THE FULLY NETWORKED CAR

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Multi-channel Car Acoustic Echo Cancellation for car hands-free voice communication

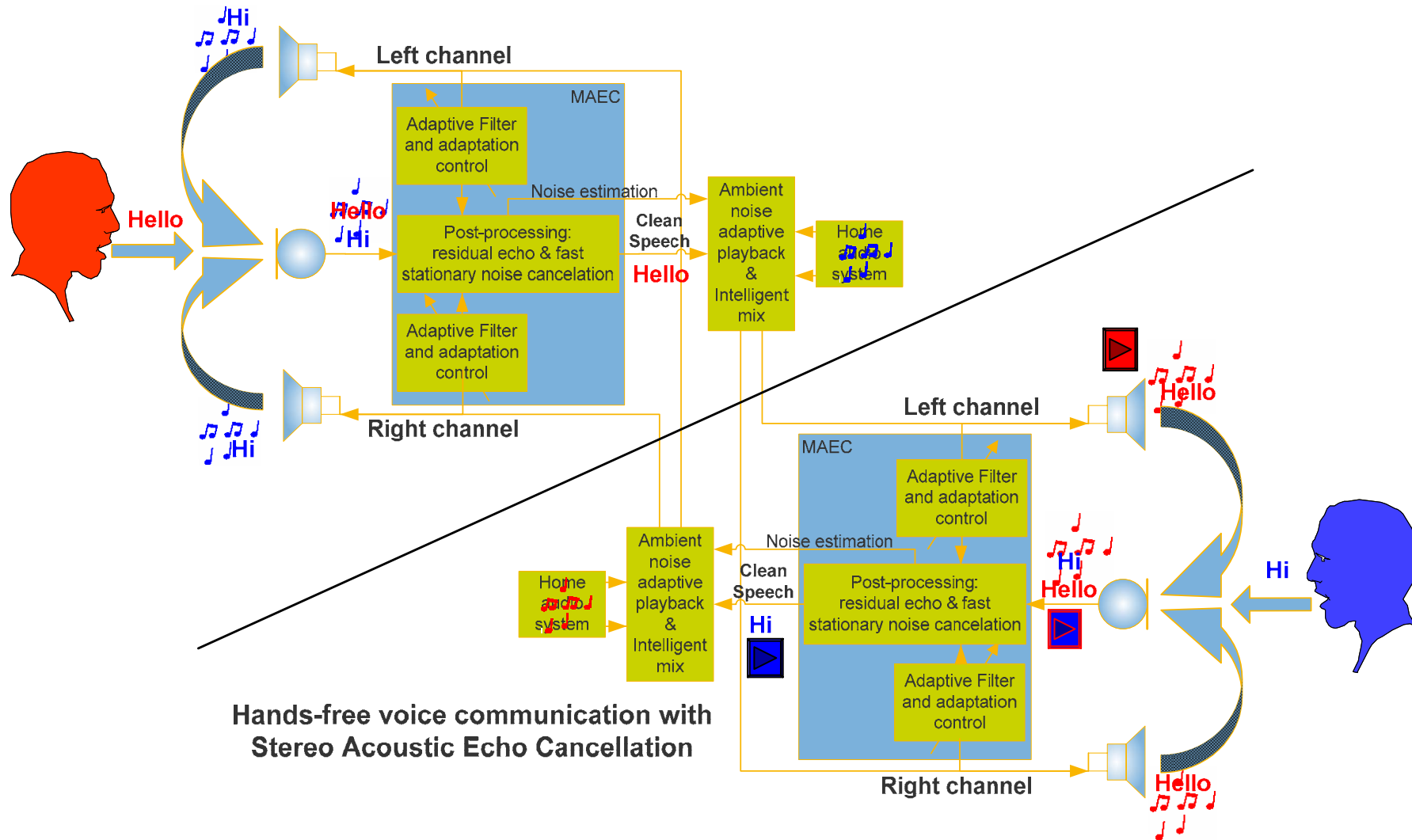## NXP Semiconductor

Geneva, 5-7 March 2008

ISO   IEC   ITU International Telecommunication Union

o Car hands-free voice communication implies:
- A big distance between the mouth and the microphone.
- A loud signal produced by the loudspeaker.
- A noisy environment.

o Consequences:
- A big acoustic echo is added to the desired speech signal that causes:
  – Howling in hands-free to hands-free operation making calls impossible.
  – Un-intelligible speech in handset to hands-free operation.
- A low speech to noise ratio @ the microphone position:
  – Reduced speech intelligibility.
  – Listener fatigue.
  – Parts of the speech lost, masked by non-stationary noises.
- A reverberation effect on the captured speech signal:
  – Reduced speech intelligibility.
  – Listener fatigue.

➢ Acoustic Echo Cancellation is mandatory for all hands-free communication systems:

- Without AEC, hands free voice communication is impossible due to huge acoustic echo and howling.

- The quality of the AEC defines the speech quality of the hands-free voice communication.

- Stereo or surround AEC is needed to allow listening to stereo car audio (news, traffic info, radio, navigation...) during a phone call.

- Car AEC must include noise reduction.

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Two parties hands-free voice communication

Left channel

MAEC

Adaptive Filter and adaptation control

Noise estimation

Post-processing: residual echo & fast stationary noise cancelation

Clean Speech

Ambient noise adaptive playback & Intelligent mix

Home audio system

Hello

Adaptive Filter and adaptation control

Right channel

Hands-free voice communication with Stereo Acoustic Echo Cancellation

Left channel

MAEC

Adaptive Filter and adaptation control

Noise estimation

Home audio system

Ambient noise adaptive playback & Intelligent mix

Clean Speech

Post-processing: residual echo & fast stationary noise cancelation

Adaptive Filter and adaptation control

Right channel

Hi

Hello

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Acoustic Echo Cancellation: technology

Sophisticated AEC like the NXP AEC contains the following blocks:

o Adaptive filter:
- Modelizes the acoustic path(s) between the loudspeaker(s) and the microphone.
- Cancels the biggest part of the acoustic echo.

o Post-processing: DENS (Dynamic Echo & Noise Suppression):
- Cancels residual acoustic echo due to non-linearity's in the sound playback chain, Echo tail (allows the use of shorter filters) and adaptive filter re-adaptation phases.
- Cancels stationary noises.

o Echo Return Loss estimator:
- Estimates the strength of the acoustic echo at the microphone position.
- Provides automatic AEC tuning to the acoustic setup and car acoustics.

o Path change detector:
- Detects fast acoustic path changes (car passengers movements).
- Prevents residual echo during acoustic path changes.

o Comfort noise injection:
- Injects stationary, low level noise in the clean speech.
- Provides stable noise floor in the clean speech, avoids noise gating effects.

o Optional: Small Microphone Array with adaptive beamforming:
- Focus on, reinforce the desired speech source(s).
- Cancel non-stationary noises.

Quality assessment

o The quality assessment of all types of hands-free voice communication systems is addressed by ITU-P340 recommendation: *Transmission characteristics and speech quality parameters of hands-free terminals*.

o ITU-P340 assesses the quality of the complete system: a car with a built-in hands-free voice communication system including the network transmission.

o ITU-P340 is a set of more than 50 objective measurements. ITU-P340 prescribes also subjective listening tests.

o VDA (Verband Der Automobilindustrie) has made a recommendation based on ITU-P340 dedicated to automotive applications: *VDA specification for Car Hands-free Terminals*.

o Head Acoustics and B&K provide automated tests systems to measure hands-free voice communication systems according to ITU-P340 and VDA.

Quality assessment is in continuous evolution (objective speech quality evaluation, wide-band speech...)

Measurement Setup in Real Car Cabin
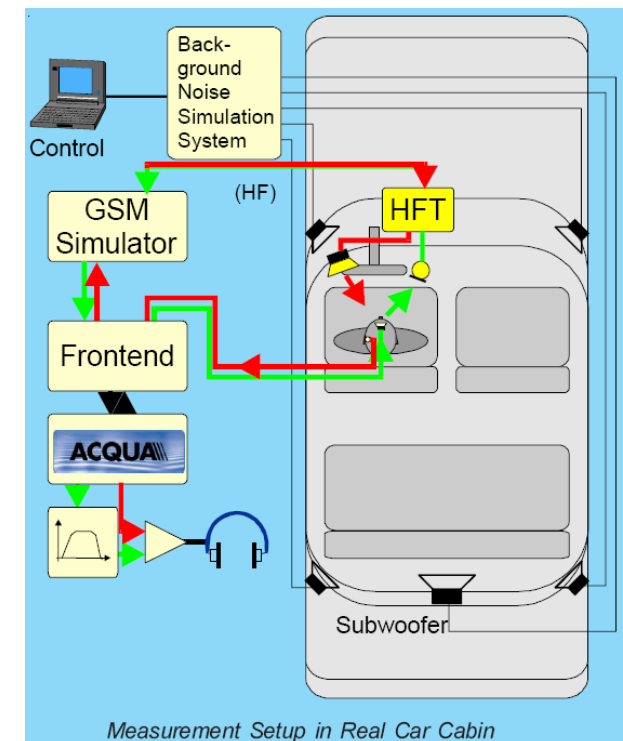
VDA measurements

o Several hands-free voice communication solutions have been measured according to the VDA recommendation.

o The global results are summarized below:

Category	NXP SAF7780 in Audi A4, Renault Scenic and Espace, Ford S-max	Bluetooth module in Renault Scenic	Bluetooth car kit in Ford S-max	Two microphones Bluetooth car kit in Renault Scenic	Car Radio with Bluetooth hands-free in Renault Scenic	Car audio system with Bluetooth hands-free in Ford Galaxy	Car audio system with wired hands-free in Mercedes E220
Quality	VDA compliant	Not VDA compliant	Not VDA compliant	Not VDA compliant	Not VDA compliant	Not VDA compliant	Not VDA compliant
VDA Duplex Rating	Full VDA 1	Partial/No VDA 3	Partial VDA 2a	Partial VDA 2c	None VDA 3	Partial/No VDA 3	Partial VDA 2b
Noise Reduction	++	+	--	+	-	+	+
Type	OEM	OEM	After-market car kit	After-market car kit	After-market car radio	Factory installed	Factory installed

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VDA compliance issues

o **Delay:** the delay is too big. This is mainly due to the Bluetooth link, it is almost impossible to be compliant (delay <=30ms) when a Bluetooth link is used.
  - 6.02.2b Delay Receiving, HFT Unit
  - 6.02.1b Delay Sending, HFT Unit

o **Frequency response:** normal for aftermarket (no equalisation tuning possible for the car acoustics) but should not be a problem for factory installed system.
  - 6.04.1 Frequency Response - Sending
  - 6.04.2 Frequency Response - Receiving, nominal

o **Receiving quality:** should not be a problem, no processing required in receiving direction.
  - 6.05.2 One Way Speech Quality in Receiving (TMOS)
  - 6.08 Distortion in Receiving

o **Acoustic Echo Cancellation quality:** this is the real challenge of hands-free
  - 6.05.1 One Way Speech Quality in Sending (TMOS)

Speech quality is affected by the mandatory echo cancellation and noise reduction post-processing.
  - 6.10.1b Activation - Sending
  - 6.10.3 Attenuation Range – Sending
  - 6.09.2a Echo Level vs. Time, - 5dBm0
  - 6.09.2b Echo Level vs. Time, - 25dBm0
  - 6.09.3 Spectral Echo Attenuation

The challenge is to combine enough and uniform attenuation with fast response.
  - 6.11.1 Attenuation Range DT- Sending
  - 6.11.3 Echo Attenuation during DT

VDA Cat 1 Full Duplex is almost never achieved.

Hands-free Voice Control with barge-in

o **Problematic:**
  - Automatic Speech Recognition systems cannot work in presence of acoustic echo => the car audio is usually muted while uttering the voice command.
  - Muting suppress the audible feedback of the effect of the voice control command (example: volume control, music track/preset zapping...).
  - Voice control uses a "push to talk" button only meant for the driver => other passengers cannot use voice control.

o **Solution:**
  - Use Acoustic Echo Cancellation as front-end of the ASR to allow barge-in.
  - Use continuous ASR without "push to talk".
  - Use the noise reduction of the AEC to improve the ASR performances.

o **Specificities:**
  - Stereo or surround AEC is needed.
  - Voice control happens most of the time while the car audio is producing sound, double talk performances are crucial, full duplex is mandatory.
  - AEC speech distortion must be kept as low as possible unless ASR is trained for "AEC distorted" speech => AEC for hands-free voice control is differently tuned than hands-free voice communication.
  - In case of hands-free voice control, without "push to talk" button, the ASR must be a connected/continuous ASR and must support word-spotting.

o **Problematic:**

- Communication between passengers in a car is often very difficult while:
  - Driving on rough roads (road-noise).
  - Driving at high speed (engine, road and wind noise).
  - Audio (stereo music) is present.
- Voice communication from the front passengers to the rear passengers is more difficult than the other way around.
- Front passengers (also the driver!) often turn around their heads to enable proper communication.
  - ➢ **Comfort and safety issues !**

o **Solution:**

- Reinforce the voice of the front passengers by playing it back on the car audio installation.
- Use Acoustic feedback Suppression, including AEC, to prevent the howling due to the acoustic feedback between the loudspeakers and the microphone.
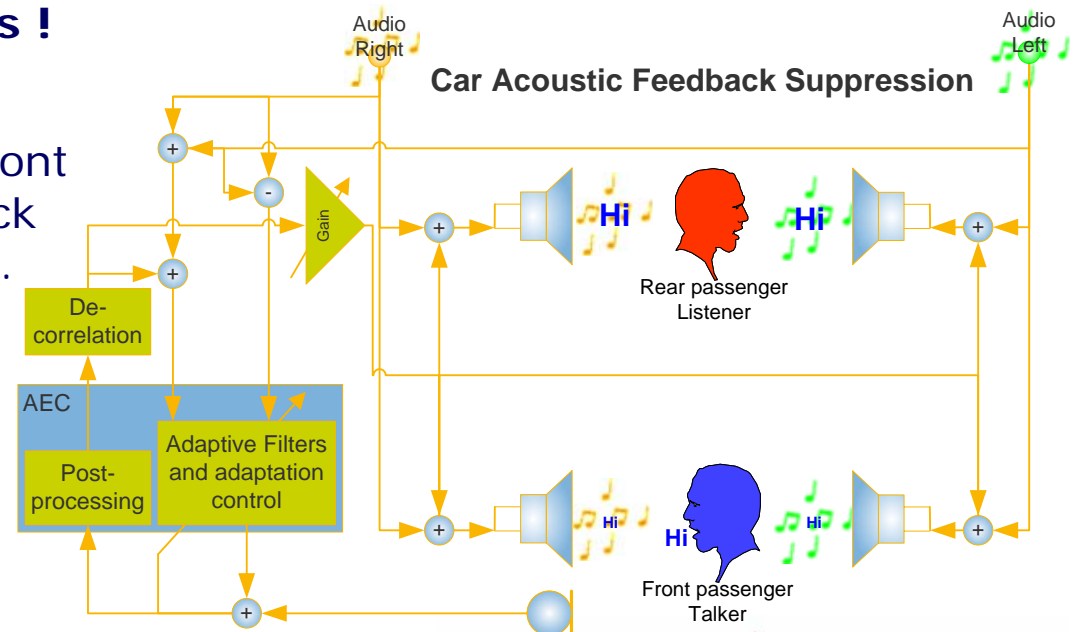
Car Acoustic Feedback Suppression

Motivation: improve hands-free voice communication quality because current voice communication is not safe enough.

o Stereo and multi-channel AEC:
- Stereo or surround AEC is needed:
  – To listen to stereo car audio (news, traffic info, radio…) during a phone call.
  – To provide hands-free voice control with barge-in in order to voice control the car audio/navigation while it is playing, without muting it.

o Wide-band, high quality AEC:
- Speech bandwidth: wide-band speech improves the speech intelligibility
  – Narrow-band speech of current mobile phone network limits the speech intelligibility:
    o Frequencies above 3.3kHz are missing: most energy of consonant lies above 3kHz and consonant are the most important for speech intelligibility in most languages.
    o Frequencies below 300Hz are missing: the pitch of human voice lies below 300hz.
  – Wide-band speech networks are becoming available:
    o Wireless mobile phone network will switch to 3G with wide-band speech.
    o Bluetooth 2.0 supports wide-band speech.
- Speech quality: wide-band speech codecs like AMR wide-band provide better speech quality and less masking of AEC artifacts => AEC speech quality must also be improved.

o Multiple microphone AEC:

- Non-stationary noises are the most problematic for speech intelligibility.

- Single microphone noise reduction:
  — Cannot cancel non-stationary noises.
  — Can only cancel stationary noises up to 10-13dB.
  — Introduce speech distortion and artifacts.

- Multiple microphones noise reduction allows:
  — To localize and track the sound/speech sources.
  — To focus on, reinforce one or several sound/speech sources.
  — To cancel non-stationary noises.
  — To better cancel stationary noises:
    o More cancellation.
    o Less speech distortion.

Conclusion/Summary

o Acoustic Echo Cancellation is mandatory for all hands-free communication systems.

o The quality of the AEC defines the speech quality of the hands-free voice communication system.

o The quality of the voice communication is crucial to ensure safety during car hands-free voice communication.

o Most current system do not comply with current quality requirements.

o Better quality car hands-free voice communication is needed to improve safety.

o The evolution is toward multi-channel, full duplex, high quality, wide-band speech, multi-microphone AEC.

o AEC is used for other features than hands-free voice communication:
  • Hands-free voice control with barge-in.
  • In-car voice communication improvement.