Design an ANC headset using the AS3415

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In my last article, "Active noise cancellation: Trends, concepts, and technical challenges," I explained what different active noise cancellation (ANC) topologies are available, and we got an insight into the production challenges of ODMs and contract manufacturers. Another challenge in the development phase is the ANC circuit development itself. This article will describe the development steps necessary to design a feed-forward ANC headset based on the AS3415 ANC chipset from ams.

Equipment Overview
Before we can actually start with any kind of ANC headset development it is important to know that special audio equipment is necessary. The most important part is an audio measurement system that is capable of doing frequency- and phase response measurements. Audio equipment suited for these measurements is, for example, Audio Precision, Brüel&Kjaer and Soundcheck.

In addition to the audio measurement system it is also important to have an ear simulator like the IEC711 (in-ear ANC products) or a Head & Torso simulator (on-ear and over-ear products) from Head Acoustics, Brüel&Kjaer or GRAS. The simulator is necessary to emulate the human ear when doing the headset characterization. These artificial ears do have a highly accurate microphone integrated that allows us to measure what a person would actually hear when wearing the headset.

To determine the passive attenuation of the headset, which is part of the filter characterization process, a speaker is also necessary. The speaker should be a two-way speaker system, preferably a two-way coaxial speaker to make sure the distance for high and low frequencies from the speaker to the headset are the same. Last, but not least, you need an AS3415 evaluation board that includes all the necessary connectors and preamplifiers to make the characterization process as smooth as possible.

Why do we need characterization of the headset?
Each headset behaves differently in terms of acoustics. The reason is rather simple to explain. The headsets are using different components like speakers with different impedances and transfer functions. The cushions differ from on model to another as well as the front-side and back-side cavity.

For ANC headsets it is crucial for the development to know the characteristics of the headset in order to get good ANC performance. A feed-forward ANC headset is using an electret condenser microphone (ECM) to pick up the noise at the outside of the earcup. The electronics create an inverted anti-noise signal and this signal is played back with the speaker.

In theory, the ANC circuit can be a simple inverting circuit but the reality looks different. Because a headset has different components that influence the frequency and phase response, a simple inverting circuit does not fulfill the requirements to get decent ANC performance. In order to
understand how the headset behaves in terms of gain and phase it is important to characterize the ANC headset.

To get to the ideal ANC filter curve we have to do three measurements with the equipment described in the first paragraph. The first measurement is a passive attenuation measurement shown in Figure 1.

![Figure 1: First Feed-Forward Characterization Measurement](image)

We start a frequency sweep (20 Hz to 22 kHz) with the coaxial speaker and measure the sound that arrives at the human ear. This sound can be measured with the microphone inside the ear simulator. We characterize how the noise is damped by the headset itself - what is called passive attenuation.

The second measurement, shown in Figure 2, measures the frequency response of the microphone that picks up the noise. Again, a sine sweep signal is played back with the coaxial speaker and picked up by the ANC microphone.
The third and last measurement, **Figure 3**, is a frequency and phase response measurement of the speaker inside the headset. A frequency sweep from 20 Hz to 22 kHz is played back with the speaker inside the headset and the signal is picked up by the microphone inside the artificial test head.
This measurement represents the transfer function of the anti-noise signal played back by the speaker and how it is received at the human ear. For all three measurements the phase is very important because if the anti-noise signal that is played back with the speaker is in phase with the noise that travels from the noisy environment to the human ear, we amplify the noise instead of attenuating it.

Ideal ANC Filter Calculation

Ideal ANC Filter Calculation

Once the three measurements are finished we can use it to calculate the ideal ANC filter for the headset. The needed filter amplitude is calculated as follows:

$$A_{\text{Filter}}(f) = A_1(f) - (A_3(f) + A_3(f)) \quad [dB]$$

where:

- $A_{\text{Filter}}(f)$ = Ideal ANC filter gain response
- $A_1(f)$ = Gain of characterization measurement 1
- $A_2(f)$ = Gain of characterization measurement 2
- $A_3(f)$ = Gain of characterization measurement 3

The desired filter phase is calculated as follows:

$$\varphi_{\text{Filter}}(f) = \varphi_1(f) - (\varphi_3(f) + \varphi_3(f)) \quad [DEG]$$

where:

- $\varphi_{\text{Filter}}(f)$ = Ideal ANC filter phase response
- $\varphi_1(f)$ = Phase of characterization measurement 1
- $\varphi_2(f)$ = Phase of characterization measurement 2
- $\varphi_3(f)$ = Phase of characterization measurement 3

The calculation can easily be done in an Excel sheet and a sample filter is shown in Figure 6. Looking at the sample frequency and phase response makes clear that we are far away from an ideal system, which just requires an inverting amplifier across the complete frequency range to generate the necessary anti-noise signal.

Filter Development

The key to success for a good ANC headset is the filter development. Even the best ANC chipset does not help if the filter design is not done properly. The goal when doing the filter development is matching the gain and the phase response as closely as possible. The better the match at a certain frequency, the more ANC performance you can expect.

Because the signal processing is analog based, the filter simulation is usually done with a spice simulation tool. What Figure 4 shows is a spice simulation circuit that represents the ANC microphone filter signal path.
Figure 4: Spice Filter Simulation Example

The goal of the ANC filter design engineer now is to match the gain and phase response of the filter simulation circuit shown in Figure 4 with the calculated ideal ANC filter curve as closely as possible. Typical filters that are being used are low-pass filters 1st order, notch filters, high- and low-shelf filters.

The designer has to know how the different topologies look and how to calculate the cut-off frequencies, pass bands and stop bands. This is, of course, not an easy task - especially if you are not used to a spice simulation tool and analog filter developments in general.

Feed-Forward Filter Simulation Tool

To overcome this problem, the AS3515 evaluation software has an integrated feed-forward filter simulation tool shown in Figure 5. The design engineer can use this tool to develop the ideal ANC filter.

Figure 5: AS3415 Feed-Forward Filter Simulator
Instead of changing component values and physical filter topologies the tool provides you with a set of predefined filter structures. These predefined filter structures are based on filter simulations ams did in the past for many different customers, and it should be possible to cover almost 90% of any possible ANC acoustic.

The simulation result for the given example of the tool is shown in Figure 6. The green curve represents the ideal ANC filter gain and phase response. The blue curve shows the simulation result of the ANC filter developed with the tool shown in Figure 5.

Figure 6: Simulation Result

When developing the filter it is important to know what areas we have to focus on. ANC headsets do work up to a certain frequency range. The reason for this is not a limitation of the AS3415 electronics itself. It is related to the speed of sound and the acoustic behavior of the headset.

When we analyze the ideal filter curve and look at the gain response it should be an easy task to design a filter that matches the curve. The tricky thing in ANC filter design is matching the phase as well. Because the phase at the higher frequencies is shifting by approximately 180° it is possible to design a filter that matches the frequency response, but not the phase.

Depending on the headset and the phase response you can typically try to match the filter up to 1.5 kHz. Higher frequencies have to be attenuated as much as possible. If we do not attenuate these unmatched higher frequencies we introduce noise. We attenuate noise at the lower frequencies but because of the phase mismatch at the higher frequencies, noise gets amplified instead of attenuated. To avoid this behavior we try to reduce that gain to a minimum in those areas where we cannot match the phase and the gain.
The green transparent area, shown in Figure 6, indicates the area where we can typically meet the gain and phase with a minimal mismatch. The red area is the area where we try to attenuate as much as possible. It is always important to find a good trade-off between high-frequency attenuation and phase response because when you attenuate at the higher frequencies too much it influences the phase response at the lower frequencies, and therefore you might lose ANC performance.

**Filter Verification and ANC test**

Once you are satisfied with the filter curve, the AS3415 filter simulation tool provides you a BOM export function. Since the tool is linked to the evaluation board of the AS3415, the components listed in the BOM can be soldered to the eval board to test the ANC performance with the developed filter. It consists of two measurements. First is a passive attenuation measurement of the headset put on the artificial head. Second is the same measurement again, now with the AS3515 switch on and configured for feed-forward ANC operation. The ANC performance can be calculated as follows:

\[ A_{\text{ ANC}}(f) = A_{\text{ active}}(f) - A_{\text{ passive}}(f) \]  

[\text{dB}]

where:

- \( A_{\text{ ANC}}(f) \) = Active noise reduction level
- \( A_{\text{ active}}(f) \) = Passive attenuation with ANC on
- \( A_{\text{ passive}}(f) \) = Passive attenuation with ANC off

The calculation can be done with an Excel sheet to create a plot of the ANC performance over frequency, which is very common in the industry. The development tools for the AS3415 as well as application notes and templates for the ANC headset development are available upon request. For more information please visit [www.ams.com](http://www.ams.com).

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