Azoteq
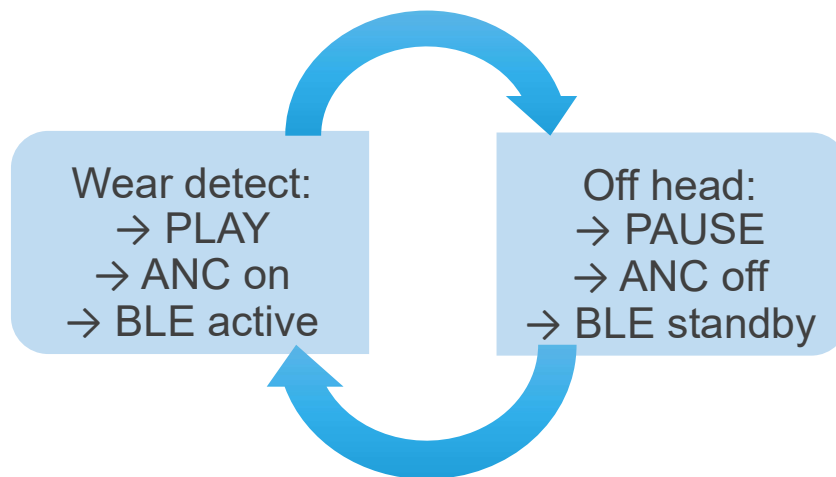
AZD097 – ON-EAR DETECTION FOR HEADPHONES

This is a summary of what Azoteq offers for headphone applications with specific focus towards on-ear ("wear") detection. This guide applies to the most typical headphones use in the form of on-ear or over-ear headphone designs where capacitive detection of a wear (donned) state can be acquired through a ProxSense or ProxFusion sensor in one or both earcups.

1 Azoteq technology for headphones

- Capacitive touch (play / pause / ANC control / voice assistant)
- Capacitive slider / trackpad (skip track / previous track / volume up / volume down)
- HALL sensing (mechanical scroll wheel rotational control)
- **Capacitive on-ear / "wear" detection (play/pause/power mode)**

Wear detect:
→ PLAY
→ ANC on
→ BLE active

Off head:
→ PAUSE
→ ANC off
→ BLE standby

Copyright © Azoteq (Pty) Ltd 2020.
All Rights Reserved.

AZD097 On-ear detection for headphones - Update
Revision 2.00

Page 1 of 14
November 2022

Contents

2 Touch button

2.1 Design guidelines

Azoteq technology for touch buttons allows for very flexible implementation with regards to the following:

- Overlay choice: up to 5mm thickness

- Non-conductive overlay materials: all plastic types that are typically used are OK for use (excluding NCVM and similar metallic plastics)

- Metal overlay: Large floating metal or metal connected to circuit GND should not be used. Floating metal will be touch sensitive. Smaller floating metal above the touch sensor have been used successfully in many cases.

- Temperature drift: Azoteq touch technology tracks any temperature changes very well and offers the same performance over the whole temperature

- Temperature shock: Azoteq touch technology offers multiple integrated options to prevent false touches in extreme environment changes.

Button layout:

- Flexible button size: With Azoteq's high signal-to-noise ratio capability, touch electrodes with diameter of 4mm and more is possible.

- Flexible button shape: Typically, round buttons are used. Various shapes are possible.

- Circuit ground (GND) presence: With GND around the sensor (on the same PCB/FPC), performance and directivity are improved. The gap between the pad and GND should be equal to the overlay thickness. A larger gap will introduce proximity effects ("hover touch") and smaller gaps will decrease sensitivity.

Response time:

- Azoteq solutions are tailored for optimal current consumption vs button response

- The response time is highly flexible and Azoteq provides market leading current consumption for typically required response times

- See a specific ICs reference design response times vs power consumption (contact Azoteq)

Please refer to application note *AZD008 Design guideline for touchpads* for further technical detail.

Copyright © Azoteq (Pty) Ltd 2020.
All Rights Reserved.

AZD097 On-ear detection for headphones - Update
Revision 2.00

Page 3 of 14
November 2022

3 User interface options

3.1 Slider options

Azoteq solutions offer the possibility of adding one or two 1D sliders (each composed of up to 4 channels per slider). A single IC per headphone earcup can easily provide abundant channels to satisfy all required sensor implementation. Gesture recognition is integrated into the slider solutions for up/down/left/right swipes along with position tracking via slider (volume adjust). Tap and hold "gestures" are also standard.

Please refer to the IQS269A datasheet for more details on slider offerings.

3.2 Trackpad options

Azoteq offers multiple trackpad options for smaller hardware. These range from 3x3 projected technology to 2x4 self-capacitance technology.

Please refer to the IQS626A datasheet for more details on small integrated trackpad offerings.

3.3 Mechanical scroll wheel (HALL rotation sensor)

Mechanical rotation of a small magnet can be detected with Azoteq's ProxFusion® multi- sensor IC's: IQS624 and IQS625 in addition to the available capacitive sensors featured on both devices. The rotational Hall sensing is discussed in detail in *AZD092 IQS624 application note*.

Figure 3.1   *Mechanical user rotation inputs can be sensed by ProxFusion Hall rotation devices*

4 Wear detection

The latest headphone products boast features such as automatic play/pause functions upon wear detection or removal. Capacitive proximity sensing provides a contactless method to fulfil such functions with a minimalistic and highly configurable implementation.
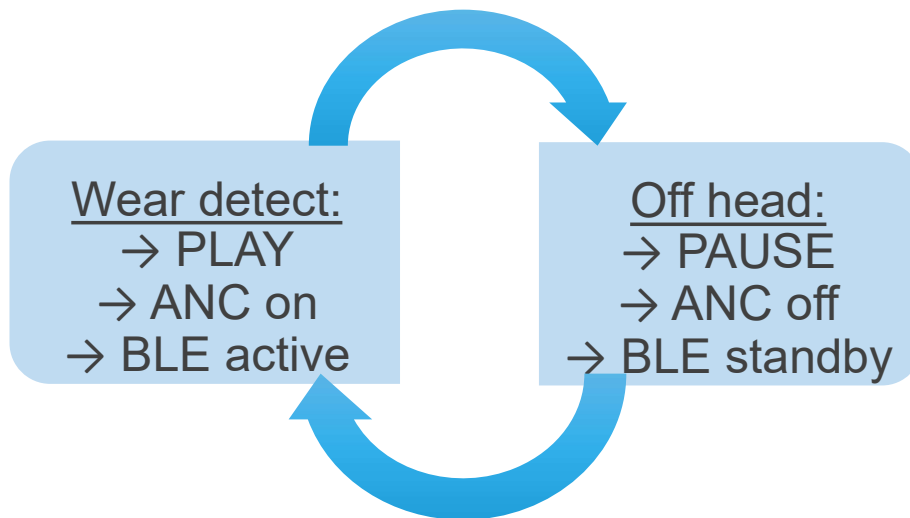

Figure 4.1 *Representation of the two distinct states to be determined, each with their own assigned functionality based on UI requirements. Each condition can typically endure for an undefined duration.*

4.2 Design guidelines

The IQS269A is Azoteq's recommended sensor device for wear detect implementations.

Please refer to application note *AZD107 Introduction to wear detect* for detailed design suggestions.

4.3 Sensor electrode design

Self capacitive sensing is the recommended sensor mode to be used for proximity wear detection.

This method of sensing charges a single conductive electrode multiple times and measures the amount and deviation of charge accumulated at regular intervals. These measurements are referenced towards the common system ground, usually the device battery negative potential, which is shared, through a weaker coupling, towards the user wearing the product. It is ideal to optimise this shared ground coupling as explained later in this document in section 5.3.

A method to ensure excellent user-reference-to-system-ground (GND/VSS potential) capacitive coupling is by means of a dedicated electrode or reference electrode. A reference electrode is used to sense an additional reference / environmental tracking channel to counter for small drift variations during long term wear (activation) states. But such electrodes also serve the dual purpose of providing a good ground reference when a main sensor conversion is taking place to ensure a strong and stable ground coupling to the user's body.

Design parameters includes:

> Ear position and ear to sensor separation distance
> Speaker position and separation to sensor PCB/FPC
> Ear to ground plane / reference Cx distance compared to ear to main Cx distance
> ANC microphones or additional microphone placement
> Power, I^{2}C & RDY connection to host (across headband if implemented in both earcups)
> Temperature, humidity and body heat exposure to electrode, -substrate and IQS-device
> Vibrations and mechanical / user movement rejection
> ESD protection and aesthetical overlay & cushion requirements

Copyright © Azoteq (Pty) Ltd 2020.
All Rights Reserved.

AZD097 On-ear detection for headphones - Update
Revision 2.00

Page 5 of 14
November 2022

Figure 4.2   *Typical sensor electrode assembly in the earcup shared with the host (main MCU). Both earcups can be fitted with similar individual IQS sensors and electrodes but this will require power & I²C + separate RDY connection to pass through the headband.*
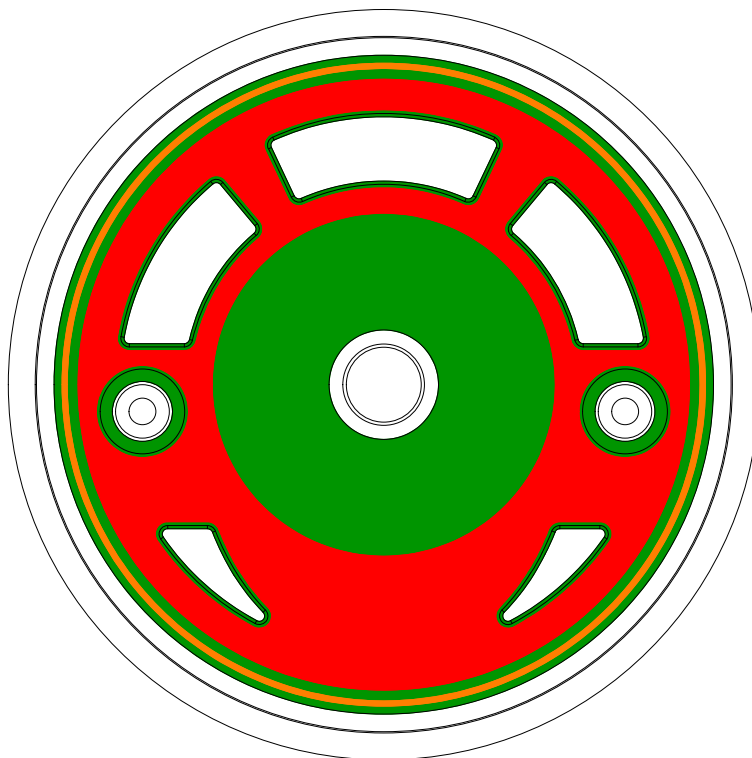
Main Cx
Reference Cx

Figure 4.3   *Suggested sensor PCB electrode layout (Main Cx and Reference Cx trace layouts, single layer user facing)*

Copyright © Azoteq (Pty) Ltd 2020.
All Rights Reserved.

AZD097 On-ear detection for headphones - Update
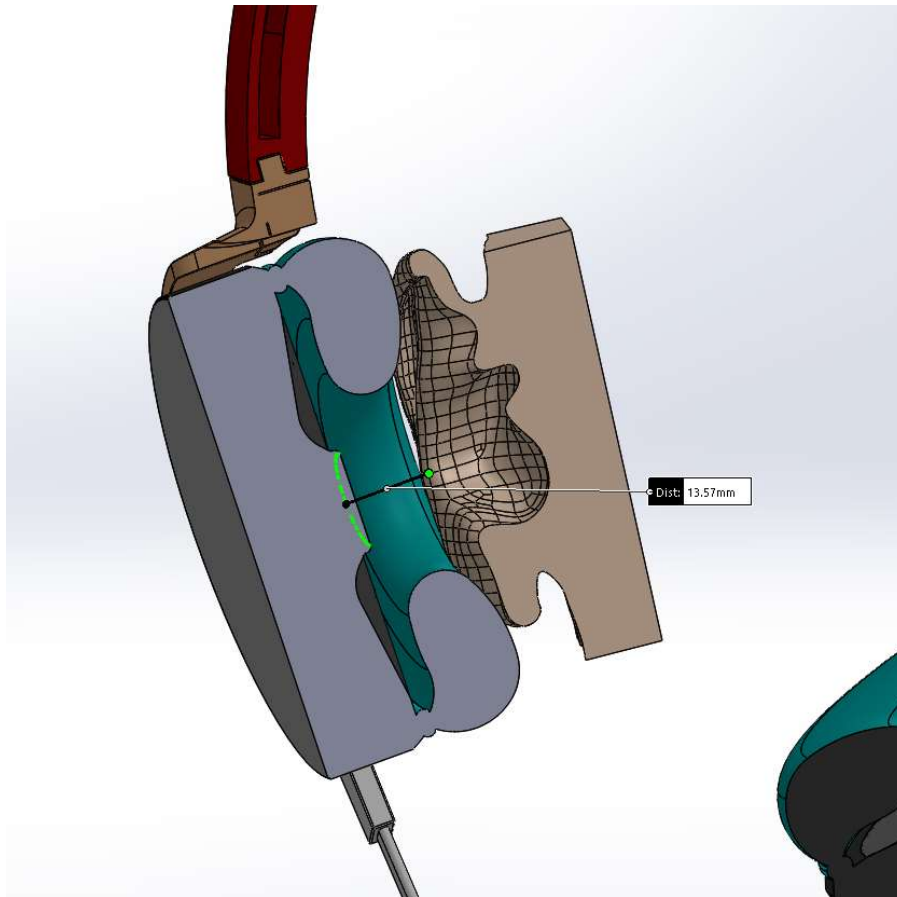Revision 2.00

Page 6 of 14
November 2022

Figure 4.4   *Sectional view and closest measurement of a typical ear-to-sensor separation distance for on-ear headphones (this implies that prox sensitive performance is required from capacitive sensors).*

4.4 Sensor Design Considerations

Designing for wear detect applications and associated use conditions requires strict system stability and qualification over various environmental conditions.

Topics of concern are:

- Temperature drift:
    - o Long term temperature change while still maintaining prolonged activation.

- Temperature shock:
    - o Sudden change in temperature and sensor sensitivity.

- Drop impact, movement on ground references:
    - o False activations or change in reference (LTA) can occur to influence signal integrity.

- Close-by speaker and microphones
    - o Depending on the analogue design and operational amplifier layout of audio circuitry, speakers (and microphones) can act as a reference towards ground for a closely situated capacitive sensor conductor pad or routed line.
    - o Please ensure that feedlines of audio signals are shielded or kept away from open capacitive sensing conductors.

Copyright © Azoteq (Pty) Ltd 2020.
All Rights Reserved.

AZD097 On-ear detection for headphones - Update
Revision 2.00

Page 7 of 14
November 2022

- o The use of twisted pairs and co-axial wiring can be used to effectively counter such disturbances. Best practice is still to plan layouts well in advance for dedicated operation of capacitive sensors in combination with other RF and analogue electronics.

- o Frequency overlap of Class D amplified speakers or commonly used digital MEMS microphones sampled with similar clock frequencies in the same frequency band as capacitive conversions or 1st and 2nd harmonic orders lower may induce radiated noise on capacitive measurements.

- ESD qualification:

    - o System level design for ESD protection or suppression to protect sensor and other IC's.

    - o TVS diodes and suitable ESD 'safe' ground plane connections may be used to divert transient energy away from sensitive electronics.

- Humidity and moisture entrapment:

    - o Internally: Inside cavities or chambers where electrode and electronics are situated because of water and/or dust proof/resistant housing designs.

    - o Externally: Seams and joints of ultrasonic welds trap water/fluids within cavities and can retain the moisture. Similar behavior can be observed on cloth material covers over speaker holes. Electrodes should not exhibit capacitive coupling towards such parts/disturbances.

4.5 Material choice

Substrate material choices are limited due to the curved surfaces normally found in headphone housing designs. Implementation of wear detect electrodes needs to be thin, non-invasive and shielded.

- PCB (FR4):

    - o Inexpensive and commonly used. Rigid and stable over temperature but can retain moisture. Preferred substrate for wear detect sensors in headphones.

- FPC:

    - o Flexible and thin. High precision design and manufacturing. Parasitic loads can easily be excessive in multi-layer designs due to thin thickness of PI core material. Keep inherent parasitic capacitance loads to a minimum with single layer layout approach (do not route Cx traces/electrodes above or below opposite layer conductors such as GND pours – forming paralleled plate capacitor sandwiches on thin FPC). Overlays should be used to prevent user interaction, alterations, or possible circuit damage.

- LDS on plastic:

    - o Higher cost and limited manufacturing possibilities to a single disconnected housing entity. Requires a contact pin connection to sensor circuitry. Single layer and exposed conductor usually unable to be shielded on another layer.

Copyright © Azoteq (Pty) Ltd 2020.
All Rights Reserved.

AZD097 On-ear detection for headphones - Update
Revision 2.00

Page 8 of 14
November 2022

4.6 Filtered long term average during non-activation ("off-head") states

The Long-term average (LTA) is an averaged parameter calculated form the current counts values measured per channel over a long period of time. This serves as a reference per channel to track slow moving environmental changes over time, such as temperature. The LTA is used as a reference, as the delta (current counts value -LTA) will indicate high frequency changes in the system such as a proximity / touch event. See Figure 4.5 as an example of how the LTA is implemented to follow slow variation in counts during non-active states. Figure 4.5 highlights how the LTA is used to track a channel's counts over a slow change in temperature over time.
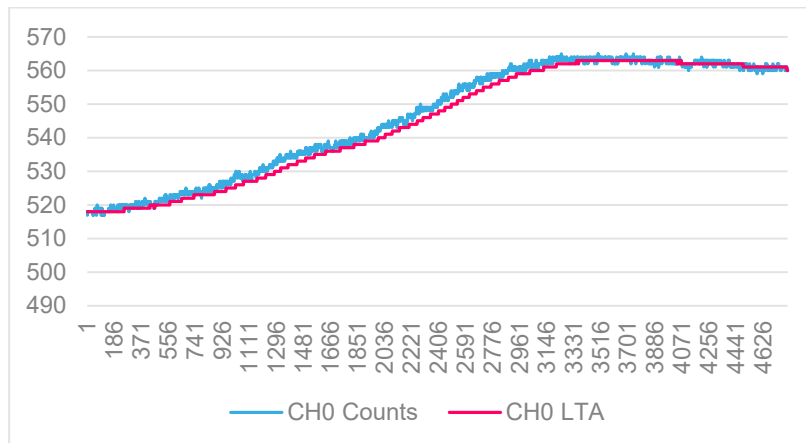
Figure 4.5   *LTA tracking sensor counts due to environmental drift during long term inactive use*

4.7 Halted long term average during activation ("wear") states

Consider a single channel system implementation for explanation purposes: When a sudden desirably big change in capacitive counts occur (decrease in counts for self capacitance), as a result of a person wearing a headphone, the LTA filter is halted (or 'frozen') and the value will remain fixed to accurately determine the delta amount (difference between counts & LTA). See Figure 4.6 below.

Although the sensor counts for CH0 is expected to remain stable as long as the headphones are on-head, actual measurements in most systems have shown slow dynamic behavior present in the count value due to temperature and humidity related variations over the extended period. This may result in a significant offset in counts to incur a stuck condition when the headphones are removed with the counts steady state value not corresponding to the initial halted LTA value. The LTA cannot be updated during activation states (to track environmental changes) as no additional information is available apart from the single measurement actively monitoring the coupling towards the user.
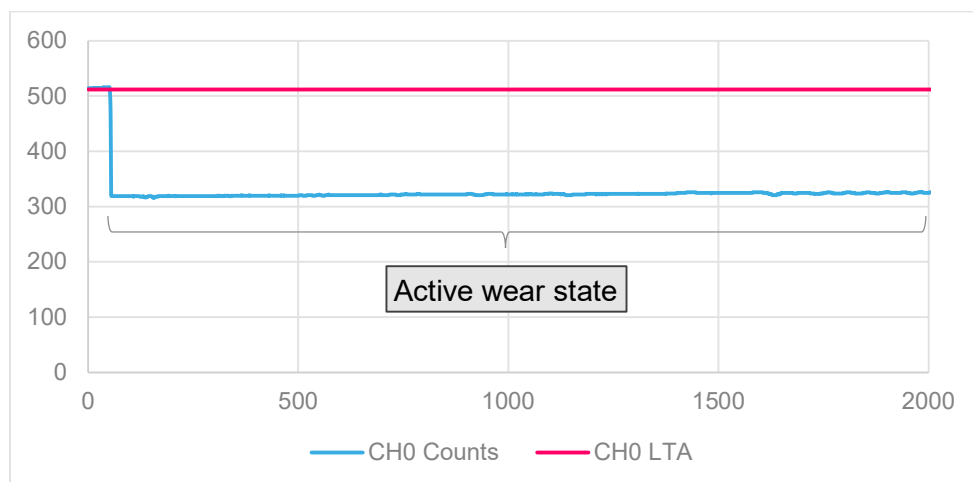

Figure 4.6   *LTA halted during active sensor output and unable to track any environmental drifts*

4.8 Reference channel LTA compensation for temperature & humidity effects

When combining an additional sensor channel (reference channel) to compensate for predominantly temperature and humidity related changes the integrity of the LTA can be maintained even during prolonged activation states.

Figure 4.7 shows a typical IQS269A response to temperature change. Note the following:

- Cooling down changes output result ("Delta no Ref") from about 30 to 75 counts

- With delta changes like above, the output will likely become stuck in "wear detect"

- By using a "reference channel", the "Ref Delta" can be achieved, resulting in an insignificant change on the "wear detect" output. The ideal 'flatline' response is desired across environmental operating ranges.
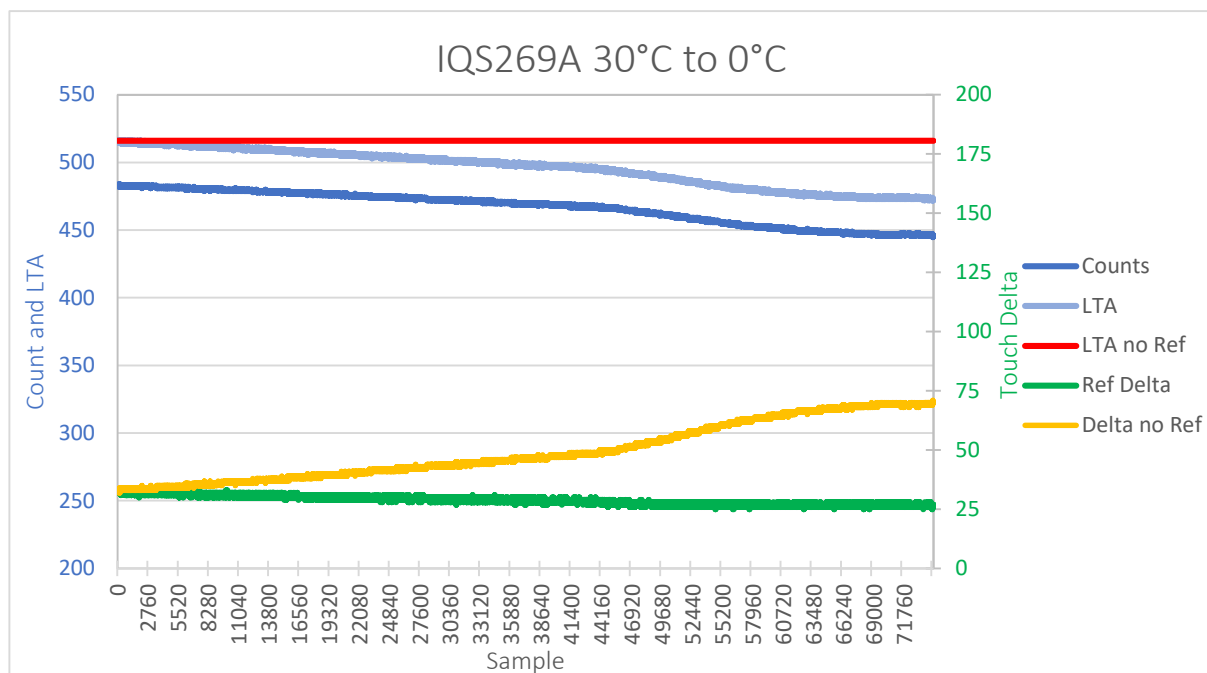
Figure 4.7   *IQS269A temperature change example using an IQS269AEV01 module PCB*

For more detail information of previous and current generation IQS temperature response and related topics please refer to AZD118: Temperature response IQS269A vs IQS620A.

4.9 Moisture & condensation

If a design is sensitive to moisture changes (typical for devices that are over-ear - entrapping air), then the following topics should be considered:

> Moisture change inside the earcup cavity during wear (extended periods)
> Water or condensation on the "wear detect" area (earcup or inside speaker clefts)
> Condensation on wear detect electrode itself
> Water retention in fabrics or porous materials covering electrodes

Copyright © Azoteq (Pty) Ltd 2020.
All Rights Reserved.

AZD097 On-ear detection for headphones - Update
Revision 2.00

Page 10 of 14
November 2022
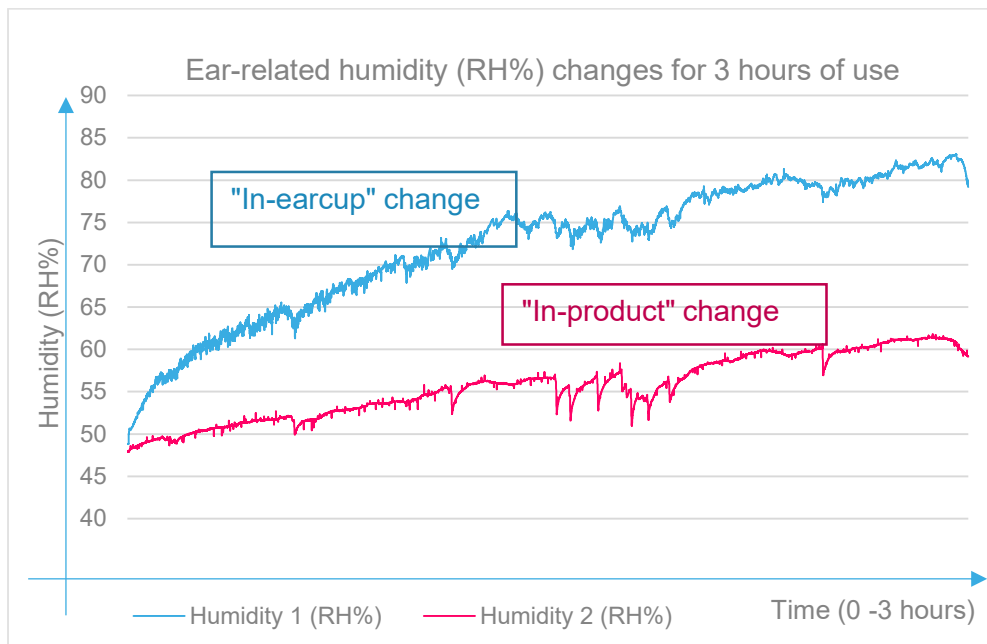
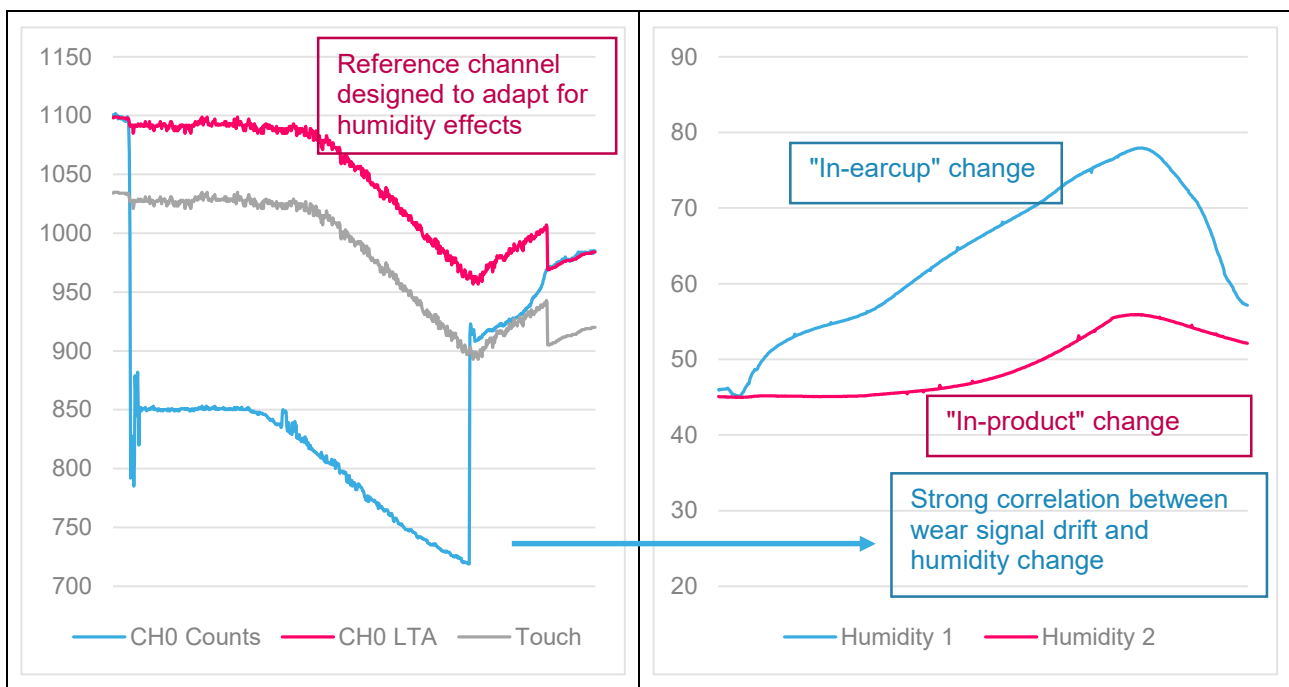*Figure 4.1 Humidity changes possible "in-earcup" and "in-product" during use*

Figure 4.2 An example of correlation between "wear detect" signal drift and humidity change during the wear state.

As example, over-ear headphones units with pressure relief openings have an increased risk for moisture effects. Moisture increase and moisture retention during wear will typically result in a failure to release (or significant release delay) when removed from the ear.

Avoid some of these effects by using materials that are less sensitive to moisture like:

> LDS (plastic printed sensing pads)
> Copper tape
> Single layer FPC designs

Copyright © Azoteq (Pty) Ltd 2020.
All Rights Reserved.

AZD097 On-ear detection for headphones - Update
Revision 2.00

Page 11 of 14
November 2022

4.10 **Connection design**

Please refer to application note *AZD107: Introduction to wear detect*; section 4. *Connection design* for detail and specific topic discussions applicable to connection design.

Copyright © Azoteq (Pty) Ltd 2020.
All Rights Reserved.

AZD097 On-ear detection for headphones - Update
Revision 2.00

Page 12 of 14
November 2022

5 System characteristics

5.1 Connectivity (I²C, RDY & GPIO)

IQS269A offers the following host connectivity:

- Standard two wire (SDA & SCL), *Fast-mode (Fm)* I²C up to 400kHz clock frequency.

- IQS269A supports clock-stretching to slow down communication speed if required.

- An additional host/MCU interrupt signal (RDY) for IQS event indication: open drain, active low.

- External pull-up resistances required on SDA, SCL & RDY signals to the VDDHI supply voltage.

- GPIO3 & GPIO4 outputs are provided by default as push-pull (active high logic).

Other IQS products offer reduced combinations (only I²C or GPIO) or alternative GPIO output signals. Please refer to each device's datasheet for detail functionality descriptions.

5.2 Current consumption & response times

For specific current consumption figures, please refer to the IQS269A or other specific IQS sensor's datasheet & reference design documents. Contact Azoteq for relevant document numbers.

5.3 Power cable connection and ground reference influence

Most headphone devices can be used during battery charging and this is extremely useful when traveling to utilize a connected power supply to keep batteries fully charged. Whether the device is being charged from a laptop, battery pack, car charger or in-flight USB port it is important to consider the change of ground reference once the device is plugged into this power supply (earthed or not). Ultimately the user relative ground reference (which is now shared between system GND and a much larger grounded power supply) is changed due to this power connection. This can directly affect the sensitivity of the device, achieving more significant capacitive change. The human body being sensed is now referenced to a larger ground shared with the device's system ground for increased capacitive charge to exist in relation to the sensor system ground.

To minimize this effect, it is recommended to design a well-referenced sensor which has a stable ground referenced electrode on the sensor PCB near the human body being measured. Thus, enabling the theoretical parallel plate capacitor (an open-folded version) to exist alongside or close to the human ear / head.

5.4 Headphone audio jack connection

Connecting a device via an external headphone jack to play music can also influence the capacitive signal's ground reference as explained in the previous section (or refer to application note *AZD014 Grounding effects in the power supply of capacitive sensors*). Although the impact might not be as severe as a power connection (depending on internal regulators or shared ground planes), it is still a point of concern when optimizing sensitivity. Designers are requested to confirm operation with experimental tests in this regard.
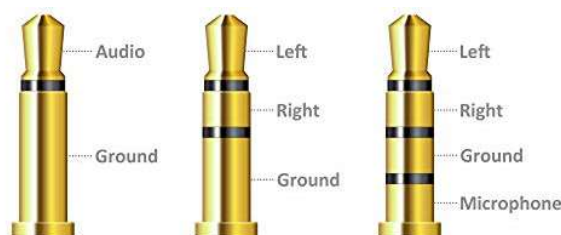

Figure 5.1   Various headphone jack connections with shared ground GND connections may alter capacitive sensitivity if the system ground reference changes in battery powered devices

Contact Information

	USA	Asia	South Africa
Physical Address	11940 Jollyville Suite 120-S Austin TX 78759 USA	Room 501A, Block A, T-Share International Centre, Taoyuan Road, Nanshan District, Shenzhen, Guangdong, PRC	1 Bergsig Avenue Paarl 7646 South Africa
Postal Address	11940 Jollyville Suite 120-S Austin TX 78759 USA	Room 501A, Block A, T-Share International Centre, Taoyuan Road, Nanshan District, Shenzhen, Guangdong, PRC	PO Box 3534 Paarl 7620 South Africa
Tel	+1 512 538 1995	+86 755 8303 5294 ext 808	+27 21 863 0033
Email	info@azoteq.com	info@azoteq.com	info@azoteq.com

Visit www.azoteq.com

for a list of distributors and worldwide representation.

Patents as listed on www.azoteq.com/patents-trademarks/ may relate to the device or usage of the device.

info@azoteq.com