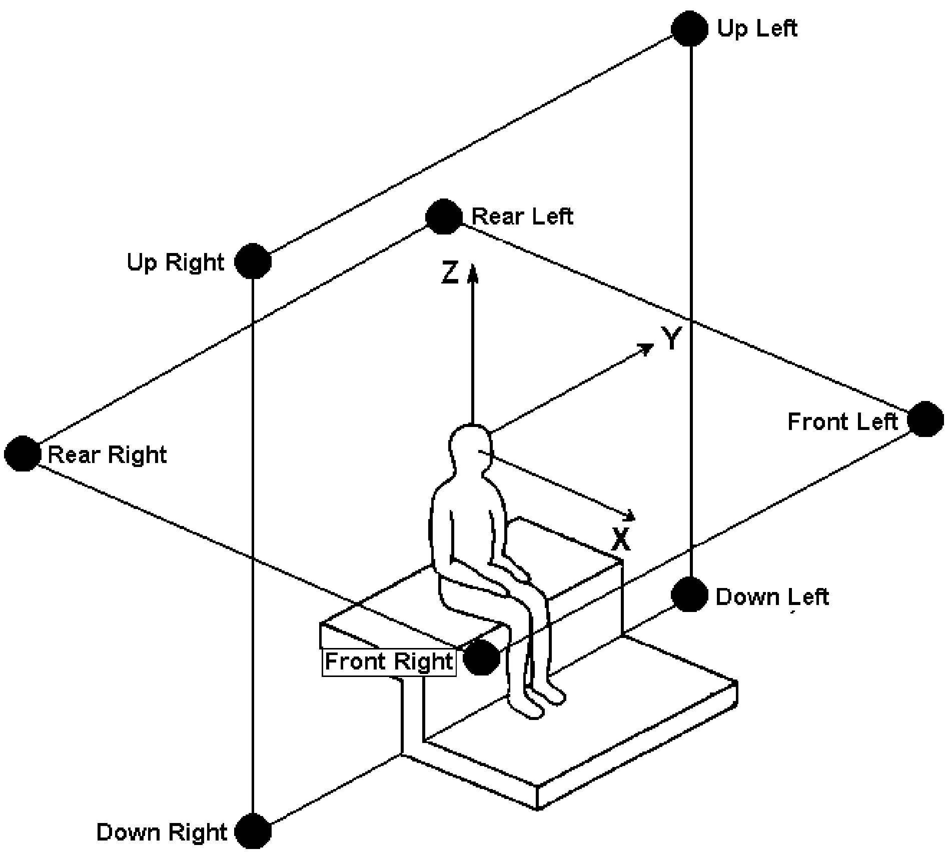

Inverse filters




Effect of the filters

# B-Format reproduction system

Bi-square Ambisonics array



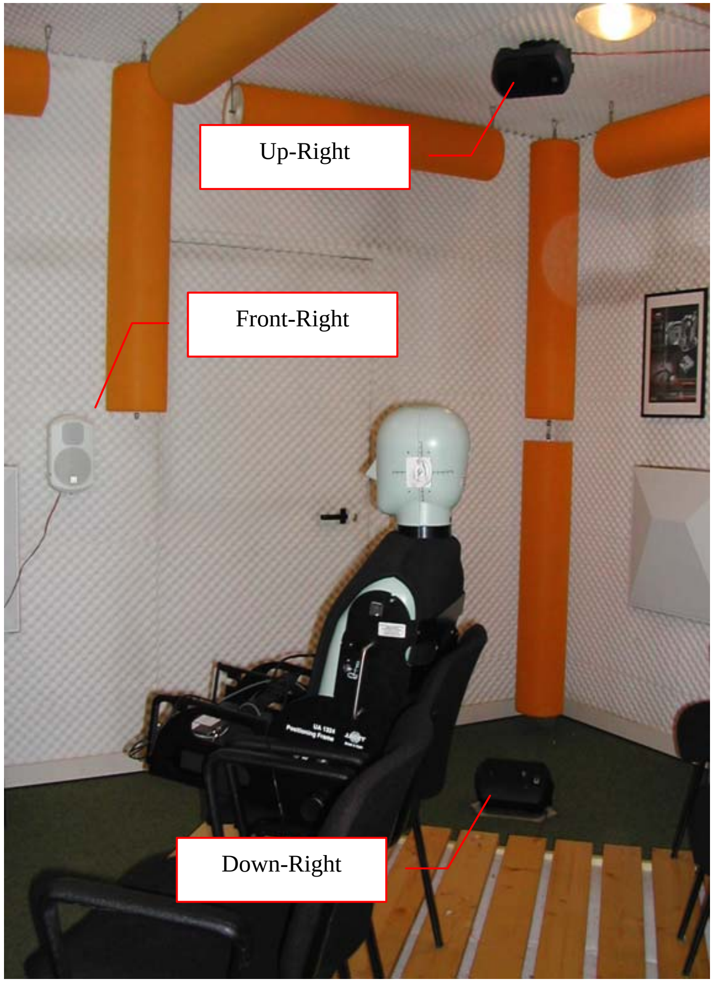

advantages:

- Three-dimensional
- Good lateral perception
- Good bass response
- Wide sweet spot, no colouring outside it

disadvantages:

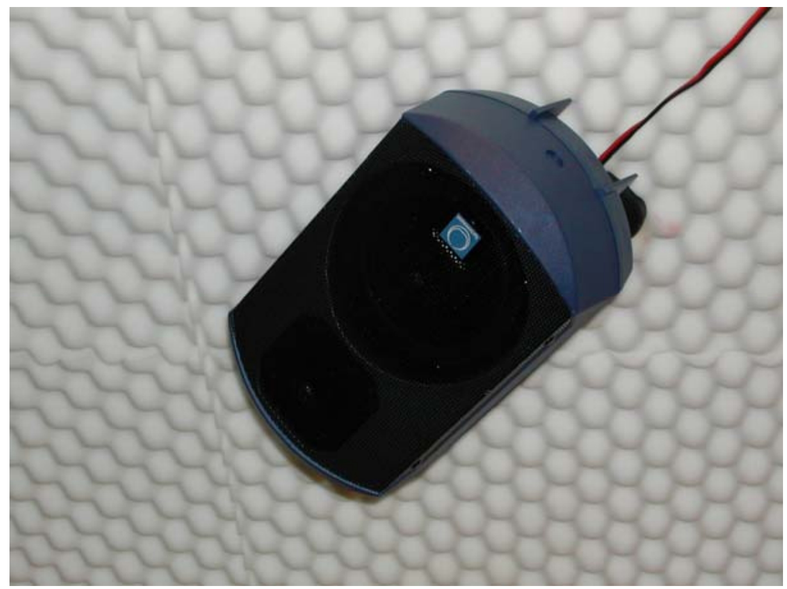
- Not isotropic
- Requires advanced decoding (Y treated differently from X,Z)

# Bi-square Ambisonics array




8 Turbosound Impact 50 loudspeakers:

- Light, easily fixed and oriented
- Good frequency response
- Very little distortion



# DSP system for Ambisonics decoding

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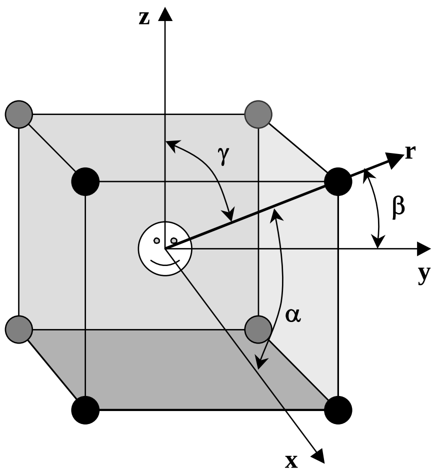
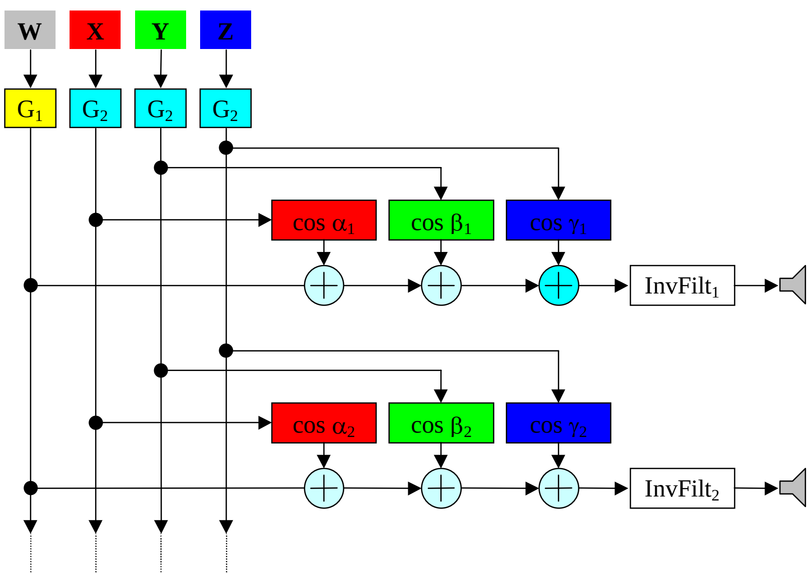
*BSS Soundweb 9088-II (8 ins, 8 outs)*


*SID Futureclient fanless PC (Pentium-III 1 GHz)*

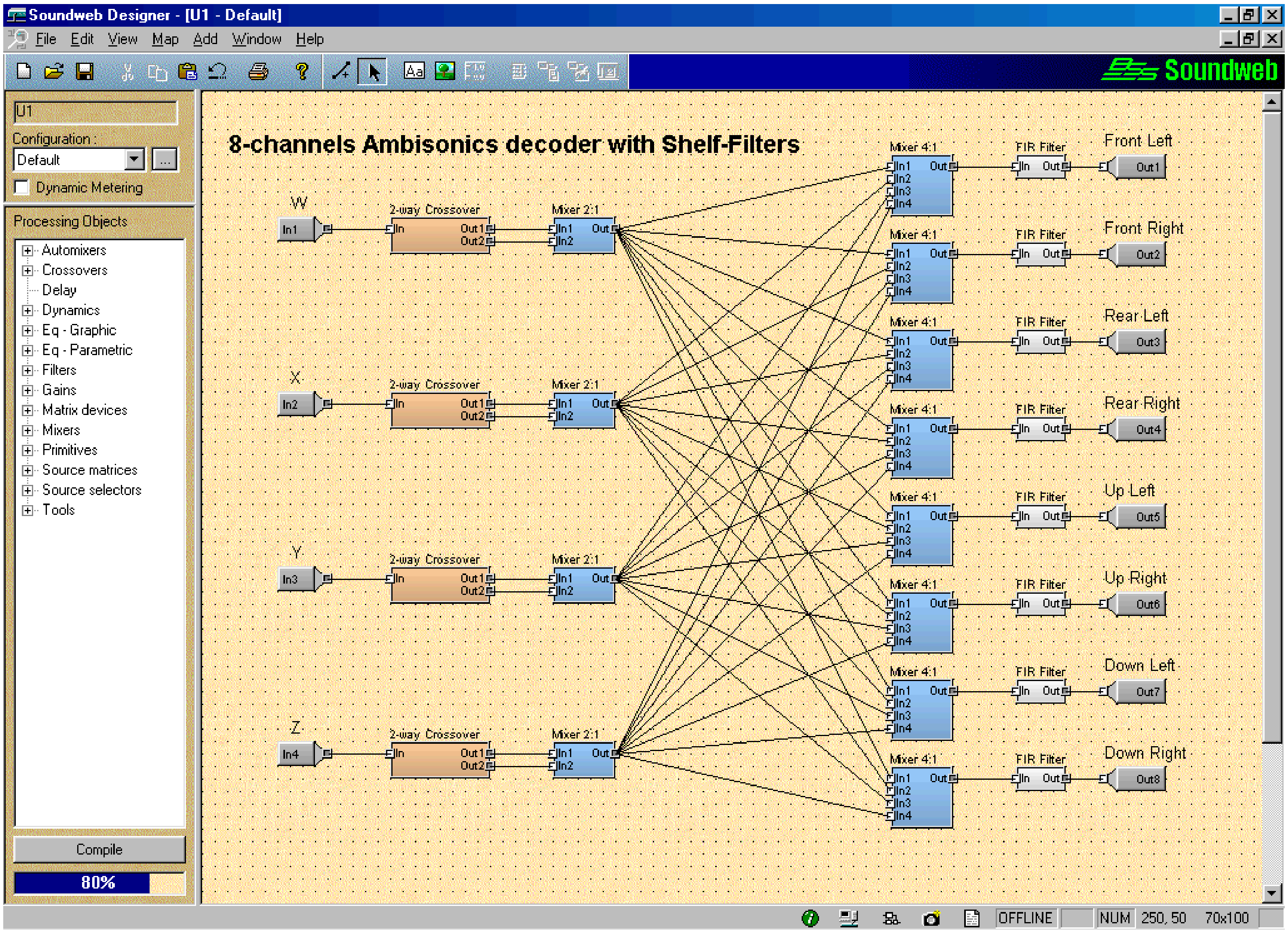
# Algorithm for Ambisonics decoding



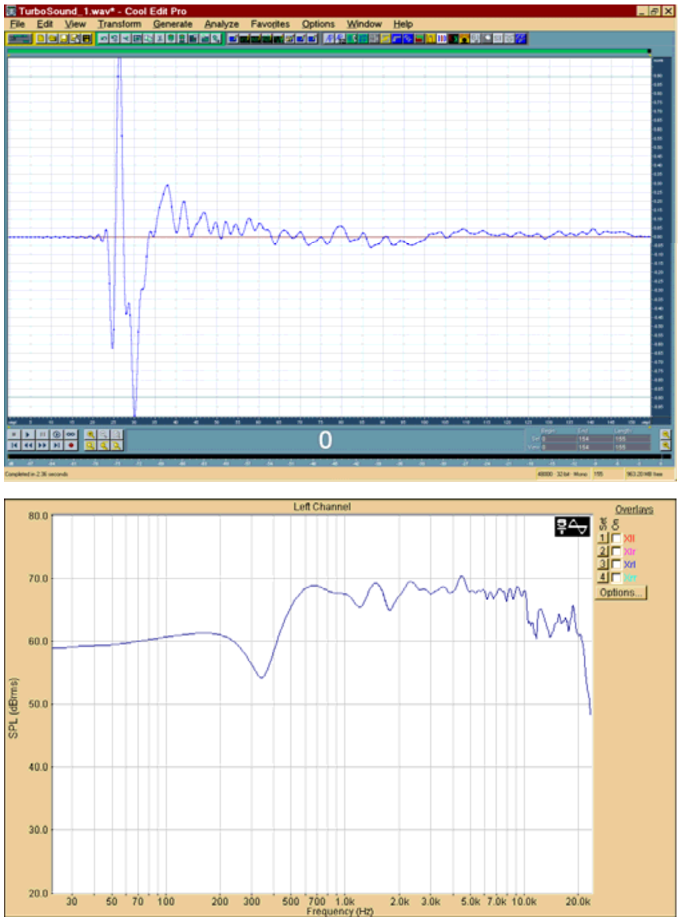




- Each speaker feed is basically simply a linear combination of the 4 inputs signals (WXYZ)
- The gains depend on the position of each particular loudspeakers
- A speaker-dependent FIR filter is added, for compensating its individual response curve, and providing some high-frequency phase randomization

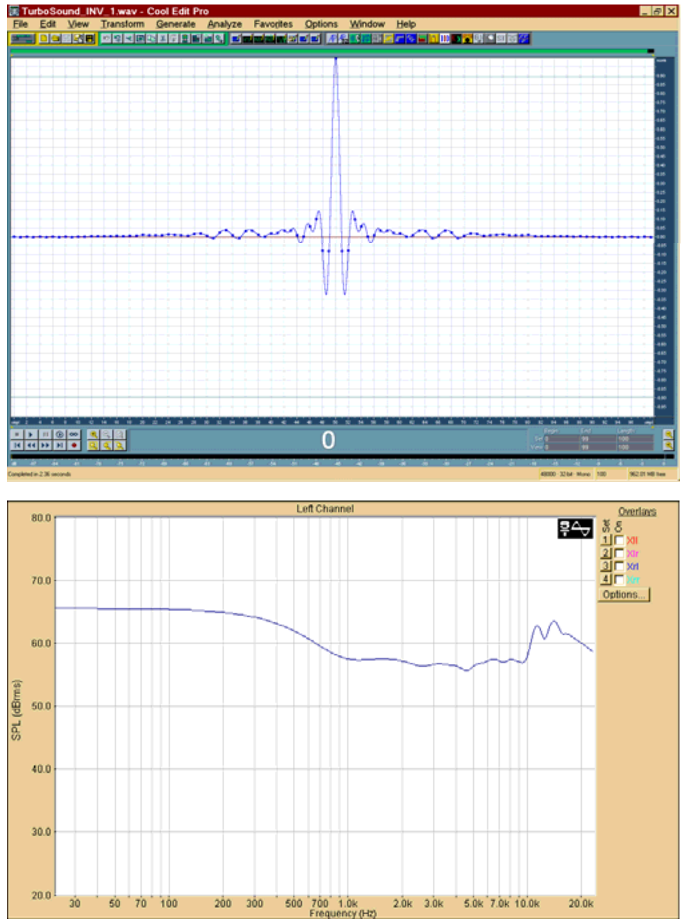
# Programming the decoder onto the SoundWeb



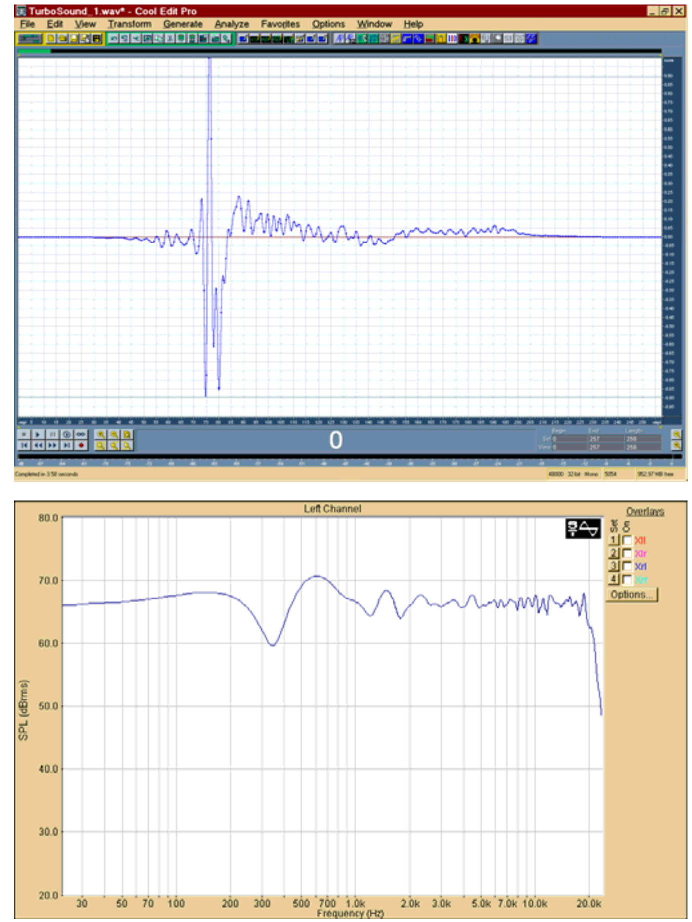
# Effect of the FIR equalization of each loudspeaker




Measured transfer function of Front-Left loudspeaker

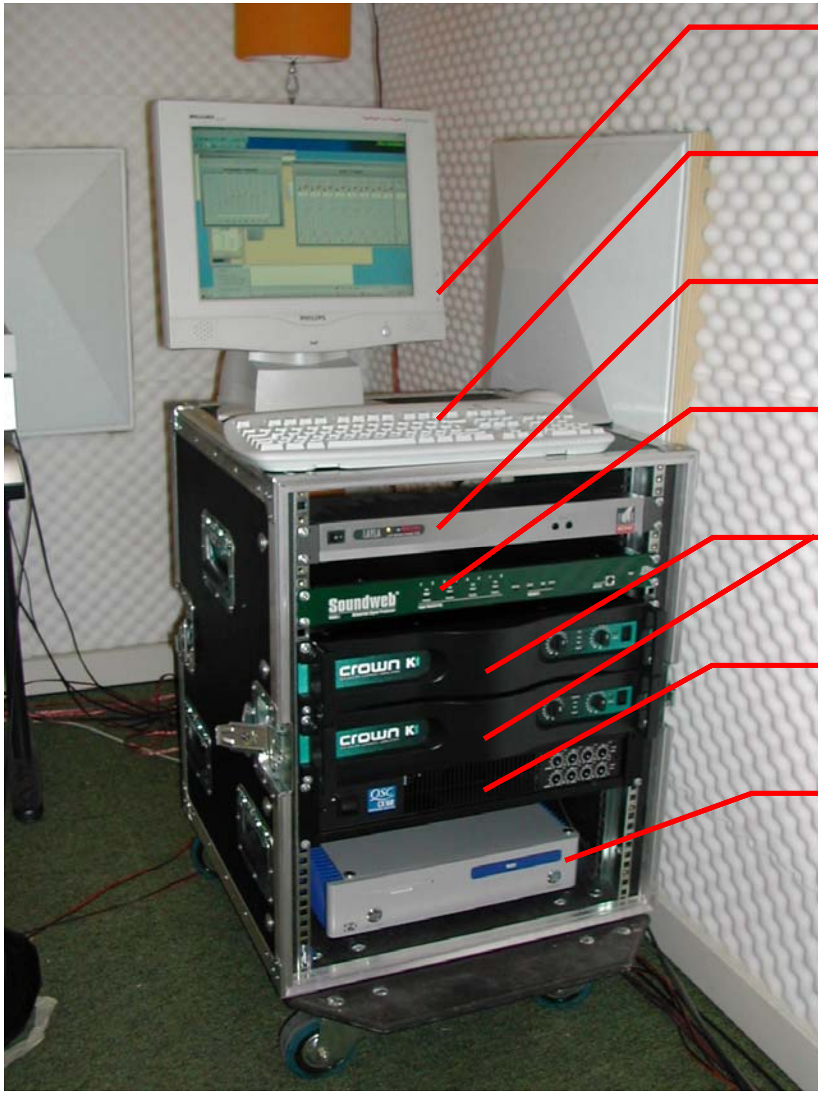



Minimum-phase inverse filter (100 taps)




Effect of the filter

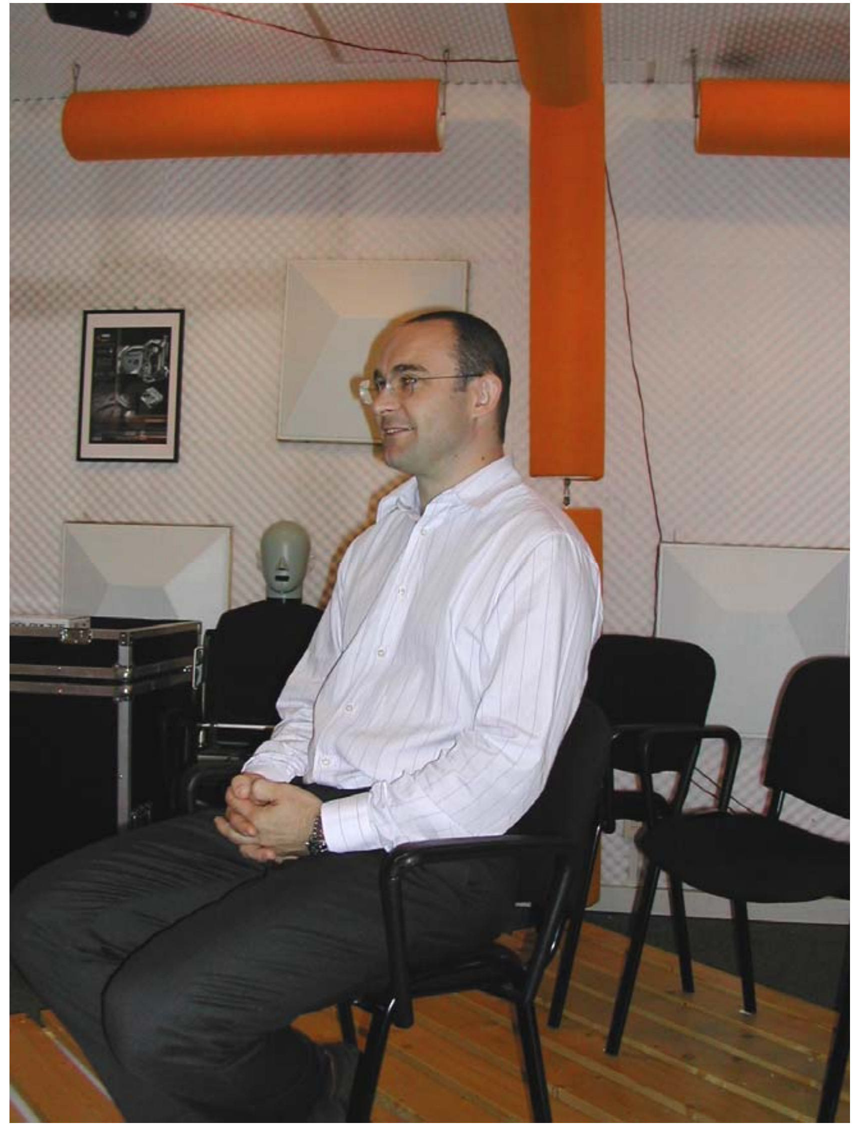
# Complete system setup




- Philips 15” Brilliance LCD display
- Logitech wireless keyboard & mouse
- Echo Layla Soundboard (8 ins, 10 outs)
- BSS Soundweb digital processor
- 2 Crown K1 amplifiers
- QSC CX168 8-channels amplifier
- Signum Data Futureclient fanless PC

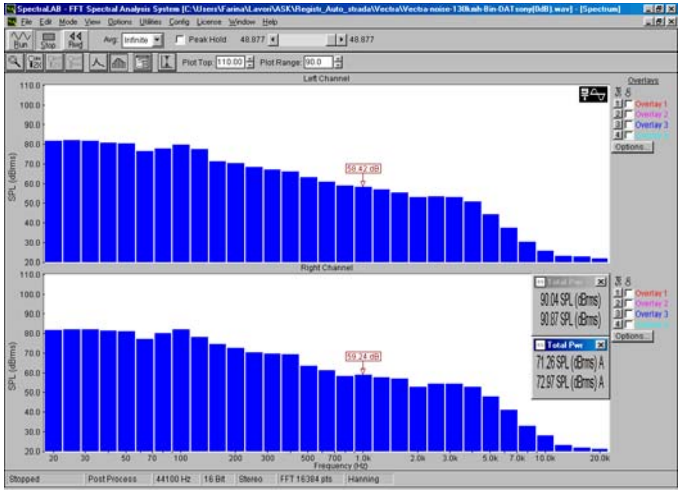
# ASK Listening room

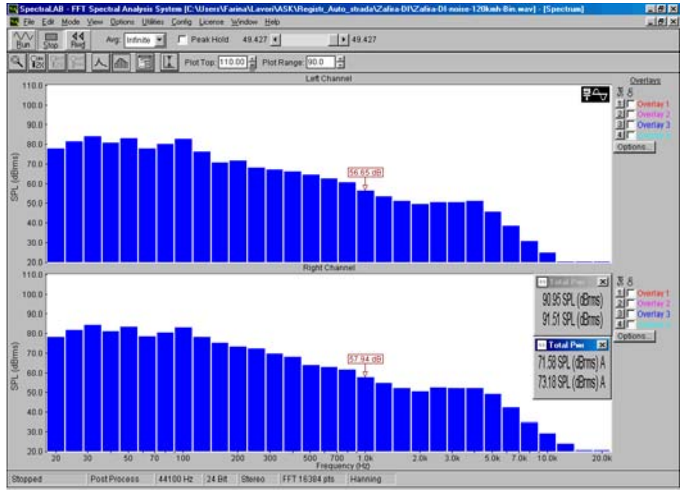
Subwoofer: Audio Pro
B1-20

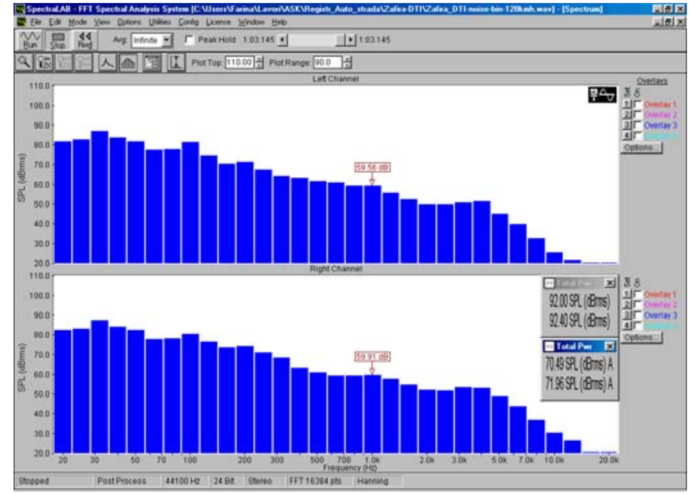


The room is completely treated for high absorption at all frequencies

# Experimental results







- Background noise recordings on three very similar cars:
  - Opel Vectra 2.0 DTI (130 km/h)
  - Opel Zafira 2.0 DI (120 km/h)
  - Opel Zafira 2.0 DTI (120 km/h)

# Software for automatic collection of questionnaires

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4 music pieces superposed over the background noise

Original sound system on all the three cars

Istantaneous switching between the three cars A, B, C

# Results

- The first results coming from the listening tests show that some light difference between the three cars can be systematically perceived (some subjects reliably identify each of the three cars, also after random shuffling the sound samples);
- Nevertheless, an ANOVA performed over the subjective responses, shows no significant difference among the three cars;
- The subjects employed for the tests revealed to be unsatisfactorily trained to listen to background noise;
- The scores obtained by the sound systems (IPA) are much worst in presence of the reproduced background noise than in absence of it;

# IPA scores

| IPA values of cars: | Without noise | With background noise |
|---|---|---|
| Vectra 2.0 DTI | 6.7 | 5.1 |
| Zafira 2.0 DI | 6.2 | 5.0 |
| Zafira 2.0 DTI | 6.4 | 5.1 |

Note: the IPA value is a dynamically-weighted average of the score to 6 of the questions

# Conclusions

- The sound quality evaluation is heavily affected by the presence of car's background noise;
- The questionnaires employed for evaluation in absence of background noise revealed to be partially unsatisfactory for assessing sound systems in presence of background noise;
- Technicians used to evaluate sound systems by listening to music reproduction inside a silent environment need some further training for becoming used to listening with background noise;
- The hybrid reproduction systems revealed to be satisfactory for the reproduction of the sound recorded inside a car compartment, and can be further improved by means of a portable multichannel soundboard;