Active noise cancellation: Trends, concepts, and technical challenges

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Active Noise Cancelling (ANC) headsets are an attractive proposition to consumers, since they offer a superior listening experience in conditions that are normally hostile to audio reproduction, such as trains, airplanes and busy urban areas. In fact, while the idea of silencing ambient noise is a simple one, its practical implementation is complex.

Nowadays the trend for music headsets goes to big over-the-ear headsets, whereas five years ago in-ear systems were the most popular. Consumer preferences have obviously changed in the last couple of years and besides the original use case (listening to music), headsets have turned into a fashion statement.

Developing an ANC headset requires considerable know-how, especially if you want to combine a piece of art with modern ANC technology. No matter in what kind of headset ANC is implemented (in-ear, on-ear or over-the-ear headsets) there are basically three different concepts to tackle the ambient noise.

ANC Concepts The most common is the feed-forward topology (see Figure 1), in which a microphone exposed to the exterior senses ambient noise, and the ANC circuit generates an anti-noise signal that the speakers reproduce (together with the user's audio playback signal). This headset type consists of four blocks: the speakers, battery, ANC circuit, and ANC microphones for the left and right channels.
Figure 1: ANC Feed Forward Block Diagram

The feed-forward topology is typically used in communication headsets like Blue-tooth headsets because of its wide ANC bandwidth. Such systems can cancel noise up to 3kHz with properly designed acoustics.

The higher frequencies in particular help to improve speech intelligibility if you are making phone calls since this is the typical frequency range of human voice. Another important advantage of a feed-forward ANC system is that there is absolutely no influence on the audio signal path.

Figure 2: Feed Forward Block Diagram

Figure 2 shows the signal flow of a standard feed-forward ANC headset. The "Dff" block represents the feed-forward delay caused by the speaker due to the conversion from electrical impulses to air pressure waves. The noise signal that is picked up by the microphone is treated with a gain and phase compensation filter G(\omega) and mixed together with the sound signal. The music playback path is completely independent from the noise reduction path.
Another interesting mode that is commonly used in ANC headsets is the monitor mode. In this mode the ANC microphone is in turn being used to actively amplify the ambient noise. In this special mode the gain and phase compensation filter $G(\omega)$ is bypassed and the microphone is connected directly to the speaker amplifier. This helps to overcome the passive attenuation of a headset when having a conversation with your neighbor or flight attended in a plane without removing the headset.

Typically this mode can be activated by pressing a push button on the headset. A disadvantage that comes with feed-forward systems is that they are susceptible to wind noise if the electronics and the acoustics are not properly designed.

**Feedback Concept**

A solution to overcome the wind noise issue is a different ANC topology. The second topology in the ANC industry is the feedback topology. This topology makes use of the same hardware blocks like we have in feed-forward applications. The only difference is the location of the microphones, which are inside the ear capsule. This makes the headset insusceptible to wind noise.

Another advantage that comes with feedback systems is the automatic compensation of little leakages. With feed-forward systems it is important to have a good sealing of the headset to the ear, otherwise you get only very limited ANC performance. This is a typical problem and very often the reason why feed-forward systems (especially in-ear systems) do not deliver the same ANC performance across various test persons.

Although this behavior can be compensated with a proper acoustic design, feedback systems usually do not show this behavior. Up to a certain degree they can compensate sealing tolerances of the headset.

**Figure 3: Feedback Block Diagram**

A major difference between the two ANC topologies is the noise reduction characteristics. Feedback systems usually have better low frequency performance (<100Hz) but do not reach the bandwidth of feed-forward systems. Typically feedback systems can work up to 1kHz and have a more flat ANC distribution with lower peak values. In turn, feed-forward systems show superior peak performances (typically up to 25dB) with a cone-shaped characteristic.
Figure 3 shows the typical block diagram of a feedback headset. The music signal is directly fed to the speaker. The ANC microphone and the speaker are located inside the ear capsule and build a closed environment, which leads to a general drawback of the feedback topology.

Since the microphone is located inside the ear capsule it picks up the noise signal and the music signal. Thus, the ANC microphone cannot distinguish between music- and noise-signal. This signal is then fed back and treated with a gain and phase compensation filter $G(\omega)$. Because both signals, noise and music, are used in the feedback path, the headset tries to cancel music and noise. This phenomenon is well-known as low-frequency loss in ANC feedback systems.

Since the feedback ANC system shows typically good low-frequency performance, the low-frequency content of the music is reduced by the ANC performance level in the frequency range where the ANC is active (20Hz - 1kHz). A simple trick to overcome this problem is shown in Figure 2. One way to compensate for the low-frequency losses is the subtraction of the music signal from the microphone signal. Very often a gain compensation filter $M(\omega)$ is used to further improve this compensation circuit. The output of the subtraction circuit is the pure noise signal that is used for noise reduction.

This solution looks quite simple on paper but is rather difficult to implement because we have an acoustic signal path (speaker to microphone) involved. A simpler approach is an EQ circuit on the music input. With a simple bass-boost function the low frequency losses can be compensated for, with the possible drawback being headroom issues with the amplifiers.

**Hybrid Topology**

While the feed-forward and feedback topologies are commonly used in headsets, the new "Hybrid" technology has rarely been used up to now. Figure 4 shows the block diagram, which is nothing more than a combination of the feed-forward and feedback topology.

![Hybrid Block Diagram](image)

This technology combines the advantages of both systems into a single unique technology. It allows you to achieve best ANC performance levels (>30dB) and widest bandwidth. One system
compensates for the lacks of the other system and vice versa. These systems typically show superior ANC performance from 20Hz up to 3kHz, which is not possible with a standalone feed-forward or feedback system.

Although the system is the most expensive one (two ECM microphones per channel) and requires a lot of mass production expertise, it is a solution that allows you to be silhouetted against ordinary ANC headsets. Therefore it is now a surprise that the trend for new high-end ANC headsets goes definitely toward "Hybrid".

ANC Production Challenges
A problem that all ANC solutions have in common is production trimming. Variations in the microphone have a very marked impact on headset performance.

The tolerances of a typical electret microphone are around +/−3dB. In order to compensate for those tolerances a fairly complex tuning procedure is necessary. Today, this is normally accomplished by adjusting two potentiometers on the PCB. This is a manual process - the adjustment is made by an operator using a screwdriver. In order to optimize performance, the operator must adjust the screw while viewing the output of the test rig until the optimum gain setting is found.

This process is both time-consuming and error-prone, because the operator must concentrate on the test results while making the adjustment. In addition, the headset assembly cannot be finished until the headset is trimmed. If the ANC circuit is integrated into an over-the-ear capsule the back of the headset must be removed during trimming. This creates the risk that the acoustic behavior of the headset will be different after re-assembling the capsule, and thus generating a new, uncompensated variation in ANC performance.

New Production Technology
If this manual process is slow, unreliable and expensive, how can it be automated? The answer is by implementing a circuit with a dedicated digital trimming capability - a feature found in a new generation of ANC ICs such as the AS3410/AS3430 feedback/feed-forward ANC solution from ams. In an automated trimming system, the audio jack becomes the trimming input of the ANC headset.

The 3.5mm audio jack is the only connection to the outside world, and therefore the only route into the internal hardware besides the battery terminal. Used as a trimming input, the jack can configure digital potentiometers in the ANC circuitry. The benefit is clear by comparison with today's headset production method: it eliminates the need for careful manual adjustment with a screwdriver, and the operator handling the headsets does not need any knowledge of the way that trimming works, since a fully-automated trimming process can be installed.

An automated trimming system such as that enabled by ams' AS3410/30 thus eliminates human error, improves production yield and generates more reliable, higher-performance outputs. The prospect is that ANC headsets can be manufactured more cost-effectively, and therefore are within reach of the mass consumer market, rather than being, as now, a high-end item for wealthy consumers.

More about Horst Gether.