Integration of Active Noise Control in future IVI system designs

How to deal with low latency requirements?
Motivation

• Active acoustic technologies, influencing vehicle sound via electronic means are becoming a mainstream feature of automotive In-vehicle Infotainment (IVI) systems

• In parallel, IVI systems are moving towards highly integrated SoC’s with high performance standard cores and software infrastructure

• Coming from an acoustics & application background, how can we make both match for future systems?
Outline

• Short introduction into Active Noise Control
• In-Vehicle Infotainment development trends
• How to integrate ANC into future IVI systems
• Summary
Müller-BBM Group

- Engineering services, special technical products and system solutions at the highest level
- Active employee participation model guaranteeing independency (company is fully owned by the employees)
- An open company culture that motivates and encourages performance, creativity as well as personal development
- Since more than 50 years continued growth and success worldwide
Müller-BBM Active Sound Technology

A growing high-tech spin-off with broad experience bringing advanced tech into automotive vehicles.

End of 2017 in production
- with 8 Audio Tier 1 suppliers
- for 9 global OEMs.
Our role in automotive industry

We deliver

- Radio & amplifier software to be integrated in Tier1 hardware
- Tuning tools for the development process
- System integration know-how and services

We do not deliver
- Production parts
- HW development and manufacturing

We partner with OEMs and Tier 1 suppliers.
Short introduction to Active Noise Control...with a special focus on control theory
Lueg (1933): Inverse replication

Conover (1956) Periodic signals
Open loop: 
\[ y(s) = d(s) \]

Closed loop: 
\[ y(s) = d(s) \times \frac{1}{1 + P(s)C(s)} \]

Sensitivity function  
(Closed loop transfer function):
\[ S(s) = \frac{1}{1 + P(s)C(s)} \]
Open loop:
\[ y(s) = d(s) \]

Closed loop:
\[ y(s) = d(s) \times \frac{1}{1 + P(s)C(s)} \]

Sensitivity function (Closed loop transfer function):
\[ S(s) = \frac{1}{1 + P(s)C(s)} \]

Noise: Engine (Orders)

Ideal control sensitivity

Result
Bode sensitivity integral

- Let $S(s)$ stable, at least relative degree 2:

$$\int_0^\infty \log|S(j\omega)| \, d\omega = 0$$

- Conservation principle
- Limit for cancellation

No ANC system can reduce noise without increasing noise at other frequencies!
• No ANC system can reduce noise without increasing noise at other frequencies!

Open loop:
\[ y(s) = d(s) \]

Closed loop:
\[ y(s) = d(s) \frac{1}{1 + P(s)C(s)} \]

Sensitivity function (Closed loop transfer function):
\[ S(s) = \frac{1}{1 + P(s)C(s)} \]

Noise: Engine (Orders)

Real control sensitivity

Result
Control theory impact on ANC

- Sensitivity can be calculated
  - Robustness can be guaranteed, effects be predicted

- ANC system component and acoustical transfer functions determine sensitivity

- Control system latency (microphone – speaker) impacts ANC performance:
  Typical requirement $\leq 3$ ms (without ANC function)
In-Vehicle Infotainment from a systems perspective

... the computer that, by the way, takes care of audio
In-Vehicle Infotainment

• IVI is a fully digital, highly integrated system
  – Continuous increase of functionality with limited package space and power / heat dissipation restrictions

• IVI is flexible, configurable and has multiple performance levels
  – Different screen sizes, audio levels, rear seat entertainment, radio bands, ...

• IVI is a communication hub with „infinite“ interfaces
  – Consumer interfaces with short life-time, often wireless
  – Package and cost enforces bus-based communication with (very) high bandwidth at vehicle interfaces

• IVI is highly integrated with the vehicle
  – Functional sounds, warning sounds, shared displays with digital dashboards
    → Startup time, safety, security?
IVI development trends

• Standard processors / cores with operating system and middleware
  – Complexity in software, not hardware
  – Application of broadly used standards and joint development (HW & SW)
  – Scalability (multi-core processors)
  – Reduced development and update cycles, capabilities for software updates in the field

• Cross-functional SoCs
  – radio tuners & audio: NXP Dirana, SiLab,
  – application core SoC’s: ST Accordo, NXP i.MX, Intel Apollo Lake, QualComm Snapdragon
  – Audio DSPs & µC: ADI Griffin, TI Jacinto

• New bus systems, partially domain specific (AVB, A2B)
• Virtualisation to separate “vehicle” and “consumer” domain
IVI system requirements

• Vehicle connectivity
  – Requires vehicle compatibility and qualified components
  – *Separate communication µC, centralised interface, data is distributed within IVI system (Info-CAN, might be tunneled: MOST, AVB)*

• Specific functions require separate HW components
  – Examples: mobile connections, radio, TV, Bluetooth, WiFi
  – Depending on system level and market → # of variants
  – *Implemented through HW modules, specific SoCs*
  – *As far as possible: integration in application processor / SoC (e.g. Software Defined Radio)*
IVI audio outputs (amplifier)

- Loudspeaker are analog components and require power via explicit wires → many pins
- Power amplifiers are critical thermal loads (even class D) → package
- Channel count and power are differentiating features of system levels → flexibility in HW required
- Branding dependencies → independent sourcing of IVI HW and brand
- (Power) amplifier remains separate components, connected via appropriate bus system (MOST, AVB, A2B)
- Amplifier (as separate component) enable option for extra features. But: features can be allocated freely, including the application processor
Audio from an IVI perspective: Signal requirements

- High bandwidth (≥ 48 kHz fs),
- High dynamic range (≥24 Bit)
- High number of channels (≥ 20 source channels, 20 target channels)
- Non-synchronous sources and sinks, different clock domains → ASRCs with latency
- Complex signal processing, block processing → latency (≥ 128 Sample, corresponds to ≥ 2.7 ms)
- Media playback: No interrupts, synchronization, latency not important → buffering with latency
- Special case Low Latency: Hands-free, ....
Audio from an IVI perspective: implementation aspects

- Functionality can be implemented in a high-level app
  - computational requirements not that special (for today’s application cores)
- OS provides standardized driver architectures and hardware abstraction
  - reduced complexity per SW component, software re-use, increased portability
  - HW, driver & OS suppliers gain importance, audio SW suppliers loose …
- Layered implementation allows for virtualisation of audio
  - audio functions need not be in the functional safety domain
- Automotive audio shrinks down to standard app like mobile, home, …

… allowance for latency cures everything …
… including OS, drivers, virtualisation, processor caching, …
How to integrate ANC with IVI?

Why is ANC different from audio?
• Data interfaces:
  – Vehicle data
  – Microphone data
  – Loudspeaker data

• Functional SW well suited for µC or DSP

• Example implementation: Audio library function, 48 kHz fs, 16 sample block size, MIPS & memory depending on function set

• Key factors:
  – Additional Microphone inputs (cost)
  – Latency vehicle data → Algorithm/Loudspeaker
  – Latency Microphone → Loudspeaker
Microphone signals

• Traditional connection:
  – Phantom powered electret mic
  – Twisted pair wiring per mic
  – High pass filter for DC removal
  – Audio-Codec (Sigma-Delta) → I²S → DSP

• Perspective:
  – MEMS mic: better low freq performance, lower component tolerances
  – MEMS → PDM → A2B → I²S → DSP: bussed system allow for less wires / pins and does not require high pass filter for DC removal

• Other bus systems: Mind the bus interface latencies (HW & SW)
Latency vehicle data (rpm)

- Requirement: $\leq 30$ ms from engine to sound
- Critical cases:
  - dynamic driving,
  - dynamic load changes (PHEV charging)
  - Cylinder de-activation

- Can be achieved with direct PT-CAN interface (approx. 20 ms) and reasonable $\mu$C / interface designs (budget approx. 5 ms)
- Critical: gateways, low speed CAN bus, tunneling through other protocols (MOST, AVB)
Latency Microphone - Speaker

- Requirement: ≤ 3 ms (without ANC function)

- Latency budgets:
  - A/D and D/A typ. 0.3 – 0.5 ms each,
  - Mic (Phantom): typ. 1 ms @ 30 Hz, < 0.5 ms @ 50 Hz
  - Block processing 16 Sample, 3 Blocks @ 48 kHz: 1ms

- Integration in main core framework (≥ 128 sample, i.e. 2.7 ms / Block) not feasible

- Bus systems / drivers / virtualisation would additionally increase latency
Traditional DSP amp integration example

UI / Connectivity (Phone, Media, BT)

Audio DSP

Audio

ECM
ANC
Mic

Phantom circuitry (analog)

A/D

ANC

3D

ANC

D/A

Power amp

Speaker

Data

PT CAN

Automotive µC
CAN & Housekeeping
Radio integration example

UI / Connectivity (Phone, Media, BT)

Audio

NXP DiRaNA 3 SoC
Radio & Audio

Tensilica HiFi 2: ANC

ANC & Audio out

Power amp

Speaker

Data

Automotive µC
CAN & Housekeeping

PT CAN

Phantom circuitry (analog)

A/D

D/A

ECM ANC Mic

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Radio w/ external DSP amp integration example

UI / Connectivity (Phone, Media, BT)

Audio

NXP DiRaNA 3 SoC
Radio & Audio

Tensilica HiFi 2: ANC

A/D

Data

Automotive µC
CAN & Housekeeping

PT CAN

DSP amp & Mixer

Speaker

A2B Audio out

A2B ANC out

Control & Diagnostics

ECM
ANC
Mic

Phantom circuitry (analog)
Generic “IVI application processor” integration example

Multi-core application processor

- App core & OS
- App x
- Audio
- App core & OS
- App x

Low latency processor: ANC

- Tuner
- ...
Generic “IVI application processor” integration example

Multi-core application processor SoC

- App core & OS
- App x
- Audio

- App core & OS
- App x

- GPU

Low latency core: ANC

MEMS
ANC
Mic

A2B / I2S

PT CAN

Data

A2B mixed ANC & Audio out

Power amp

Speaker

Tuner

App core & OS

App x

App x

GPA

App x

Audio

Automotive µC
CAN & Housekeeping

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Summary

- IVI system trends are challenging for traditional automotive audio roles, audio is no longer special but just some more data
- ANC is a standard automotive feature to be integrated in IVI systems
- ANC does not fit in mainstream audio frameworks or OS’s due to latency requirements
- IVI system designs need to consider these requirements:
  - Adding a dedicated (DSP) core for low latency processing is a well supported, efficient standard solution
  - For distributed systems, bus latencies (including interface / driver latencies), ANC signal bandwidth and diagnostic signal communication need to be considered as well
Thank you for your attention

Questions and comments welcome!