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Group Report:
Headphones Unlimited: Current Problems
and Future Opportunities

Participants: *A.K.A. "Team NAME (New Audio Methods for Ears)"*
Konstantin Merkher, Ceva DSP
Kees van Nieuwburg, ItoM
Darragh Ballesty, Xperi
Daniel Bogard, Synaptics
Michael Vulikh, P-Product
Ty Kingsmore, Cadence design system
Ramani Duraiswami, VisiSonics/UMD
Avi Keren, DSP Group
Special Thanks to Michael Ricci

Facilitator: Aaron Higgins

Framing the discussion

Problem statement

It is anticipated that the true wireless headphones market will exceed 200M units and will generate revenues in excess of $34 billion dollars by 2024. When considered as part of a larger hearables market which includes personal hearing devices and glasses, hearables are disrupting a traditionally high-volume, low-margin market with devices demanding higher ASPs and offering more convenience, capability and use. Hearable devices are benefiting from advances in low power digital signal processing, Bluetooth technology, micro-speaker design and an increasing number of sensors that can expand the capabilities of today's devices. In order to benefit from the opportunity, the group focused on identifying the state of the art with headphones today, reviewed some of the problems associated with today's wireless headphones and then posited on anticipated capabilities, modalities and use-cases for a next generation of hearable device.

Outcome

It's clear that in the hearable market today, battery life (power) in a hearable form-factor is the single biggest limiting factor when considering expanded functionality in these devices. In order to identify new areas and concepts for hearable usage (such as environmental awareness, safety, health, etc.) the team assumed that basic power requirements would be solved, and then attempted to get to a point where a common platform architecture for a next generation of hearable could be defined. The team did not succeed in this goal, but did provide a review of existing functionality, identified problem areas with today's devices and made recommendations for future hearables.

What do today's headphones offer beyond basic playback and communication?

The group took a 3-prong approach to review the capabilities of today's true wireless hearable devices. First, the team identified common use cases offered by today's headphones. It then looked at problem areas to be solved and then finally raised some key questions and recommendations for consideration when defining a next generation of hearable.

State-of-the-art

Looking at today's true wireless headphone market, the team first identified some of the common use cases and segmented the use cases into baseline requirements (i.e. expected functionality in devices today), state-of-the-art to describe use cases that are either supported today with high-end hearables, or features that have been announced and anticipated to ship within the next year. Finally, potential future requirements highlights some of the ideas that were captured, together with some hurdles that would need to be overcome in order to successfully implement the feature.

Use Cases	**Baseline requirement**	**state-of-the art**	**Potential future requirement**
Communication/Sound Augmentation			
Audio phone/internet call (with paired cellular device)	✓		
Audio phone/internet call (standalone)			High impact on battery and BOM
Acoustic Echo Cancellation	✓		
Wideband environmental noise suppression (for a remote caller)		✓	
Augmented hearing to enable a user to more clearly hear "important" or specific sounds			Would require blind source separation or a machine learning approach, both of which are computationally expensive
Multi-mic beamforming to improve voice capture	✓		
Smart Assistants (both networked and standalone)		✓	
Navigation/environmental understanding via smart assistants			Requires sensor fusion and low-power edge based processing
Consumption of entertainment (music, movies, games, xR)			
Stereo audio (up to 48kHz)	✓		
High Definition stereo audio (192kHz)		✓	
Spatial audio for gaming, mixed reality		✓	

Immersive content (games/movies/xR) playback		✓	
Head tracking for improved sound localization			Not typically found in hearable devices due to the limited compute power and impact on battery
Spatial audio with free field loudspeakers (for glasses-type hearables)		✓	
Privacy filters for free-field loudspeakers			Solutions tightly coupled with mechanical design. Medium impact on battery
Transparency mode to enable the consumer to hear the environment as if the headphone/hearable was acoustically transparent		✓	
Active Noise Cancellation for low frequencies)	✓		
High/Mid frequency noise cancellation			There are some fundamental physics issues to overcome before this is practical
Improved Bass via Piezo bass units		✓	
Connectivity			
Wired for consumption of content from a host	✓		
Wireless (Bluetooth) for consumption of content from a host	✓		
Wireless (NFC) for ease of pairing and discoverability		✓	
Intra-device low latency communication			In today's True Wireless headphones, the left typically doesn't know what the right earphone is doing. Coupling both devices with each other with a fixed low latency communication path would enable improved environmental understanding
Health, Activity and wellness			
Pulse measurement		✓	
Temperature measurement		✓	
Blood Pressure measurement			Research methods have been proposed, but again would require a significant increase in CPU.
Blood oxygen level			✓

EXG (EEG/ECG/EMG) for • Heart Rate monitor • Breathing monitor • Stress level • Seizure detection (Epilepsy, Heart attack, ..)			✓
Hearing aid mode		✓	
Skin Conductivity for stress			✓
Sleep quality • Snoring • Sleep apnea detection and prevention			✓
Affective Signal Processing (ASP) for detecting mood or emotion			✓
Life coach assistant		Available through connected devices	
Sensor Fusion for location and Ux While not a use case, the team believes that aggregating data from multiple sensors (sensor fusion) will play a key role in the next level of measurement and perception of the environment for the next generation of hearable devices.			
GPS for audio navigation		✓	✓
Accelerometer		✓	
Integration with cameras for enhanced scene augmentation and understanding		✓	
Touch surfaces to enable simpler Ux (control interface)		✓	
Haptic feedback to augment speech based directions			✓
Safety			
Hearing Protection in loud environments	✓	✓	
Environmental awareness			Scene and environmental understanding can provide cues for personal safety (for instance to notify the consumer that a car is approaching etc.)

Issues with current headphones

As a next step, the team used both primary and secondary research to consolidate issues with current headphones. Primary research was based on interviews with the team (along with several other subject matter experts during the course of BBQ) and secondary research mainly consisted of an internet review. The team identified the following problem areas with today's headphones and where possible, attempted to define a fix together with identifying a functional solution. The table below summarizes this discussion.

Issues with current headphones	**Fix**	**Functional Solution**
Size	Scalable solution	
Low quality and intelligibility	Better algorithms Better mechanics Better transducers Better microphones	Improved compute capabilities and raw components
Noise cancelation	Better algorithms Better mechanics Better transducers More better microphones Higher resolution Lower latency	Further R&D and investment necessary
Environmental sounds blocked	Extra microphones Other sensors (V2X etc.), AI	Assuming canal occlusion, AI algorithms for scene detection and ducking/muting unnecessary sounds and/or enhancing vital sounds. (Source discrimination) Need Processors to enable.
Battery life	System power optimization Power optimizations for all parts of the system New technologies	Improved processor architecture Optimized algorithms for processors improved raw materials / batteries Nuclear Fission.
Limited computational abilities	Processor and memory architecture improvements HW accelerators	Additional and specified processos. Optimized for usages (AI, audio decode, pre/post processing, command and control)
Convenience of wearing/comfort	Take it out of the ear! Materials and industrial design Improved comfort/materials/etc.	wearable "speakers" with focused beam steering More comfortable materials and designs. Personalized fitting Adapting materials (memory foam)
Easy to lose	Strap Automatic notification (beacon) Audible/visual locators	Local proximity solution required to find single earphones and/or the enablement of a beacon when an earphone has detected that it is lost.
Cumbersome and insufficient interfaces	Remove proprietary interfaces (standard only) Define a method to	5G/Wifi/BTNext? Headphone metadata to identify capabilities.

	easily connect and switch connections	
Limited abilities for control	Improved voice commands/gestures /touchless and touch capabilities	New interfaces and industry standards
Non intuitive UI	Standardized controls across brands	New industry standards for command/control
Many headphones needed to cover use cases	Solved in the above (Fashion and brand become differentiators)	Rollup of all previous
Insufficient hearing protection	This topic was covered by a second BBQ group and so considered out of scope for this report.	

Building the next generation of hearable

Some design considerations

During the brainstorming session and review of the state of the art for true wireless headphones, the team gathered a number of key questions to be addressed when considering the functionality of a next generation hearable. These questions are captured in the table below and can be considered by future groups. Note that the team considered mechanical fit and aesthetic design outside the scope of the discussion.

Question	**Opinion**
Is the headphone designed to be a single do-everything device or do we envisage a spectrum of devices to meet the use cases above?	The team concluded that it would be ideal if the device was one that would be worn at all times, would automatically adjust to the scenario that best suits the users needs based on understanding the context and environment. This has implications on both the BOM cost, battery requirements and number of sensors that would need to be integrated into an ideal device
Battery life is paramount. How long should the battery last? (and the corollary - how long will you physically wear the device?)	In order to be really useful, the team decided that the battery should minimally last the duration of a transatlantic flight on a single charge. Ideally, the device would last one day, following the smart watch context.
Do we believe that the hearable will be a standalone device, or will require pairing with other networked devices?	The team believe that the hearable will be designed to be connected. It will have core functionality in a standalone mode (music playback, health monitoring, simple smart-assistant features (calendaring etc.), but will benefit from a network-connected device. The team ultimately believes that whole-body or Personal Area Network (PAN) device ecosystems will become more common and that in order to balance the computational load and maximize battery, the computation will be distributed amongst various connected devices, beit a watch, phone, glasses, hearable, or combination of the above.

Why do we use headphones?	The team concluded that there are two primary modalities for headphone usage; (a) to escape from the environment and enable us to focus on the content that we're consuming (i.e. to shut out and minimize distractions), (b) to enhance and augment reality by using the technologies in the headphones to augment our perception and (c) to provide us with a personal and private listening experience.
Do we assume that the device will be always listening?	Following the trend of increased personal privacy (with legislation including GDPR from the EU), we believe that privacy has the potential to drive hearable design to edge based (or PAN based) solutions. If the device is going to be aware of both the environment and the context, it will need to have an "always-on" mode. Hearable companies will need to be mindful of sharing "measurements" for processing on the cloud, and this may lead to a requirement for low power machine learning ICs to be integrated into the devices.

Proposed Functionality

As a straw-man for a next generation true wireless hearable device, the team came up with the following functional design goals.

The Device should be able to determine the user scenario and adjust the device to support the required use case.

- for example, you are on a phone call and the microphones are focusing on your voice.
- once you are off the call, the microphones focus on your environment and amplify/reduce the volume and ambient noise as necessary
- when in an external conversation, the microphones will focus on the person(s) you are talking to
    - This will help to avoid social awkwardness by wearing headphones
    - people will become used to everyone wearing headphones
- When riding a bike or walking down the street, the headphones will sense dangers and alert the wearer.

The desire is to remove the need for multiple headphones

Anecdotally, each member of the team has more than two pairs of headphones. There are headphones that one uses at the gym, headphones for travel, headphones used primarily for communication. While the industry benefits from this segmentation, the group consensus was that it would be better to create a single pair of headphones that could support multiple use-cases. It was also identified that these devices should be easily discoverable and find-able. Loss of true wireless headphones is perceived as a growing issue.

The headphones will support multiple input sources and intelligently switch between them.

While investigating the use of hearable devices, connectivity came up time-and-again as an issue for current headphones. Future requirements should enable a headphone to intelligently switch from a personal device to an external devices (like the airplane infotainment system or advertisement billboard) based on user-defined preferences.

The next generation of headphones will be an integral part of a whole-body-network

As stated above, the team believes that the next generation of smart headphones will become part of a whole-body network and will be able to act seamlessly with other personal devices (phone, glasses, watch etc.) to apply the appropriate processing in the right device (with seamless handover) to drive optimal

power management, and also to drive a consumer centric user experience. This will pose interoperability challenges for the industry and we believe will lead to further vertical integration of solutions (as can be evidenced by Apple, Samsung, Huawei etc.).

Quality of Life

The team feel that while these devices will, at their core, continue to be primarily entertainment consumption and communication devices, there is a large opportunity to improve a consumers quality of life, particularly for the sensory impaired. The ability to embed intuitive environmental and context awareness into hearable devices can lead to opportunities to improve life quality that other personal devices cannot achieve. Hearing is a core sense, and a hearable is ideally positioned to intelligently enhance or augment that sense for the consumers benefit.

Personal

We believe that we will see a continuing trend towards personalization of the audio experience (personalized hrtf models, personalized EQ for hearing loss, privacy filters for audio etc.) and that in addition to form and fit, personalized functionality will play an increasingly important role as the devices get smarter.

Observations and Conclusions

The team believes that hearables will continue to be highly relevant personal devices. Purchase decisions will be made based on form, function and fashion. Consumers will continue to desire the fundamental modality of the headphones; i.e. the ability to escape the environment in order to focus on the content, and will want that experience to continue to grow, both in quality of audio, ease of connection and increasing battery life.

The team also believes that consumers will gravitate towards a new set of use cases outlined above focusing on health, wellness, improved contextual awareness and augmented audio capture but only if the proposition is sufficiently differentiated (i.e. can't be better satisfied by another personal device),
In terms of the underlying compute platform required to enable new use cases, it is going to be important that the devices perceive the appropriate user context using a combination of sensors to determine (a) where the user is and (b) what they are doing. This will likely require an edge-based machine learning architecture which will have an impact on both the compute and memory architecture. Additionally, if these devices continue to use more sensors to gather contextual and environmental inputs, it is likely that the number of required inputs (say 6 microphones, 2+ speaker drivers, potential camera inputs, accelerometer etc.) will determine the overall size of the package and not the underlying ML core.

References

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Appendix

In addition to focusing on the basic hearing/talking functionality that is a core requirement for today's headphone, the team created the following mind-map identifying some of the different modalities and use-cases that could be offered by a next generation hearable.