Technical Article

How adaptive ANC solutions improve listening experience in real-world situations

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Introduction

While ANC is nothing new to audiophiles, the technology has grown in popularity since a well-known Californian company released its first earbuds featuring Active Noise Cancellation in 2019. Since then, end user awareness of ANC has increased significantly and it has become a requisite feature for True Wireless (TWS) earbuds as well as headsets.

Static ANC Solutions

If we look back ten years, most headset designs were built using discrete electronics. At that time, few integrated solutions were available as a small number of semiconductor companies had invested in the miniaturization of electronics in this niche market.

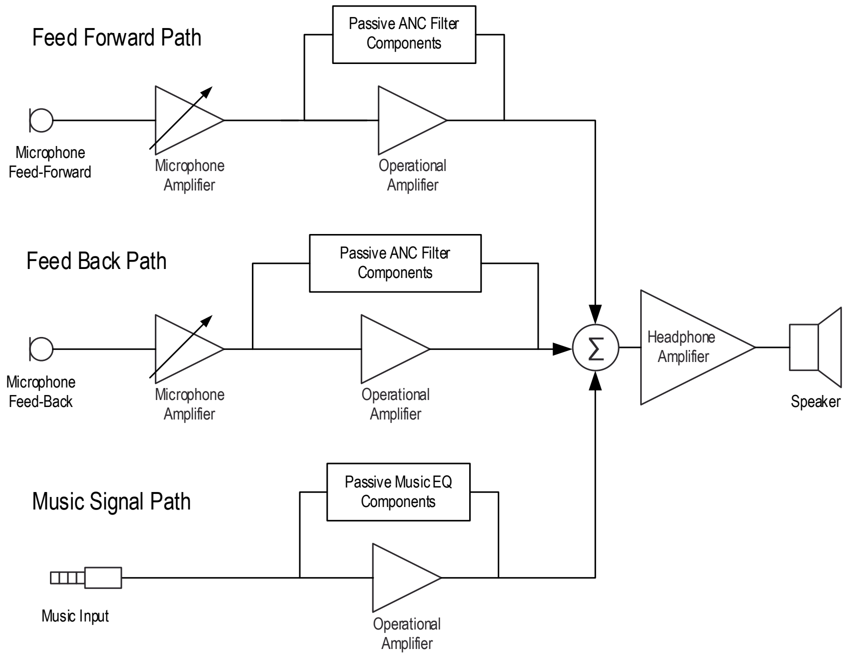


Figure 1: Typical discrete and static ANC Circuit

Looking at the typical ANC implementation, shown in Figure 1, it can be observed that there was little opportunity to implement much flexibility and innovation. All the filter circuitry was based on fixed electronic components. The only chance for tuning was calibration of the microphones during mass production via mechanical potentiometers to compensate for the electro-acoustic tolerances of the headset. During the last five years, semiconductor companies began to recognize the market potential of ANC and so released an abundance of static digital ANC solutions offering many benefits over analog solutions – as there is no longer the need to solder passive RC components for filter tuning. For example, software updates can improve the performance of a headset or solve stability issues that might occur during field testing. However, beside the move to digital signal processing the basic functionality stayed virtually the same as with analog implementations. While design engineers get more convenient tuning capabilities, drawbacks could be said to include higher power consumption and lower performance compared to analog solutions due to increased latency.

ADAPTIVE ANC FOR AMBIENT SOUND DETECTION

As silicon process nodes are shrinking to reduce current consumption while increasing computation power of digital signal processors (DSP), the capabilities of digital ANC solutions have improved. Instead of static digital ANC systems which offer limited benefits compared to analog solutions, engineers began to recognize the potential of new digital low-power ANC solutions which can provide a differentiating feature called Adaptive Noise Cancelling. As there is no official nomenclature for ANC features, there is often a misunderstanding in the industry – even between engineers who deal with ANC every day. Adaptive noise cancelling definitions vary depending on the benefits experienced by end users. The most common technology provided by many digital ANC solutions on the market is adaptive ANC based on ambient sound detection. But what does this mean or why would I want to adapt my ANC system based on ambient noise? Well, at a first glance, you might say that this makes no sense as I always want my ANC to work at its best. However, end users nowadays are wearing headphones in many different situations, each facing different noise characteristics as shown in Figure 2. The ambient noise profile in a plane is certainly different that in a café. On a plane, the user typically hears annoying, low-frequency noise caused by the jet engine, whereas in a café the user is likely to experience high-frequency noise that they prefer to limit.

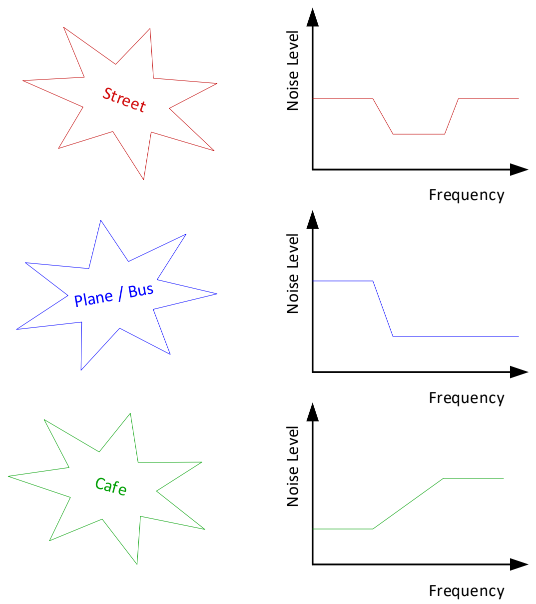


Figure 2: Adaptive ANC for ambient sound detection

The trend of adaptive ANC systems is to identify the dominant noise source and focus the ANC system on this frequency range. This task is usually implemented with additional DSP software algorithms. However, to identify the ambient noise profile, the feed-forward ANC microphone also feeds into the low latency ANC DSP and a second DSP. Based on this ambient noise profile, the ANC filter coefficients – which define the ANC characteristics of a headset – can be reconfigured. Alternatively, there are also several solutions that offer four or more different ANC presets. These can be controlled by a MCU or via button press without the need to exchange filter coefficients which helps to reduce, for example, I²C bus traffic.

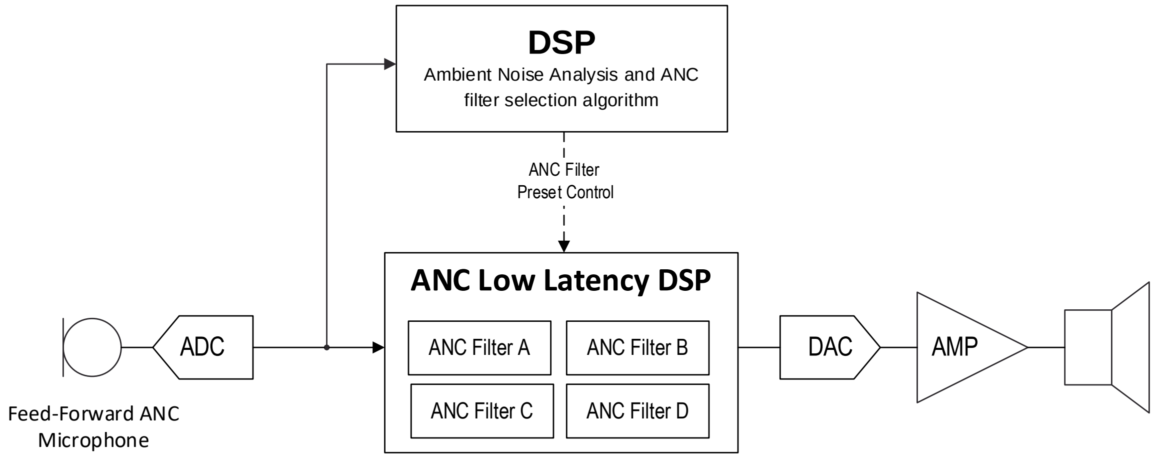


Figure 3: Adaptive ANC System based on ambient sound detection

The principle shown in Figure 3 is the same for most market solutions, however there are differences in the ambient-noise detection algorithm. The simplest way is based on FFT with frequency weighting of the noise signal. ANC vendors try to differentiate with detection algorithms and existing detection methods are going to be replaced with neural-network-based scene detection. Therefore, a headset can exactly determine environment – an office, café, plane, or somewhere else – and select the ideal ANC filter or augmented hearing profile. The system block diagram shown in Figure 3 is a simplified example and there are various implementation options to support this feature. No matter which solution, the output is always the same, the noise cancelling function is automatically adjusted based on ambient noise or detected events in this category of adaptive ANC systems.

Adaptive ANC with Automatic Leakage Compensation

The second category shares, as previously indicated, also the same name Adaptive Noise Cancelling but solves a completely different end-user problem. It is well known that good ANC performance requires high-quality ANC circuitry with low latency plus excellent electroacoustic components. However, there is a third important factor which is very often forgotten. An ANC headset with its gain and phase compensation filters are designed for a specified sealing and passive attenuation of the headset: but what does this mean in simple words? It is all about the correct fit of the earbud in the user's ears. A poor sealing of the earbud influences the passive attenuation, which affects the target ANC filter transfer function. Well, this may sound academic, but what does this mean for an end user? The influence of passive attenuation and the fit of the earbud can result in ANC performance loses among different users. This is a common problem engineers struggle with to ensure good ANC performance across a wide range of users. The drawing shown in Figure 4 illustrates the problem expressed in ANC performance loss with different earbud leakage levels.

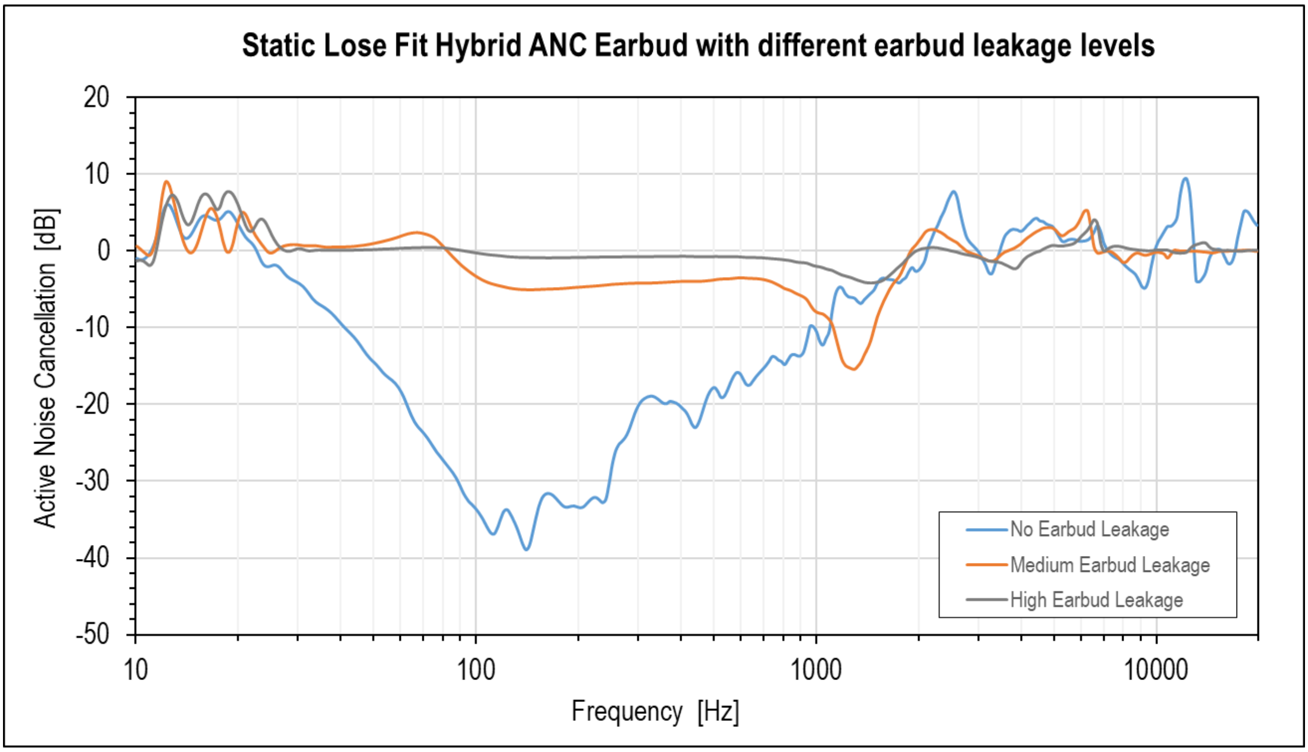


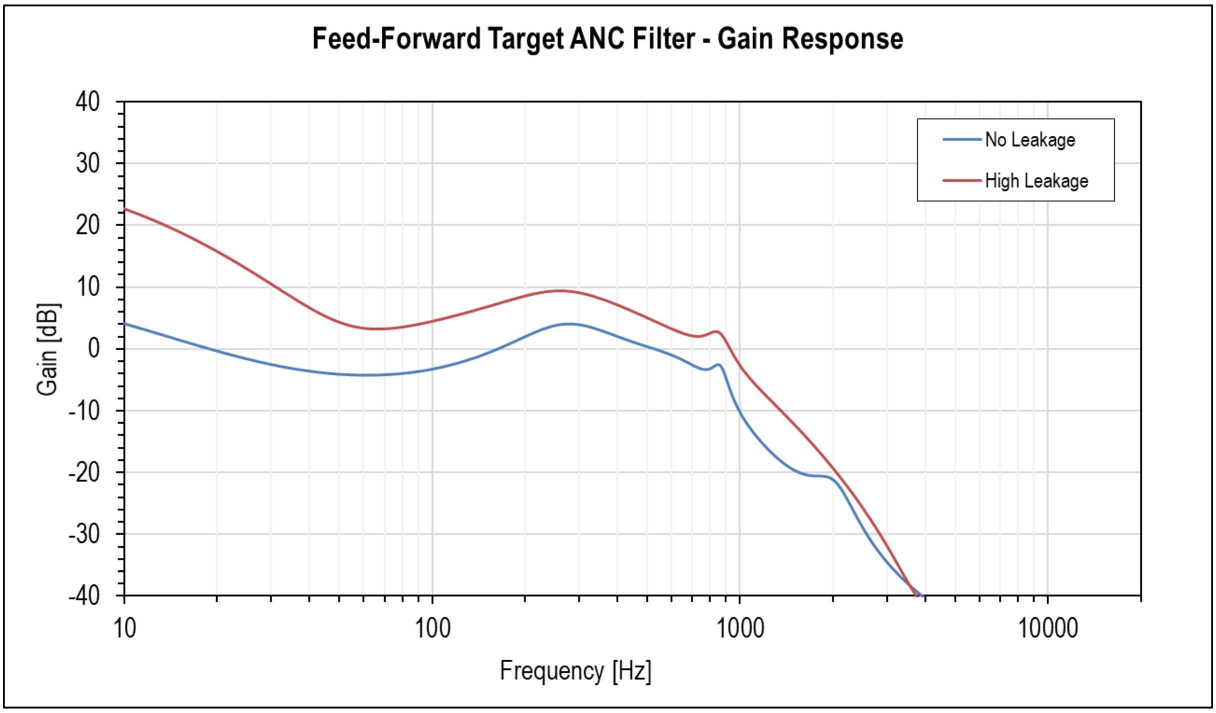
Figure 4: ANC Performance loss based on different earbud leakage levels.

The graph shows the ANC performance of a loose-fit (no rubber tip being used) TWS earbud with different controlled leakage levels. The 'No Earbud Leakage' curve is the leakage level for which the headset is designed for a good fit to the user's ear. The device shows superior ANC performance for this use case with excellent peak performance and wide ANC bandwidth. As soon as a leakage is introduced (Medium Leakage corresponds to $8mm^2$ controlled leakage) you can clearly see that the ANC performance drops by ~30dB and there is also a massive reduction of the ANC bandwidth. If the leakage is further increased (High Earbud Leakage corresponds to ~$20mm^2$ controlled leakage), which represents a loose-fitting earbud, the performance drops below 10dB which means for an end user there is virtually no ANC noticeable. The described behavior of different ANC performance levels and earbud fits among different users is a problem solved by Adaptive ANC. Therefore, this type of adaptive ANC system aims to compensate for acoustic misfit to ensure every user can get constant

ANC performance independent of the fit of an earbud to its users' ears.

How does Adaptive Misfit compensation work?

Adaptive ANC that compensates for misfit requires a complex hardware and software architecture. To get a better understanding of what is needed, it makes sense to look at the target frequency and phase compensation curves for at least one of the ANC signal paths. In the example shown in Figure 5, the feed-forward target gain and phase compensation filter curves are shown for no-leakage and high-leakage use case. As mentioned earlier in static ANC systems the filter is typically optimized for no leakage operation when the earbud is inserted properly in the ear.



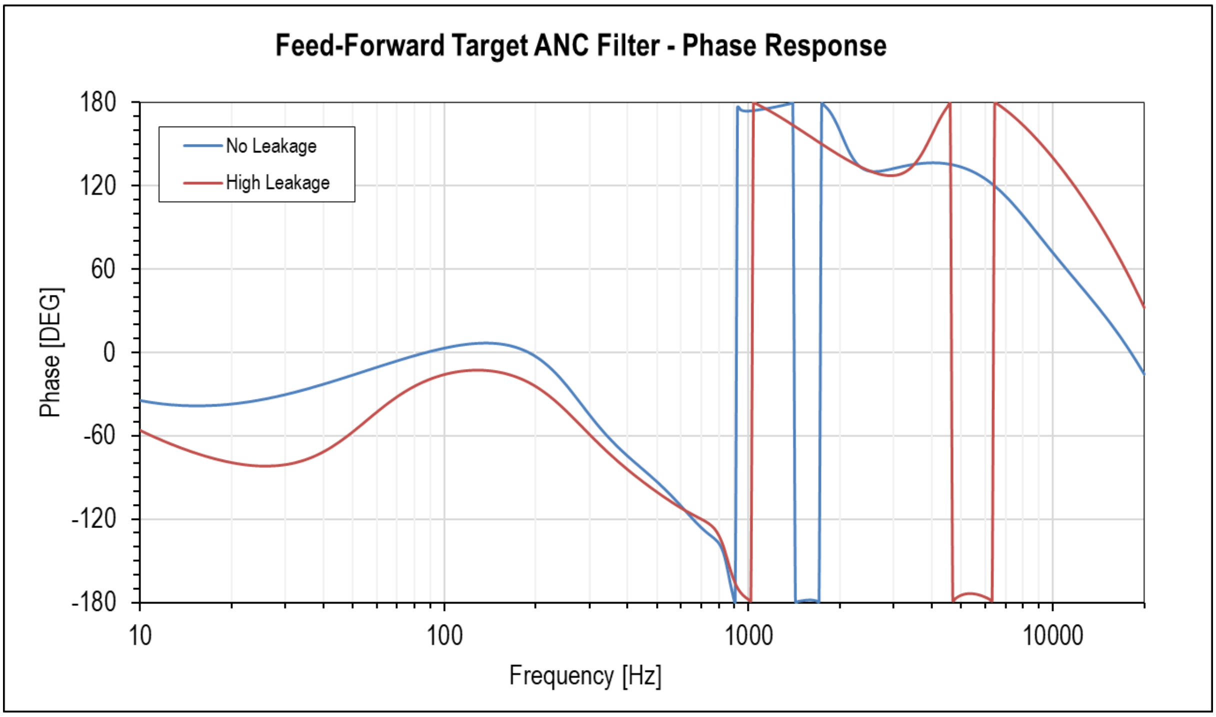


Figure 5: Target filter curves for ALC example for different leakage levels.

As we are aiming for an adaptive system, we can see in Figure 5 that the target ANC feed-forward frequency and phase response is changing for high-leakage levels which can explain the ANC performance loss shown in Figure 4 previously. In a static ANC system the gain and phase no longer matches the target curve once the earbud is not properly positioned in the ear. Therefore, the requirement is clear for an adaptive system that compensates for misfit. The device needs to be able to dynamically adjust the ANC filter transfer function based on the earbud leakage level. Perhaps this does not sound too difficult. As today's ANC systems are based on hybrid ANC technology it is not as simple as that, especially if we look at Figure 6 which shows a high-level system block diagram of an adaptive ANC system.

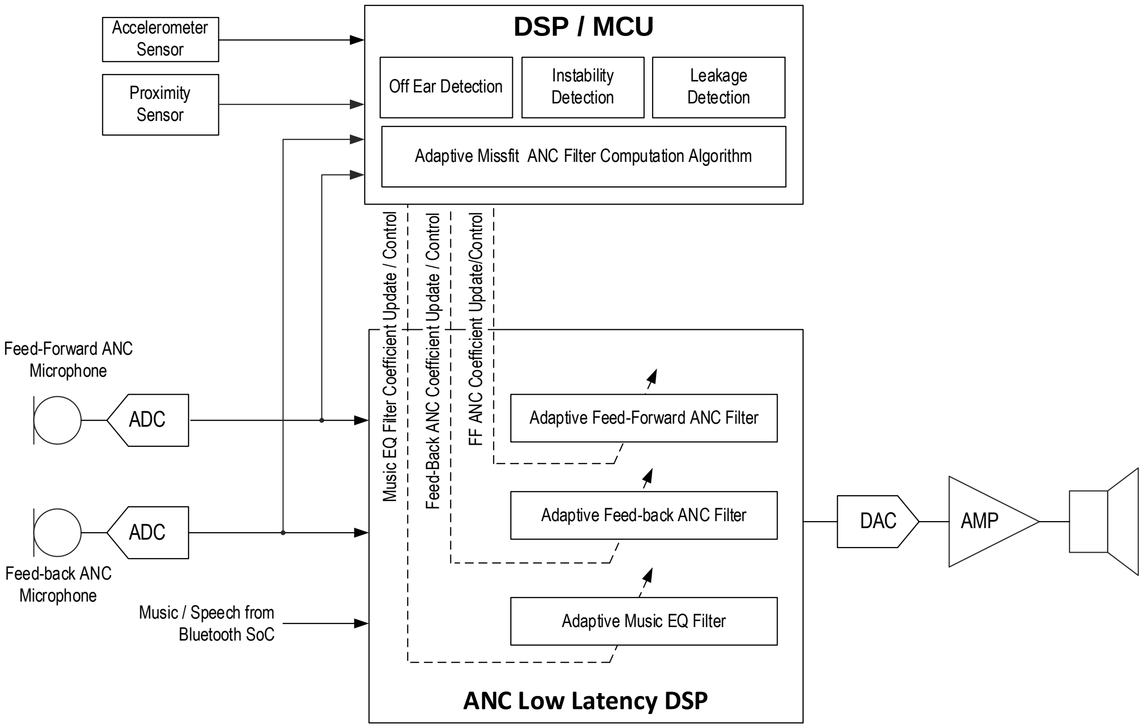


Figure 6: Adaptive ANC system for misfit compensation.

The block diagram shows a lot more system blocks compared to a static system. In principle, the low latency DSP which supports the noise cancelling function itself can be like a static system as it needs to be able to fulfill the same function. The only difference is that instead of being able to switch between different filter characteristics or presets the filter must be dynamically adjusted during run time. A switch to another filter bank or preset would cause ANC dropouts which is certainly not preferred. Therefore the DSP needs to be able to support dynamic reconfiguration of the filter transfer function while ANC is active. This makes the design of an ANC DSP more complicated because in static systems this is not normally a requirement. Important to mention is that not only is the feed-forward ANC path adopted, but – to maintain highest performance – also the feed-back ANC signal path. In addition, high-quality ANC systems also adopt the music playback frequency response to maintain the same sound quality with different leakage levels. To change the filters according to the leakage level there are also software algorithms necessary to detect a leakage level in the user’s ear. This is typically done with a second MCU or DSP which is monitoring the microphones as well as additional sensors like a proximity sensor and an accelerometer. While microphones are being used to detect the leakage level, proximity sensors are typically used to detect corner cases. As misfit compensation algorithms are also adjusting the critical feed-back ANC filters, it can happen that the system starts oscillating and becomes unstable because too much feedback gain is used in a high-leakage condition or if the earbud is completely out of the ear. Therefore, additional sensor signals help to make the adaptive system robust and detect instabilities to avoid howling inside or outside the user’s ear. This is one of the most critical functions because customers would certainly complain and think that the earbud is defective. Therefore, engineers have to ensure that under no circumstances instabilities can occur. The only questions that remain now: does this additional effort really pay off? Do these complex adaptive systems really work? Let us look at Figure 7 which shows the ANC performance of an adaptive TWS loose-fit earbud with three different leakage levels as in Figure 4 with a static ANC system. We can clearly see that for no leakage we get best ANC performance over a wide bandwidth from 20Hz up to 2kHz. If leakage is now introduced to the system, software algorithms detect the leakage and change the ANC filters accordingly. The performance level can be held high to a maximum even with high earbud leakage levels. If you look closely to the curve you might recognize that in the lower frequency area performance is slightly reduced. This phenomenon can be easily explained. This earbud design used for the adaptive ANC test has no rubber tips and falls under the category of loose-fit earbuds. In such open earbud systems with high leakage, the output power of speakers is limited due to physical size. At a certain leakage point, the speaker cannot produce enough output power to cancel the entire low-frequency noise which results in reduced low-frequency performance. In general, the results of adaptive ANC systems are promising and can elevate ANC to the next level. The technology certainly can also be applied to sealed earbuds or over-ear headsets, compensating for leakages caused when wearing glasses.

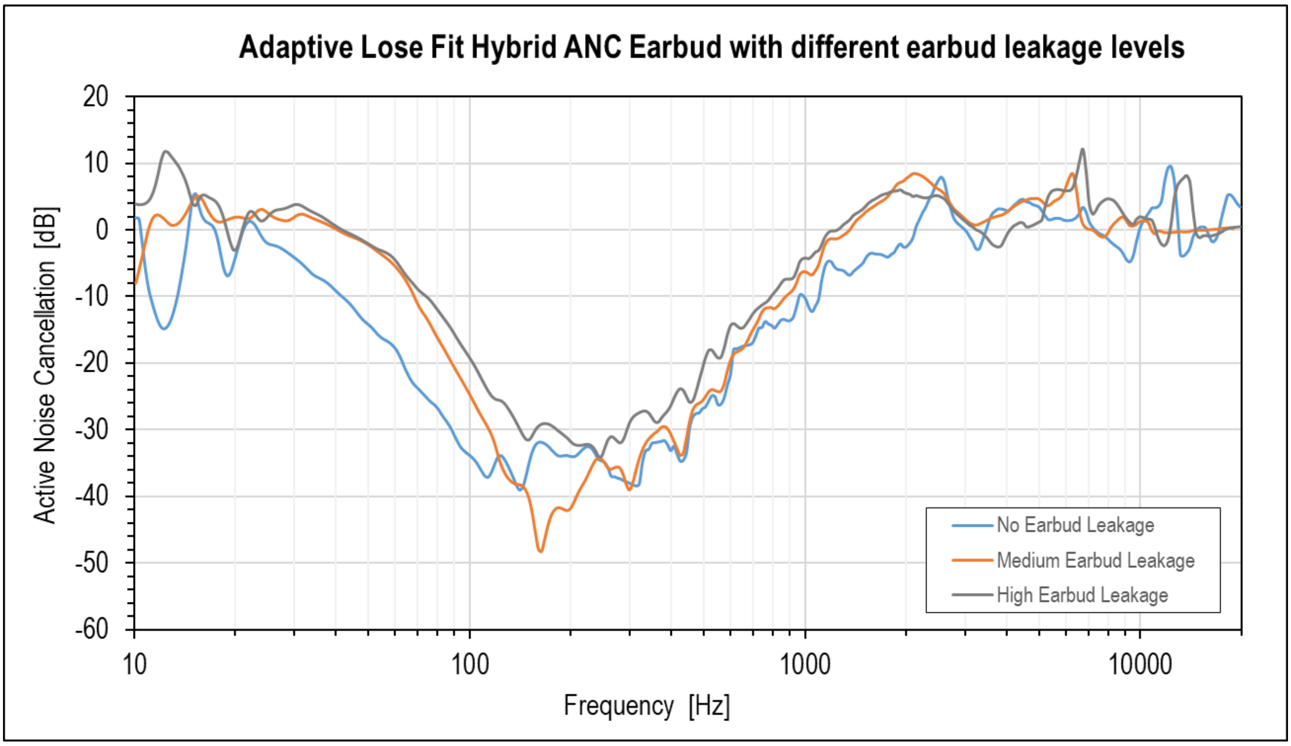


Figure 7: ALC Performance curves with different leakage levels.

In the near future, we are likely to see adaptive systems which combine adaptive misfit compensation systems with neural network-based systems that recognize the environment, so compensating for misfit and optimizing the ANC sweet spot simultaneously.

Do Adaptive ANC Systems Make Sense?

Some may say: I do not want an electronic system to take over control and I can manage operation modes and proper fit of my earbuds. Other users may benefit from a system that always delivers ideal performance independent of the environment. I believe there is no right or wrong, it is all about personal preferences and the way a product is being used. Some users may enjoy the feature, while others do not really appreciate it. Fortunately, it is possible to disable such features and the best way to evaluate options is by testing the ams AG development platform for adaptive noise cancelling solutions around the AS3460 digital augmented hearing platform. Tailor-made ANC development tools for adaptive ANC solutions, using the AS3460, are available upon request.

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