Digital vs. Analog Volume Controls

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• In a Digital Audio System what is the trade-off between using a digital or an analog volume control?
  – To answer this question we need to know:
    • How a digital volume control works and what are its limitations
    • How an analog volume control works and what are its limitations
Digital Volume Control -10dB

• Here is the number 30,003 shown as it appears to a 16 bit DAC:

0111010100110011 = 30,003

• How do we “turn its volume down” - ie reduce its amplitude? We simply multiply it by say -10dB -10db is 0.3162 and here is the result:

0010010100010000 = 9,488

• Any problem? Shouldn’t the answer actually have been

30,003 * 0.3162 = 9487.7817?

Its close, it is only wrong by 23 parts per million, but it is not right
Digital Volume Control  -35dB

• Here is the number 30,003 shown as it appears to a 16 bit DAC:

  0111010100110011 = 30,003

• How do we “turn its volume down even more”, say by -35dB
  -35db is 0.0177828 and here is the result:

  0000001000010110 = 534

• Any problem? Shouldn’t the answer actually have been

  30,003 * 0.3162 = 533.5372?

Its close, but not so close, it is wrong by 866 parts per million
866ppm – surely no problem?

- Why worry about 23ppm at -10dB, and 866ppm at -35db? Surely these are small errors?
- No they are not small:
  - 866ppm has degraded the performance of that 16 bit DAC by a factor of more than 50!
- ▶ As a digital volume control operates on a fixed-width field (ie on that 16 bit number that the DAC receives) it creates noise because the DAC cannot make the fractional part of the number.
  - And this is a large noise!
We will learn more if we are prepared to look at signals in the Frequency Domain. Here is a 16bit DAC in time and in frequency:

The amplitude here is -1dB

ENOB 15.87
SN 97.63
We will learn more if we are prepared to look at signals in the Frequency Domain. Here is a 16bit DAC in time and in frequency:

ENOB 14.35
SN 88.51

The amplitude here is -10dB
We will learn more if we are prepared to look at signals in the Frequency Domain. Here is a 16bit DAC in time and in frequency:

The amplitude here is -35dB
Clearly, the noise is not moving!

The signal is decreasing as we requested.

But the noise is not going down!

Consequently, the signal-to-noise ratio is getting worse as digital volume control is reduced.

This is why audiophiles generally avoid digital volume control.
We will learn more if we are prepared to look at signals in the Frequency Domain. Here is a 16bit DAC in time and in frequency:

ENOB 16.01
SN 98.53

The amplitude here is -1dB
We will learn more if we are prepared to look at signals in the Frequency Domain. Here is a 16bit DAC in time and in frequency:

ENOB 15.94
SN 97.95

The amplitude here is -10dB
We will learn more if we are prepared to look at signals in the Frequency Domain. Here is a 16bit DAC in time and in frequency:

The amplitude here is -35dB
Now the noise moves down as well

The signal is decreasing as we requested

Now the noise is going down as well

The signal to noise ratio is being maintained

This is why audiophiles generally like analog volume control
Can Digital be Improved?

- Analog appears to be a clear winner. But can we improve digital?
  - The digital volume control is limited because the DAC (and the data source in the last example) were both 16 bits.
  - What happens when a 16 bit number is fed to a 32 bit DAC?

Internally 32 bits, externally 16/24

-135.023 dB A

-60 dB input
Volume Control internal to DAC

• Here is the number 30,003 shown as it appears to a 32 bit DAC:

\[ 0111010100110011.0000000000000000 = 30,003 \]

• How do we “turn its volume down even more”, say by -35dB
-35db is 0.0177828 and here is the result:

\[ 0000001000010110.1000100110000100 = 533.5372 \]

• Any problem? Shouldn’t the answer actually have been

\[ 30,003 \times 0.3162 = 533.5372 \]

As indeed it is...

When the volume control has access to the additional bits in the DAC data path, there is no numerical loss of accuracy.
• A Digital volume control with access to the DAC internal data path will behave just like the analog one until it reaches the noise floor of the analog components of the DAC.

• -135dB in the ESS Sabre DAC
Analog still better?

• In fact, yes it is.
  – As long as the analog volume control has a noise floor better than the DAC noise floor, the analog one will win

• Conclusion:
  – Analog volume controls easily outperform digital, unless the digital control has access to the data path of the DAC (i.e., is internal to the DAC)
  – Exquisitely well designed analog volume controls can still beat even the very best internal digital volume controls if they have a lower noise floor than the DAC itself
    • The -135dB of the ESS Sabre DAC would need an exceptionally low noise analog volume control to beat its internal digital one
End of Volume Control Presentation

Any questions?