EarStudio: Analog volume control

The importance of the analog volume control

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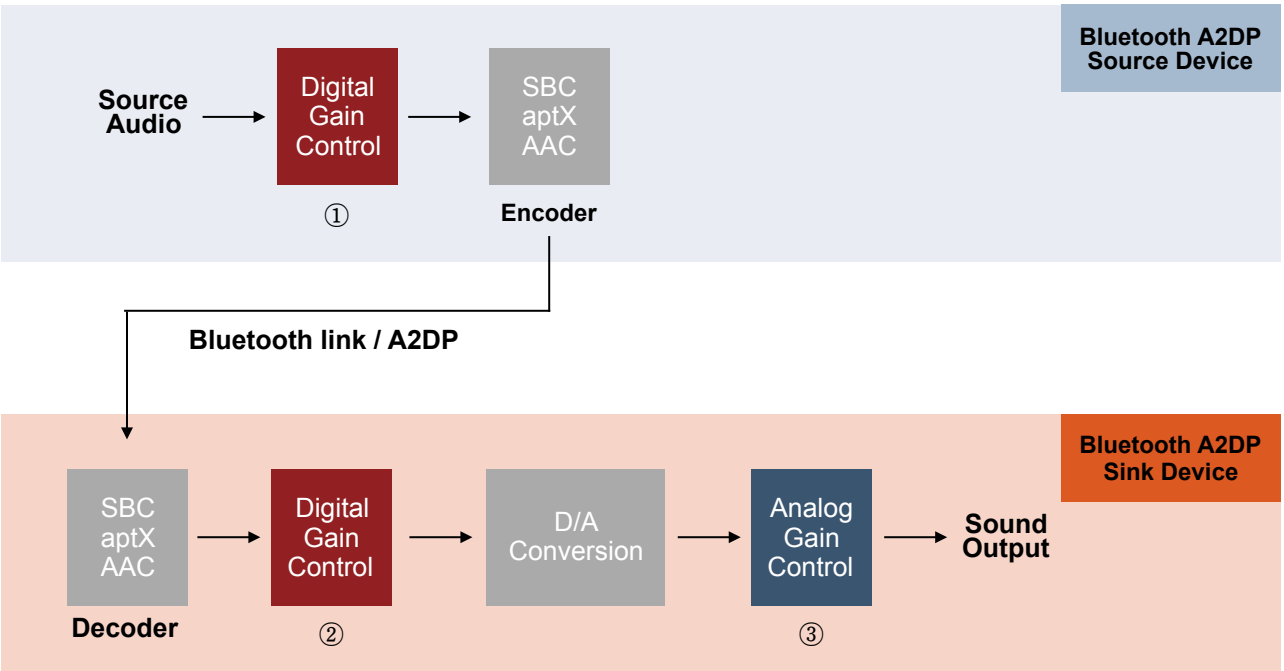
In every digital audio system, DAC is an essential component which converts digital PCM sample to the analog signal. Unlike analog audio system which always adjusts the volume in the analog domain, the digital audio system can adjust the volume in the digital domain before D/A conversion. However, digital volume adjustment has the downside because it scales down PCM audio sample before the D/A conversion, resulting in harsh sound and the loss of sound detail, SNR, as well as THD. That is why every high-end audio system uses the analog volume control to keep optimal audio performance even at low volume level.

Especially, in the Bluetooth A2DP(Advanced Audio Distribution Profile) application, the volume control can be equipped before the encoder, such as SBC, aptX or AAC, at the source device, or after the corresponding decoder at the sink device.



As shown in the block diagram above, there are 3 gain control subsystems which can control the volume along with the A2DP streaming. And we'd like to point out that there is a significant difference at a low volume level depending on which module controls the volume.

If you set the system volume to the maximum level without any saturation or overdriving, you would listen to the best quality output as much as the system could perform. However, there are not many people who listen to music at the maximum volume level.

At which level are you listening to music?
For example, iOS music player volume level is dB linear scale, ranged from -60dB to 0dB. That means if you set the volume level to the exact middle point, you will listen -30dB lower than the maximum.

EarStudio has a built-in PGA (Programmable Gain Amplifier), which adjusts the output level in analog domain after D/A conversion. To get into more details, there are two methods of analog volume control which are PGA and potentiometer. PGA is small-sized and digitally controllable which allows controllable by software, while potentiometer is mechanically operated and it has the downside of noise occurrence and bigger size. To sum it up, PGA is a better and newer way of analog volume control.

Fig.1 shows the spectral analysis results of EarStudio as a USB DAC, measured by Audio Precision Equipment for 997Hz sine wave at the maximum output level. (Please note that the 16-bit limit of EarStudio USB DAC bit resolution. The best THD+N and SNR would be -96dB theoretically.)

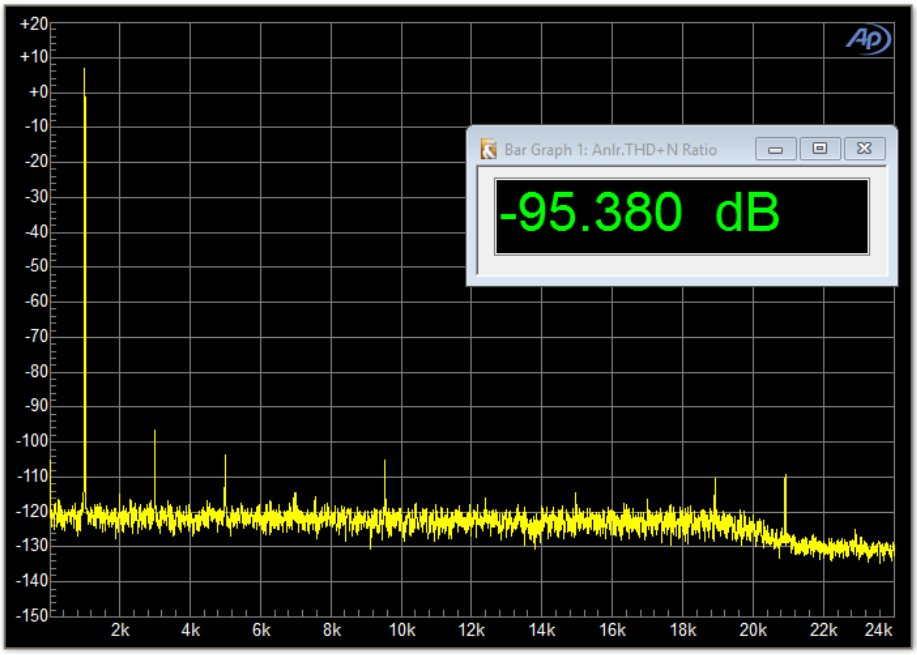
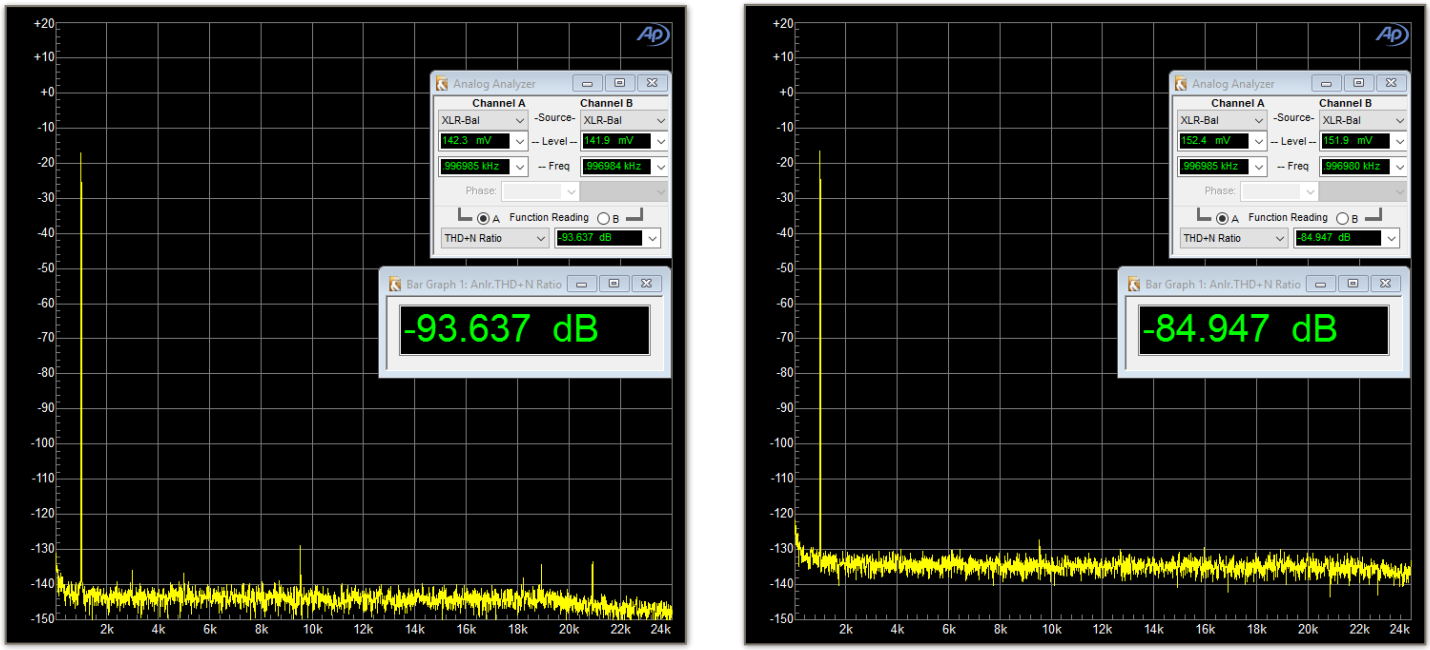


Fig.1. The maximum output level of EarStudio

(997Hz 0dBFS with USB Audio Class 1.0)

Fig.2 shows the spectral analysis results measured at -24dB volume level. As shown in the figure, the peak level of both is same. (i.e. the same output power and loudness)



a) analog volume control by EarStudio

b) digital volume control by source player

Fig.2. -24dB volume level of EarStudio (USB DAC)

In the case of b), PC delivers the reduced level of 14-bits samples, truncated by -24dB digital volume adjustment, to EarStudio. Which means, before the D/A conversion, 2-bit of LSB was lost resulting in a loss of sound details. In the other word, you will end up listening to the deteriorated 14-bit CD-quality sound, not a regular 16-bit sound. The THD+N also gets worse from -96dB to -84dB as the volume decreased by -12dB.

In the meanwhile, the case a) indicates the performance of EarStudio with analog volume adjustment controlled by the built-in PGA (Programmable Gain Amplifier).

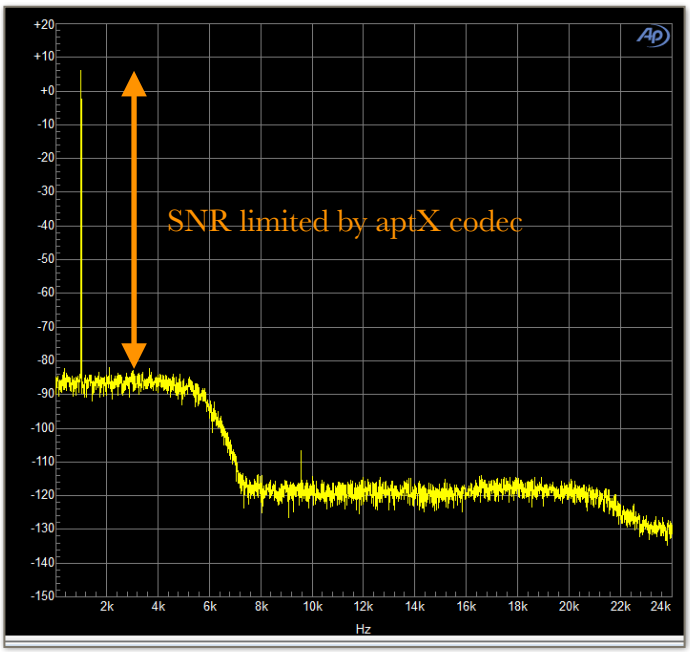
The DAC converts the full 16-bit precision source input to the analog signal, and after the D/A conversion, PGA adjusts the volume down at the desired level. Also, the overall noise floor has been decreased along with the peak keeping the best possible SNR, as the PGA adjusts the output gain of the amplifier.

The analysis illustrates the primary advantage of analog volume control keeping the best possible THD+N, SNR and sound details at a low volume level.

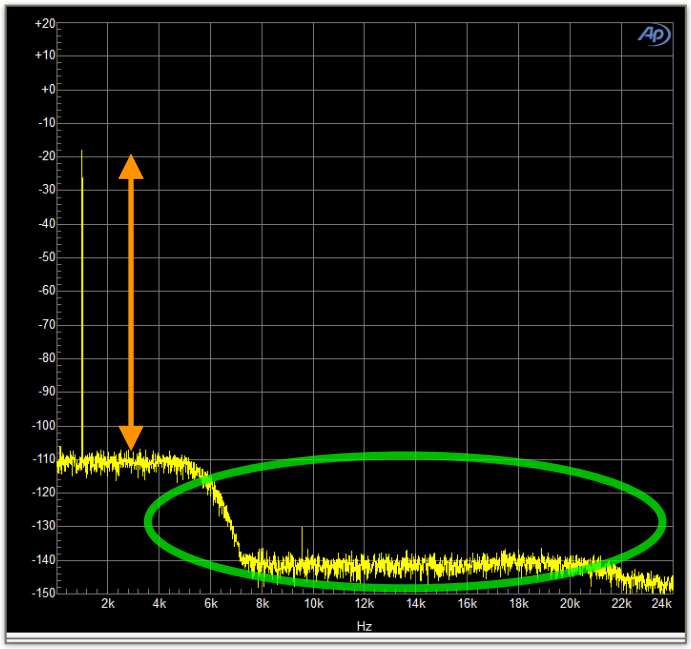
A little adjustment of digital volume in a 32-bit or a 24-bit signal chain may not cause distinguishing noise higher than the analog H/W noise floor usually caused by thermal noise. However, in a system with the 16-bit audio signal chain, the digital volume control would cause critical damage to the overall sound quality.

This is why the analog volume control is so important, especially in the current Bluetooth audio streaming, which mostly supports 16-bit only. As long as we keep the all the 16-bit precision before the encoder and before the D/A conversion, the full CD-quality sound will be delivered over Bluetooth.

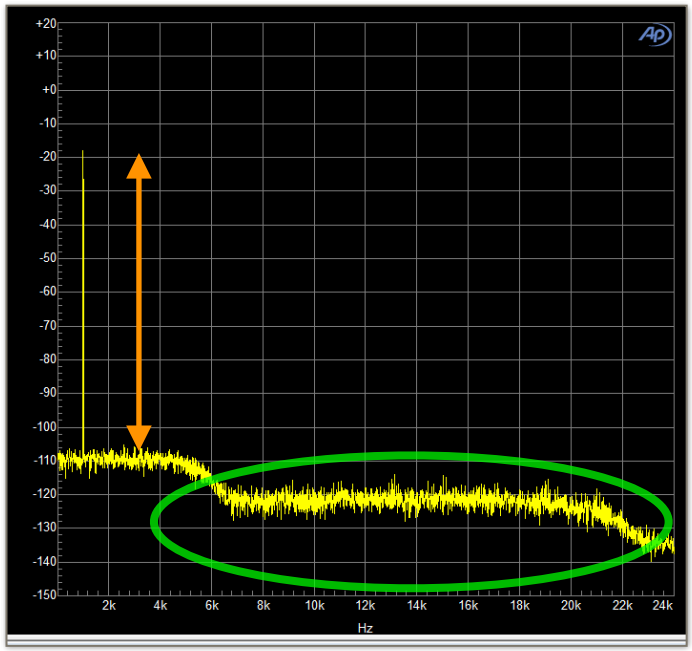
Another indication of EarStudio shown below with aptX codec which has its unique spectral response as shown in the Fig.3.



a) maximum level (0dBFS)



b) -24dB analog volume by EarStudio



c) -24dB digital volume at mobile phone

Fig.3. Spectral analysis of aptX

At a low-frequency band, the quantization noise caused by aptX codec is much bigger than the H/W analog noise. As shown in Fig.3 a) and b), the SNR at a low-frequency band is limited and determined by aptX codec. If -24dB gain adjustment assumed, there's no performance difference in low-frequency band, less than 5KHz, between digital vs. analog gain adjustment

However, in the green colored circle, a high-frequency band above 5KHz, the analog gain control shows considerably better performance. The unique spectral characteristic of aptX remains at the same as it is designed. That means aptX codec delivers the sound as best as it can. And then, PGA of EarStudio adjusts the gain after D/A conversion and keeps overall noise floor remained at the same even in high frequency, in result maintains the every detail of the sound.

On the other hand, Fig.3 c) shows the result, when the volume is adjusted in the digital domain, especially before aptX encoder at the source device. As summed -24dB gain down at source device, the only 14-bits out of 16-bits are passed to aptX encoder, resulting considerable loss especially in the high-frequency band, above 5KHz.

The test with aptX-HD (24-bit codec) also shows the similar result, keeping the spectral characteristic of aptX-HD same as designed and preserving all 24-bit resolution without any truncation or loss.

In conclusion, the analog volume controlled by PGA of EarStudio keeps the every detail of sound at any volume level. Especially, in the Bluetooth application mostly 16-bit, any gain control before the encoder (SBC, aptX, and AAC) at the source device would cause a certain amount of loss in LSB(Least Significant Bit). As a result, the encoders cannot make the best performance as much as they can, due to those bit losses of the PCM input to them.

[Remark for iOS users]

For the reasons explained above, iOS provides the option for the volume synchronization over Bluetooth AVRCP. That is:

Controlling volume on iPhone remotely controls the connected Bluetooth device volume. And the volume control at the Bluetooth device is delivered to iPhone for the synchronization back and forth. In this way, iOS guarantees AAC encoder always fed with the full precision 16-bit input at any volume levels, having AAC codec perform the best as it can do. The digital volume control after AAC decoder at the sink will cause another degradation in sound detail. However, as always Apple does, the volume synchronization would be the easiest, and user-friendly way to provide the best codec quality even for those who are not familiar with these signal flow.

Some Bluetooth receivers or headphone use this scheme supported by iOS, while the others do not. It is one of the design choices.

If any volume control on your Bluetooth receiver remotely applies to the iPhone's volume control, that means the volume between both devices are synchronized, and your receiver is safe from this issue, always receiving the full-precision best possible PCM sample as AAC can do. If not, you need to take a further step to set the iOS volume level at the maximum to keep the best AAC encoding quality, then adjust your receiver volume appropriately. Otherwise, you may not be listening to the best quality given to your system.

However, in order to manage fine analog volume adjustment, EarStudio does NOT support the volume synchronization even with the iOS device. We'd like to provide the full degree of freedom for analog volume control with finest step sizes: 0.5dB step with EarStudio mobile application and 2dB step with EarStudio HW buttons. Thus, please make sure to set and keep the mobile phone volume at the maximum level, so that the encoder in the iOS/Android would perform at best before the A2DP transmission.