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AUDIO ENGINEERING SOCIETY

Different approaches for the equalization of automotive sound systems

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Automotive Sound & Communication

Outline

- 4 analog audio-in, 4 analog audio-out system with car-audio quality;
- 4 separate channels digital processing;
- Comparison between different equalization algorithms;
- Hardware implementation on a 16 bit fixed-point DSP platform;
- Filter software synthesis with a dedicated Java desktop; application: DIGItools;
- Software implementation of different equalization algorithms;
- Experimental results;

Hardware platform adopted

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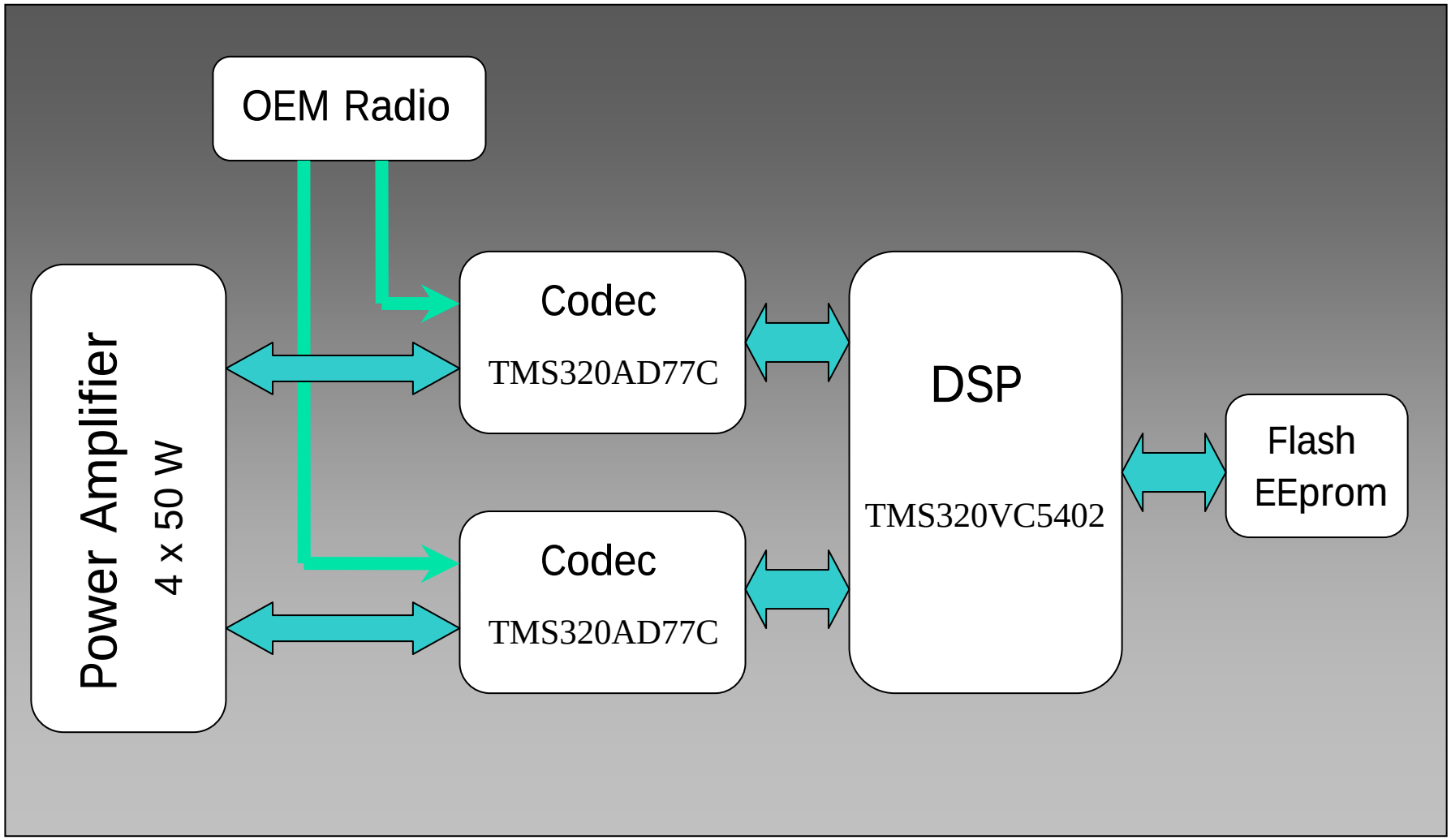
- separate digital processing of 4 audio channel
- 12 V supply voltage
- Bandwidth 20-20000 Hz, Sampling rate 48kHz,
- A/D conversion resolution 24 bit
- 100 dB Signal-to-Noise Ratio, Low distortion
- THD < 0.01%
- DSP: TMS320VC5402
- 400 MAC/sample x channel
- CODEC: TMS320AD77C, 24bit @48kHz

Hardware platform adopted



DSP Algorithms for automotive sound systems

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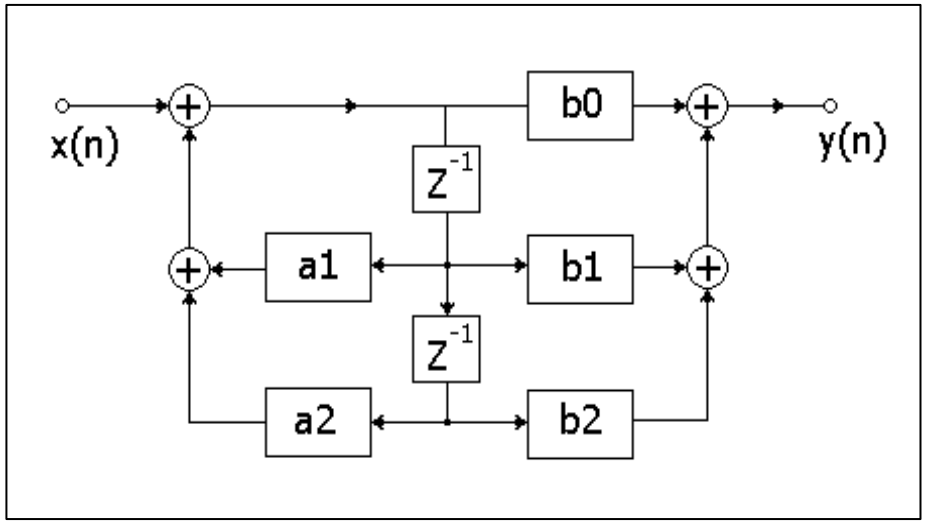
Single bi-quad IIR 2nd order filter

direct form II



$$H(z) = \frac{\sum_{k=0}^{k=2} b_k z^{-k}}{1 - \sum_{k=0}^{k=1} a_k z^{-k}}$$

IIR Filters:

advantages:

- Equivalent to analog filters
- Low power calculation needed

disadvantages:

- Not always stable
- Not linear phase

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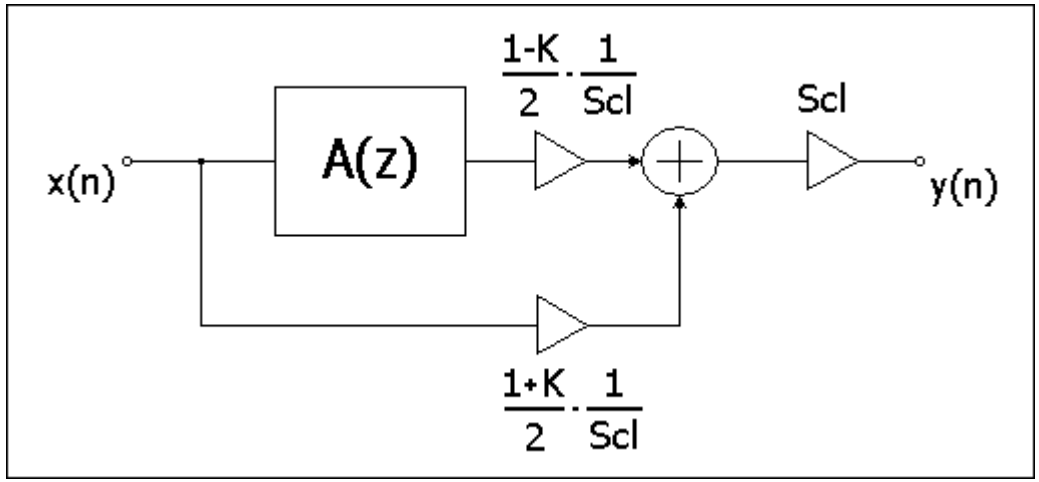
IIR filter structure



- A(z) = All-pass filter
- K = Gain
- fc and Q inside A(z)

Advantanges:

- Average energy at each node is automatically normalized to 1

Disadvantages:

- Higher cost in term of necessary power calculation

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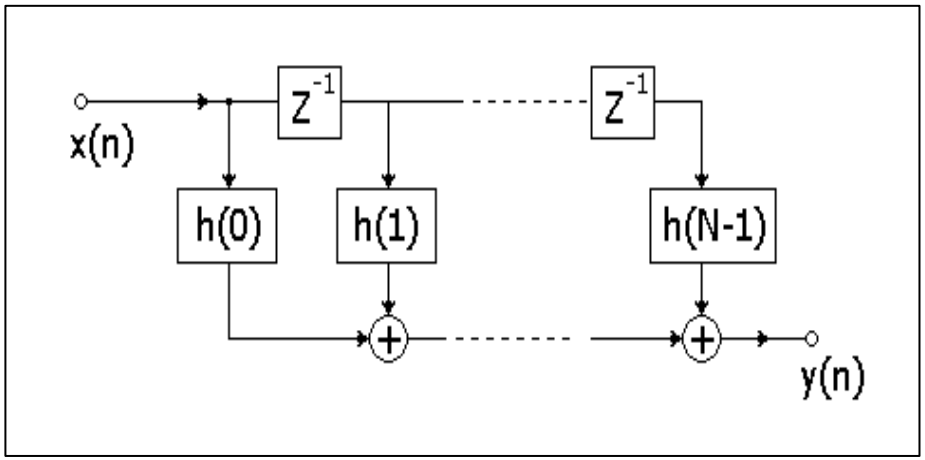

$$H(z) = \sum_{k=0}^{k=N-1} h(k) z^{-k}$$

FIR filters:

advantages:

- Always stable
- Linear phase
- High efficient algorithms on DSP platforms

disadvantages:

- Low resolution in the low frequency range

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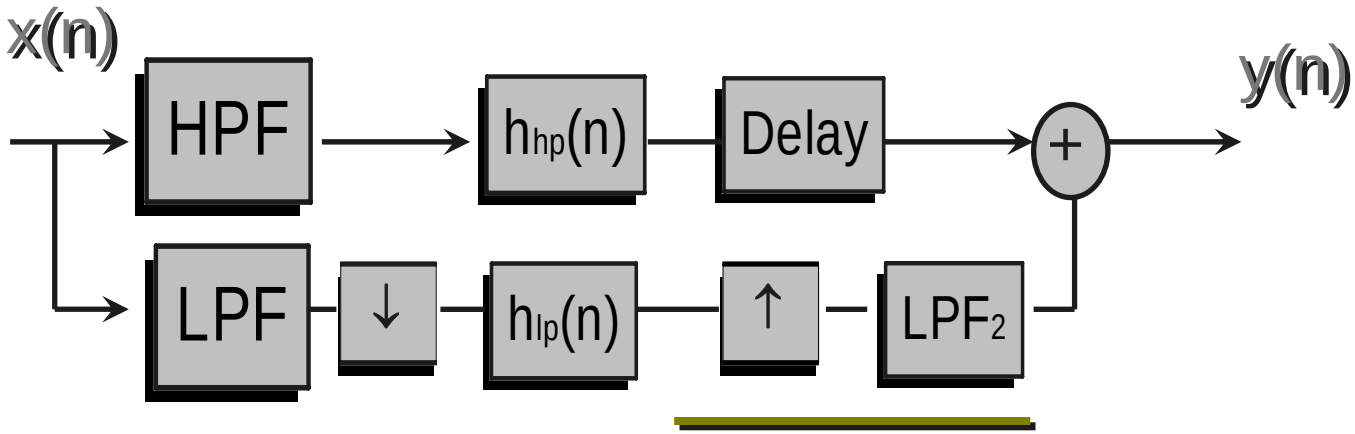
Dual-Rate FIR filter



advantages:

- better equalization at low frequencies
- equivalent increase of MAC/sample

disadvantages:

- complex structure
- very steep crossover filter require

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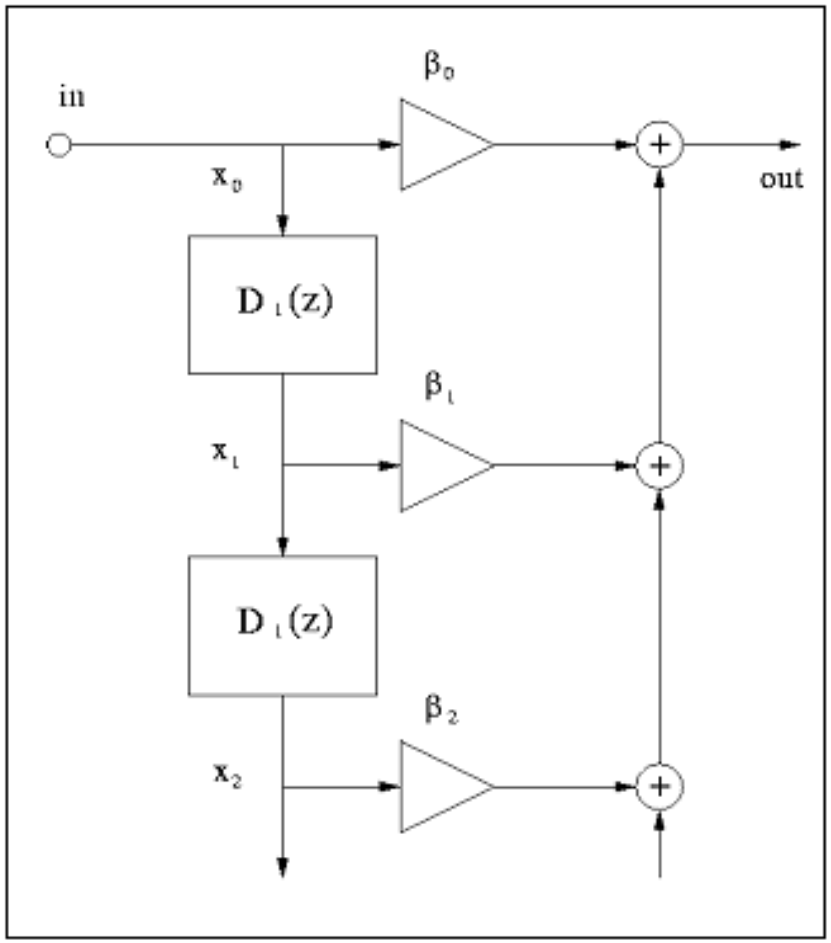

Warped FIR filters:

advantages:

- higher resolution at low frequencies, lower resolution at high frequencies

disadvantages:

- more complex structure than standard FIR filter
- potentially unstable

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Select-Save and BruteFIR filters:

- Frequency domain filters based on the FFT algorithm
- Select-Save: It allows the realization of filters with high resolution but it requires a large DSP memory to store partial results and FFT results.
- Brute-FIR: Is a partitioned frequency domain convolution filter that requires less memory than the Select-Save algorithm.

Design Flow

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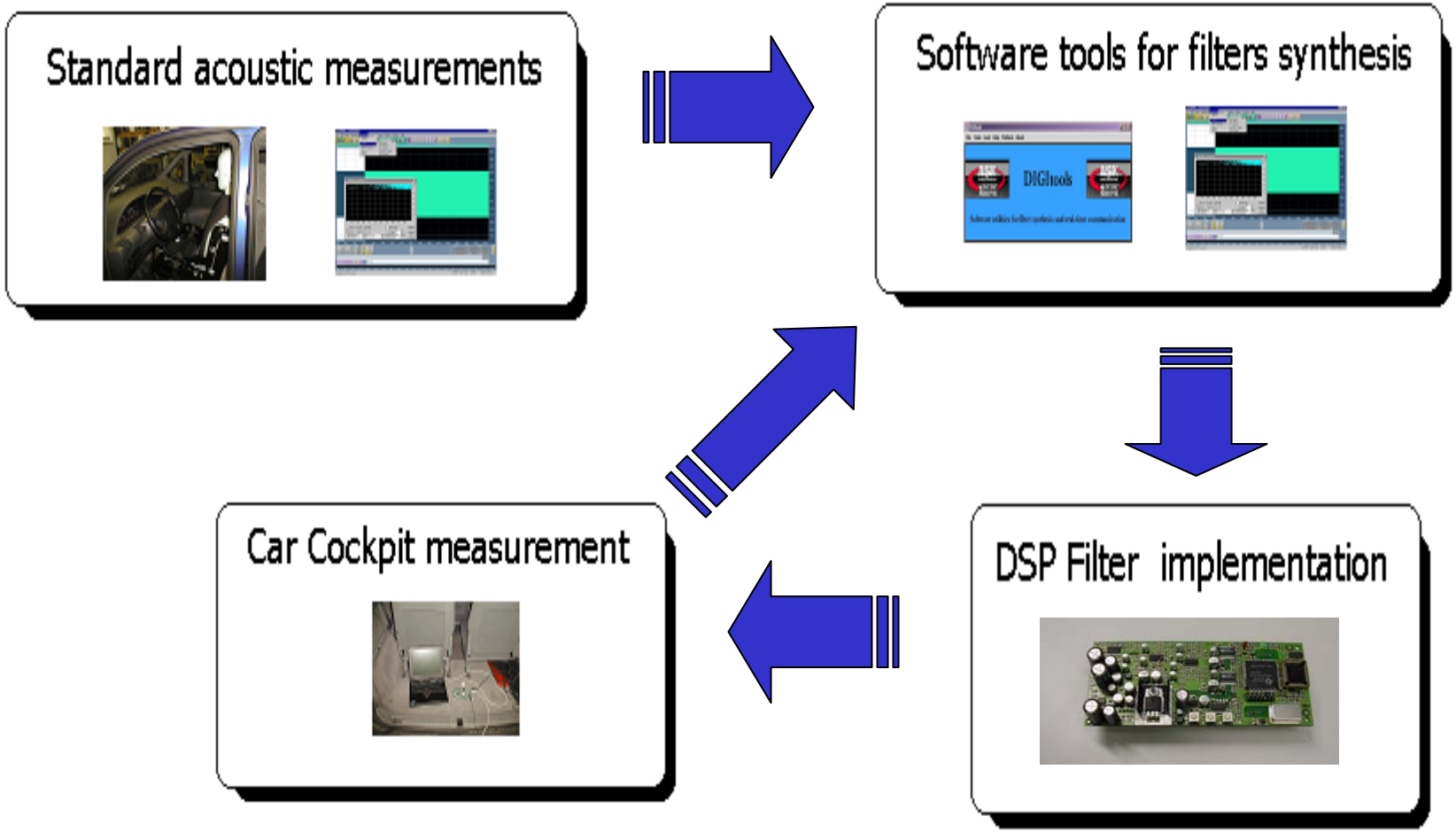
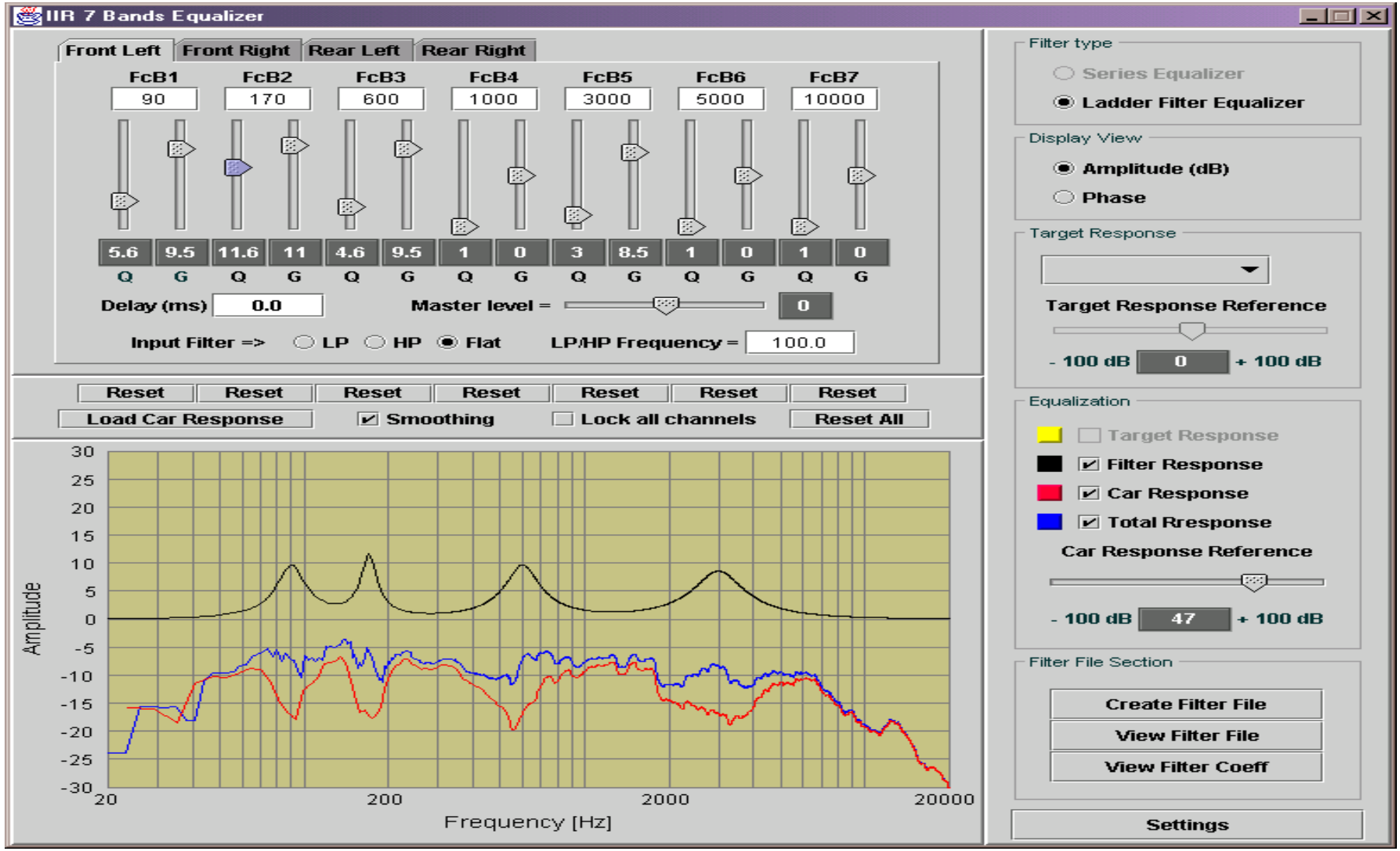


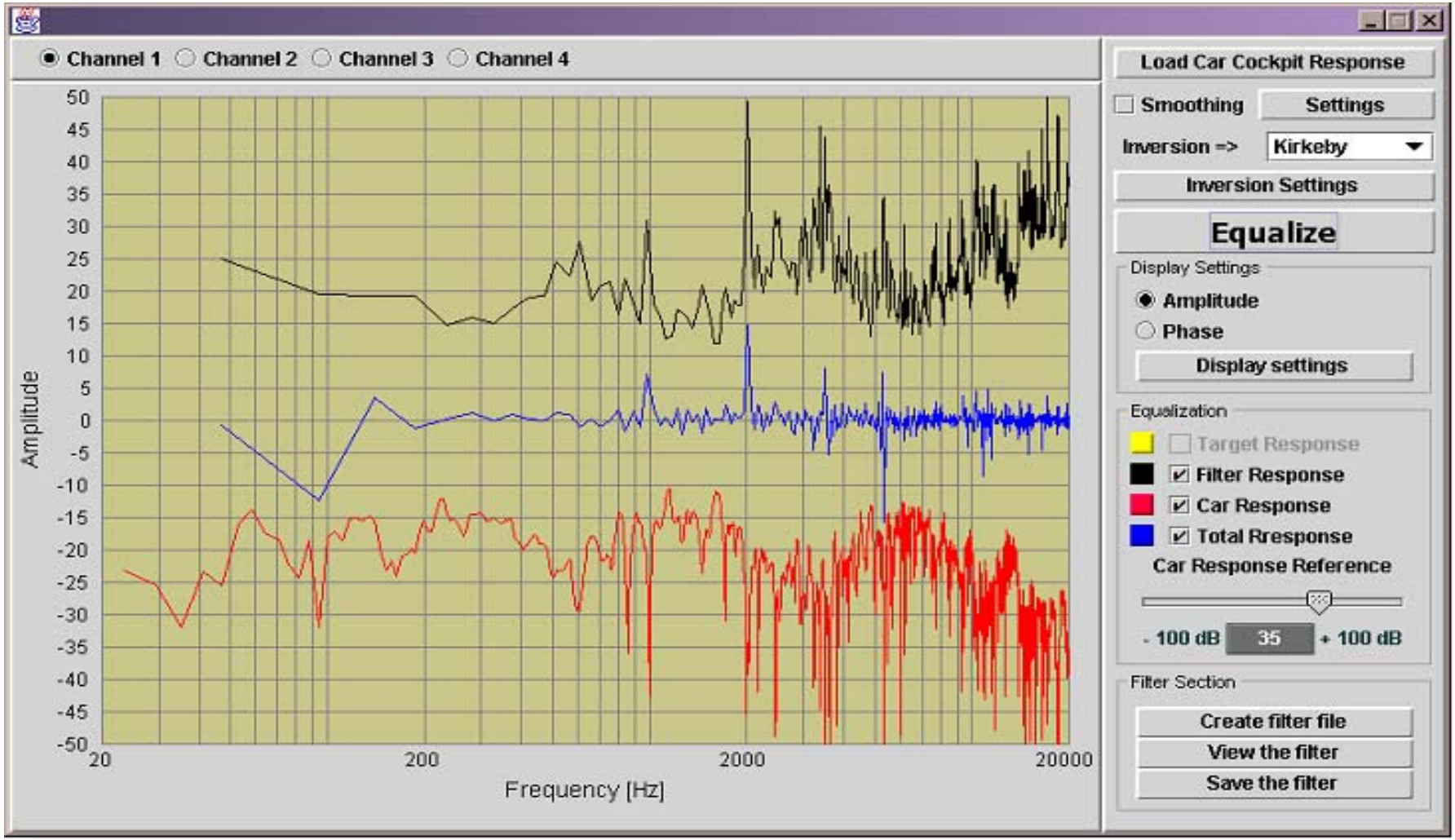
Software tools: DIGItools

- Filter synthesis
- Real-time communication with DSP
- Possibility to switch between several platforms

Software tools: IIR filter synthesis



Software tools: FIR filter synthesis

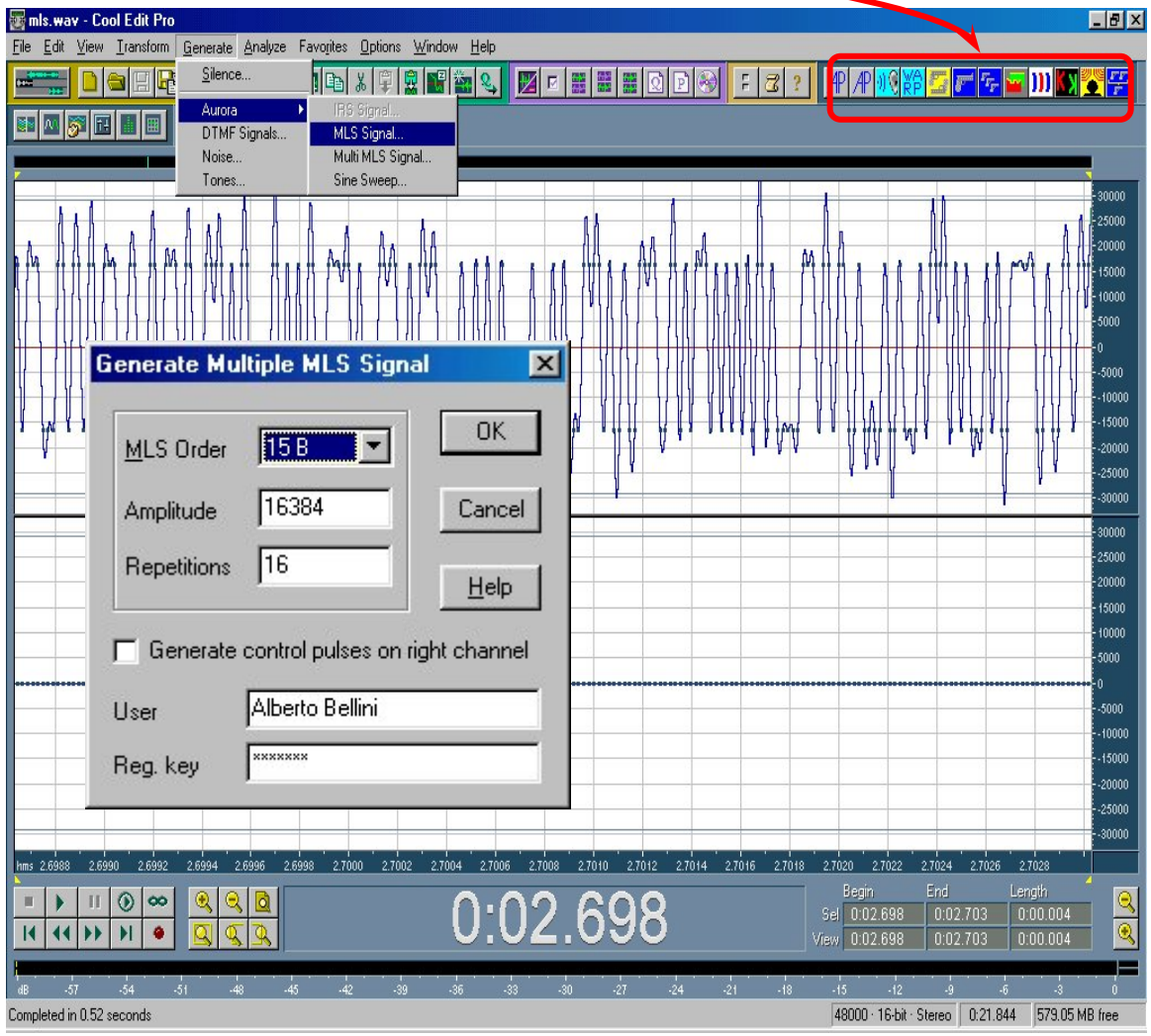


Car acoustic measurements

- Bruel & Kjaer microphones
- FL, FR, RL and RR response measurements
- Aurora software for MLS signal generation and deconvolution

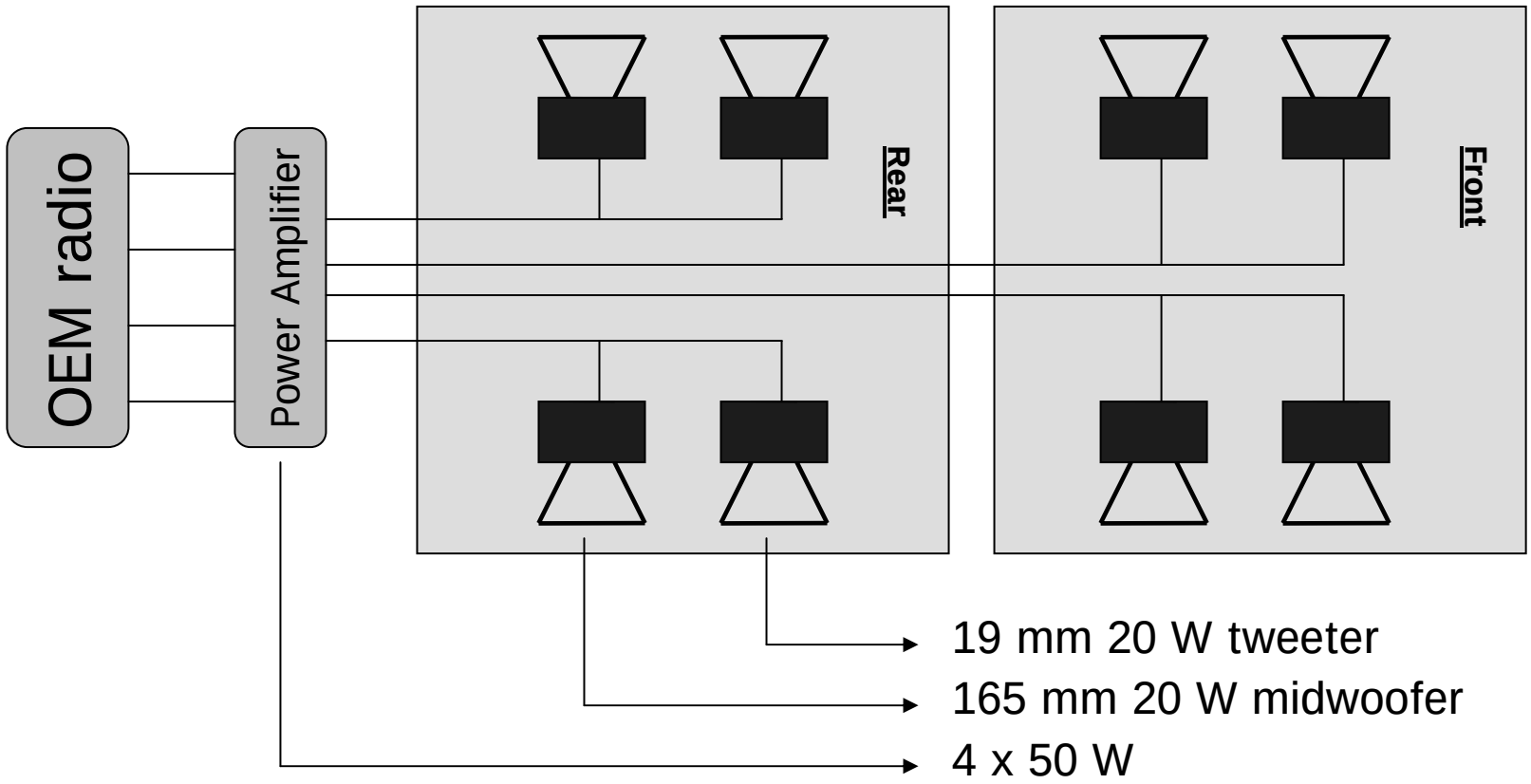
Aurora GUI

- MLS signal generations
- Car cockpit response calculation through deconvolution



Experimental set-up

- The DSP equalizer was tested on FIAT Stilo equipped with the sound system configured as follow:



Delay Introduction

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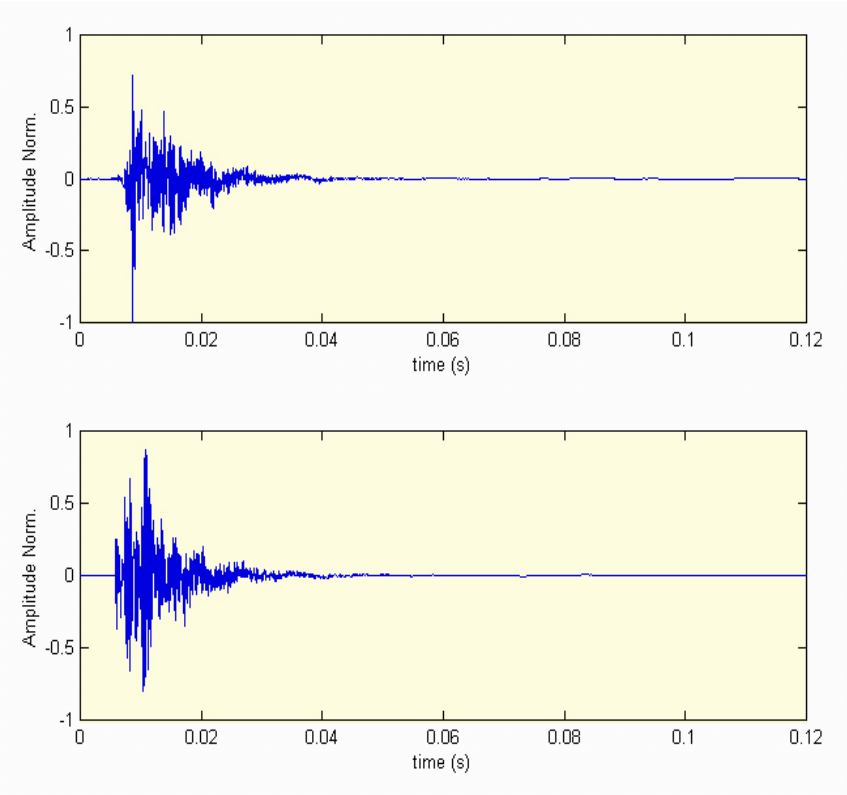
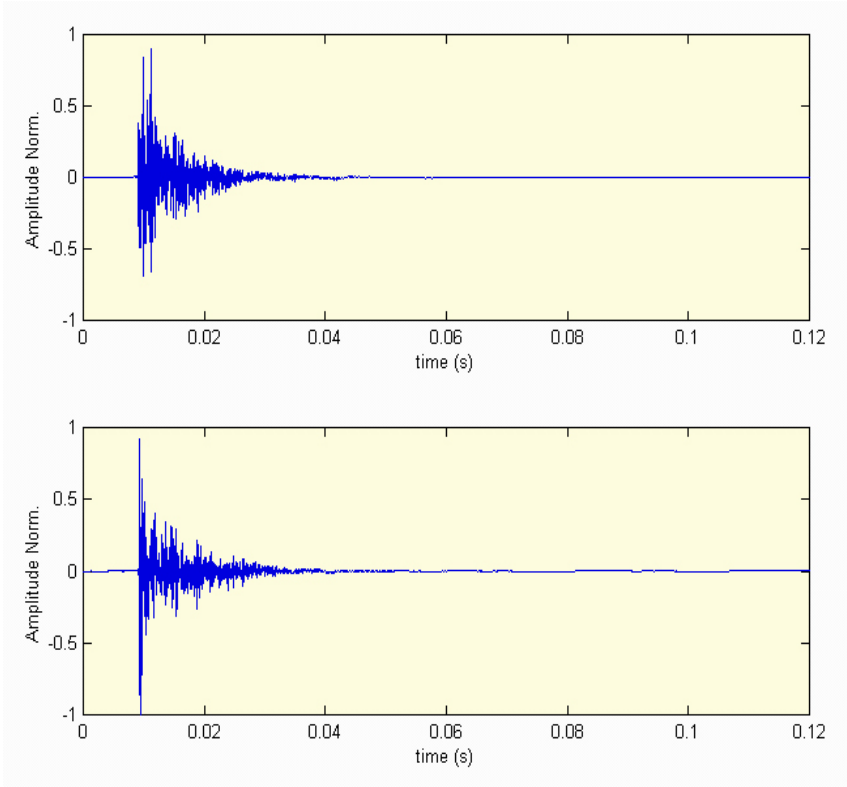


Not Aligned responses



Aligned responses

FIR experimental results

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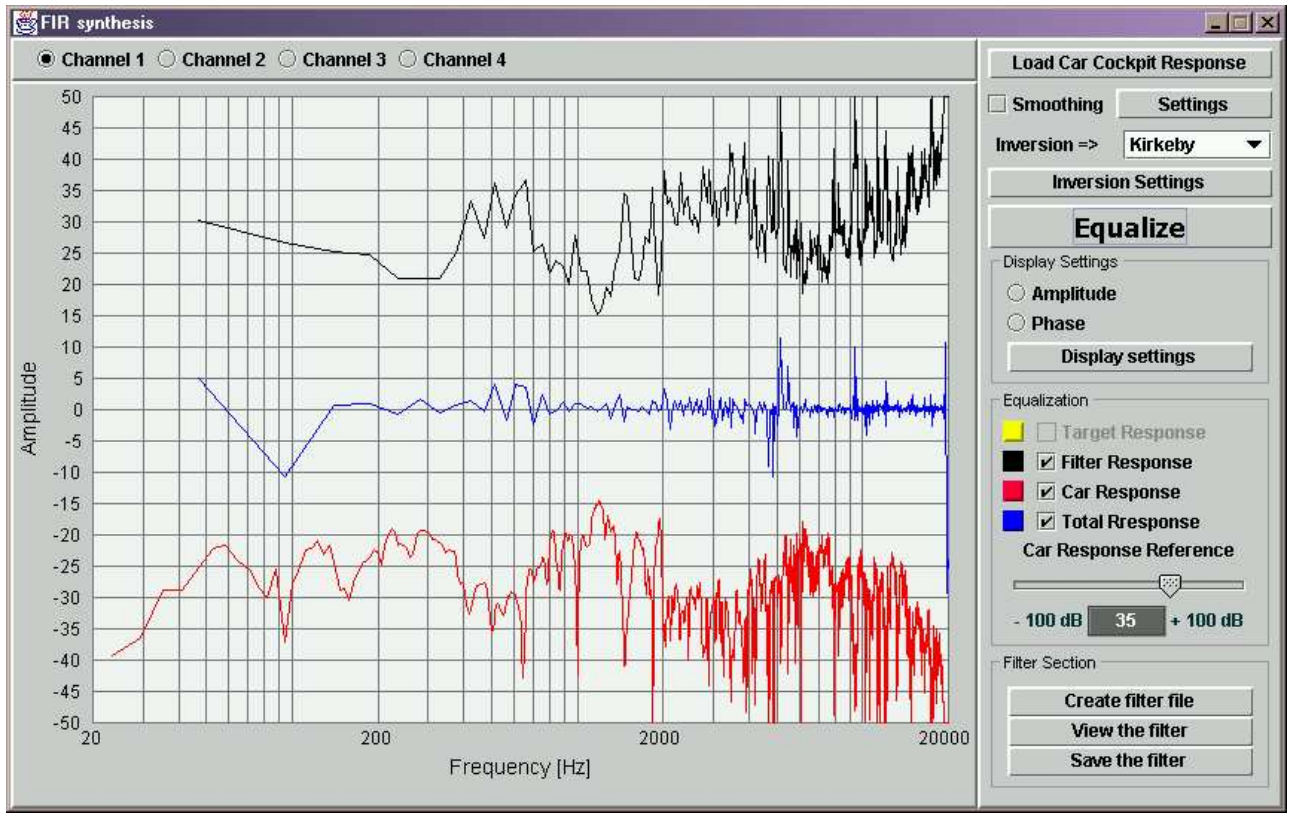
FIR filter synthesis with DIGItools

- FIR filter
- Normal Car response
- Equalized



FIR experimental results

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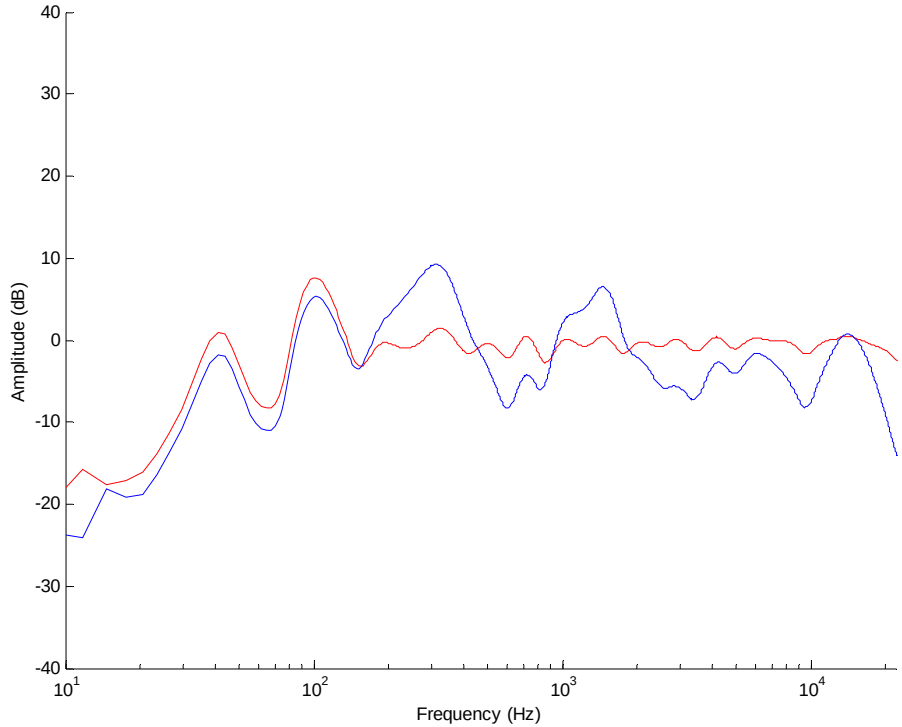
Equalized car measurement

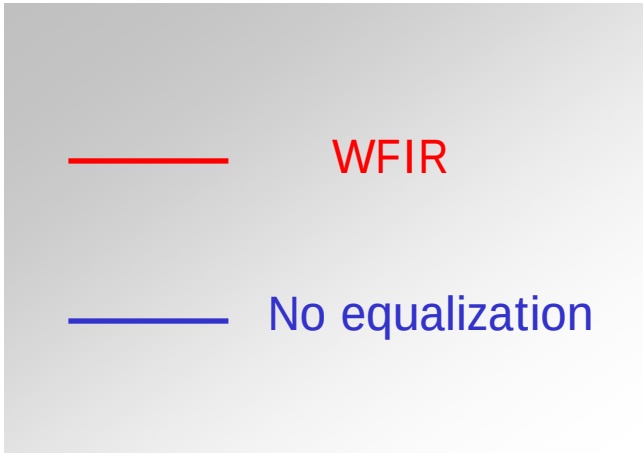
SPL measurements
DIGIcar 455 FIR equalization

Equalized
Normal



FIR experimental results

- AQT della misura FIR



IIR experimental results

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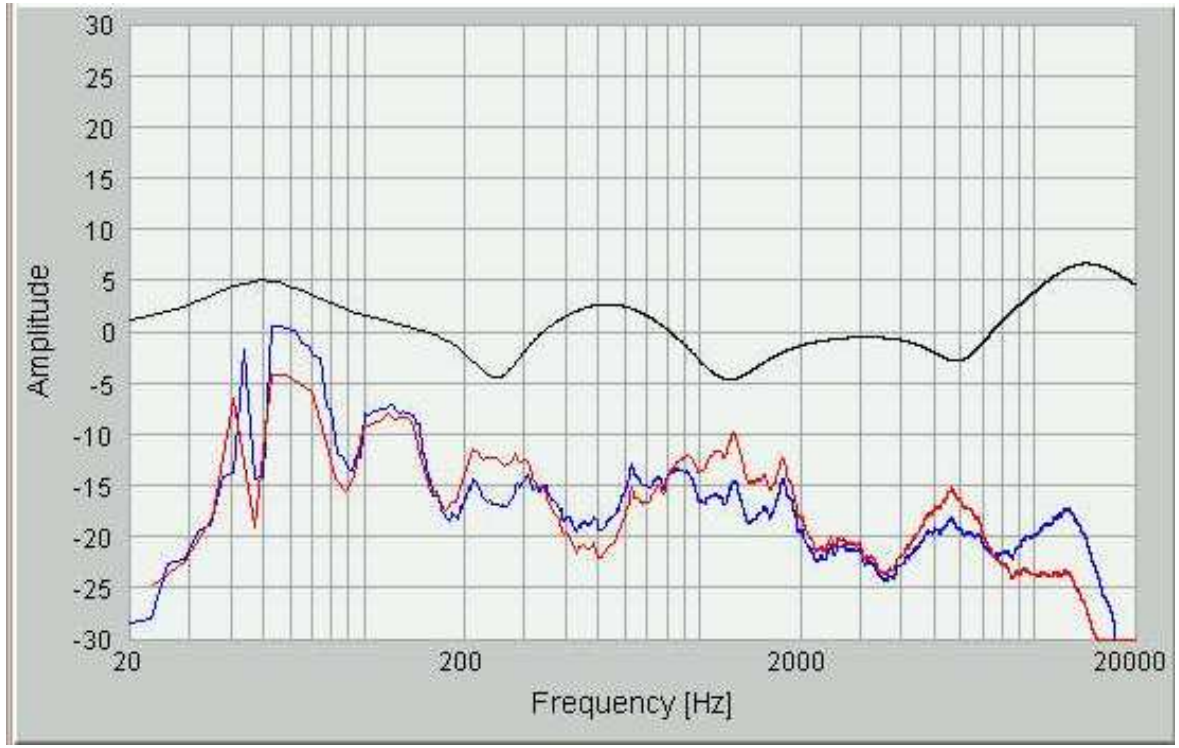
IIR Filter designed with DIGItools

- IIR Filter
- Car cockpit response FL
- Equalization



IIR experimental results

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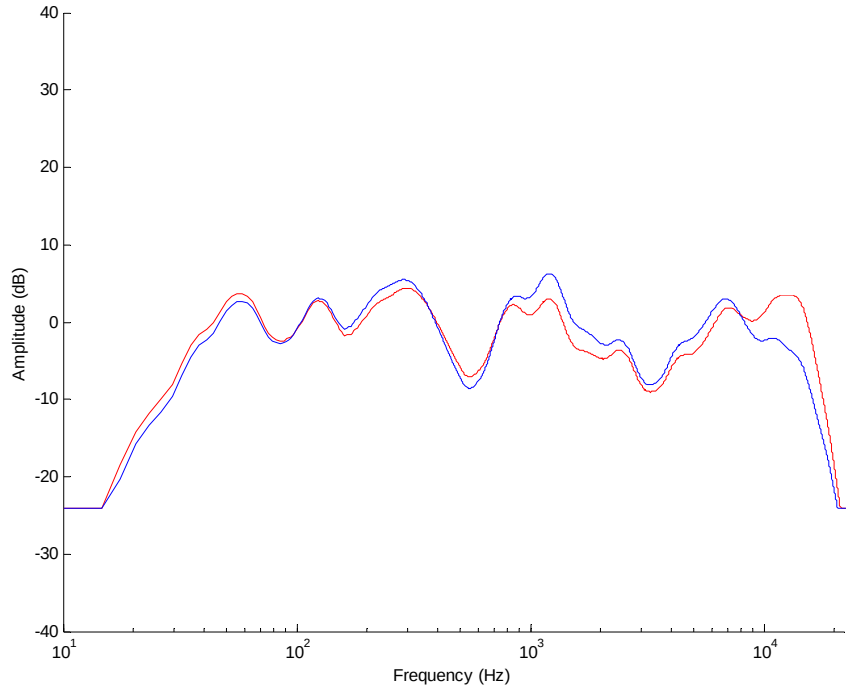
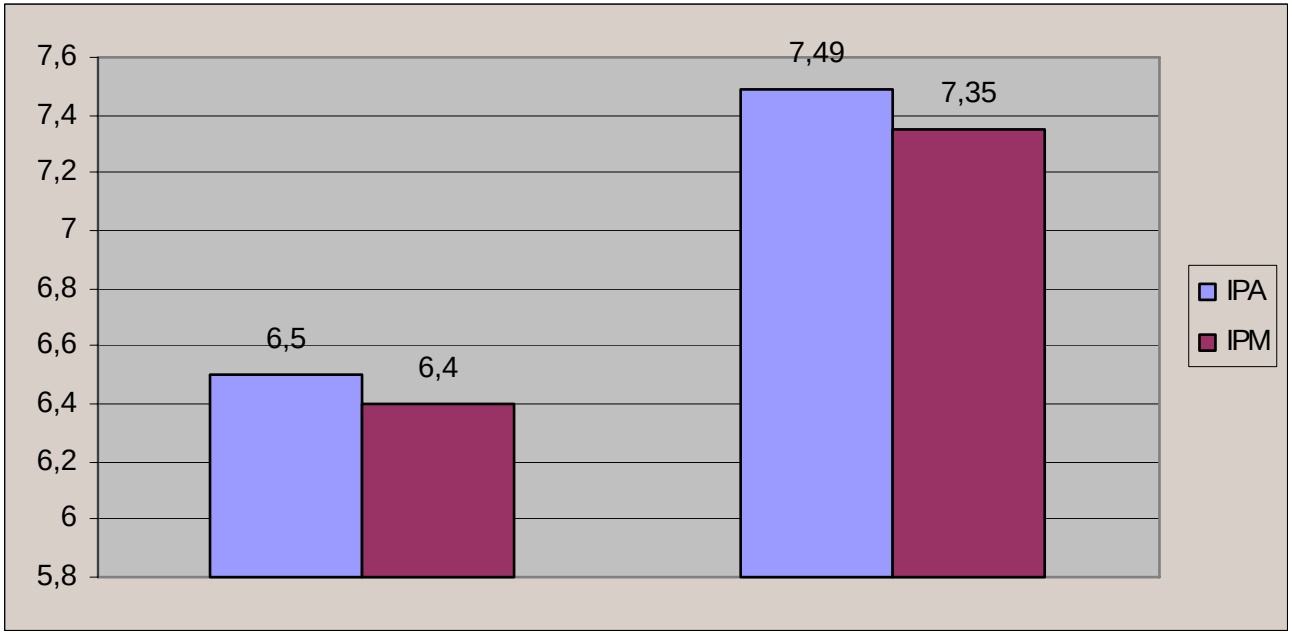
- Filtro misurato in auto

WFIR

No equalization



Listening tests



sound system without equalization

sound system equalized with FIR filters

Conclusions

- Multi-channel digital filters equalization;
- Automatic design of digital filters with the software *DIGItools*;
- Implementation on DSP systems;
- Experimental results and listening tests;