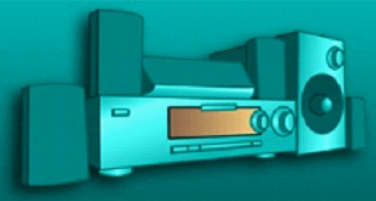
Digital vs. Analog Volume Controls

October 2011



Summary of this Presentation

- 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



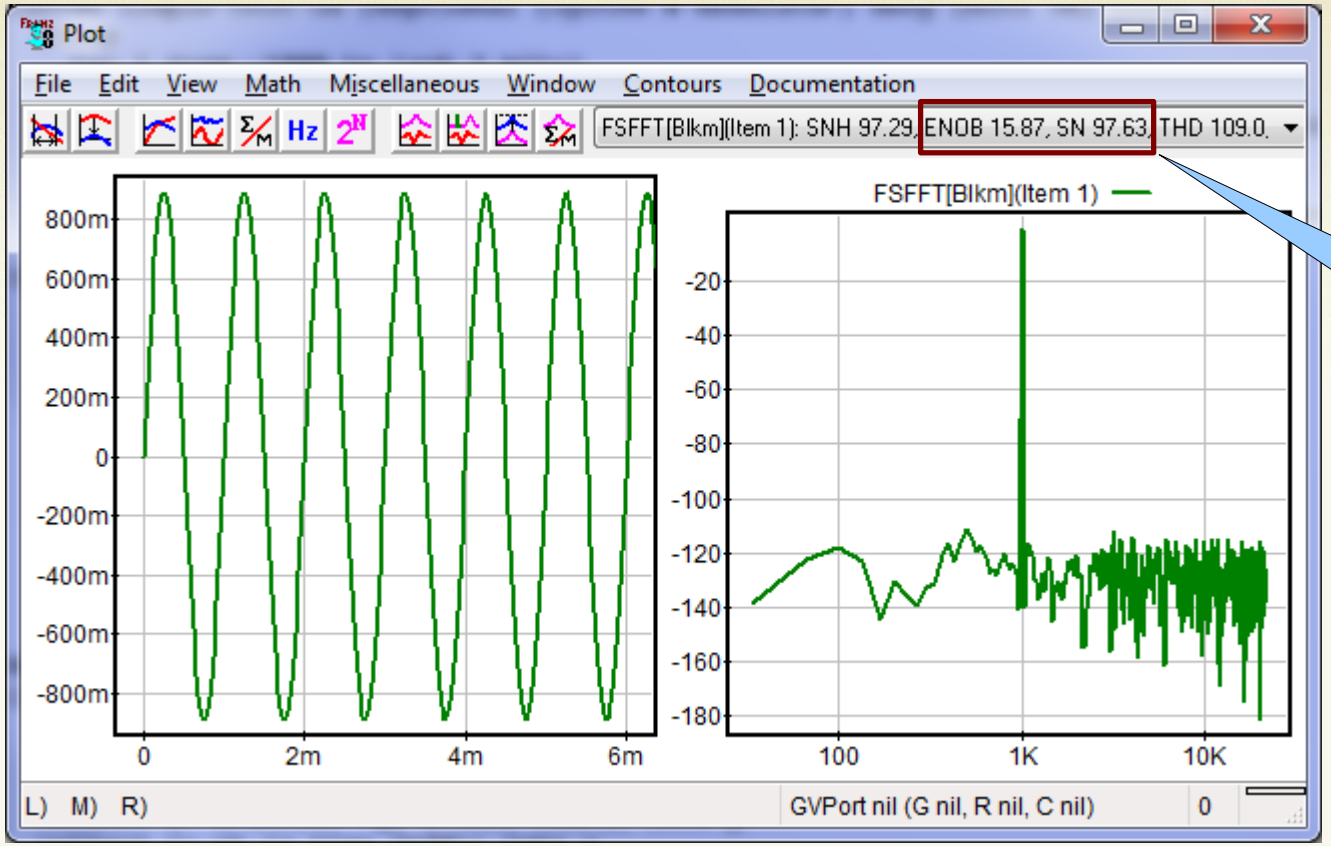
866ppm – surely no problem?

- 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!



Digital (Frequency Domain) -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 15.87
SN 97.63

The amplitude here is -1dB

Digital (Frequency Domain) -10dB

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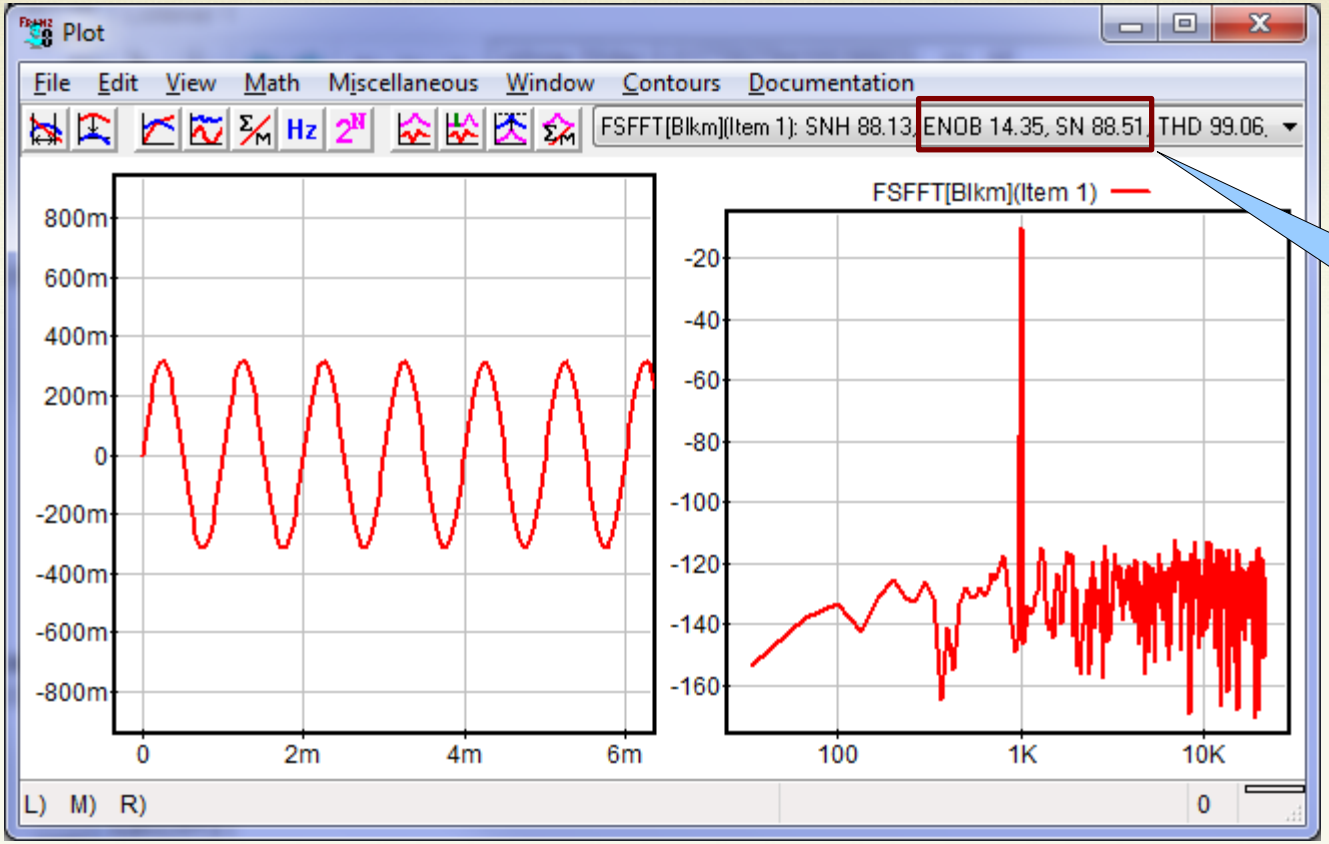
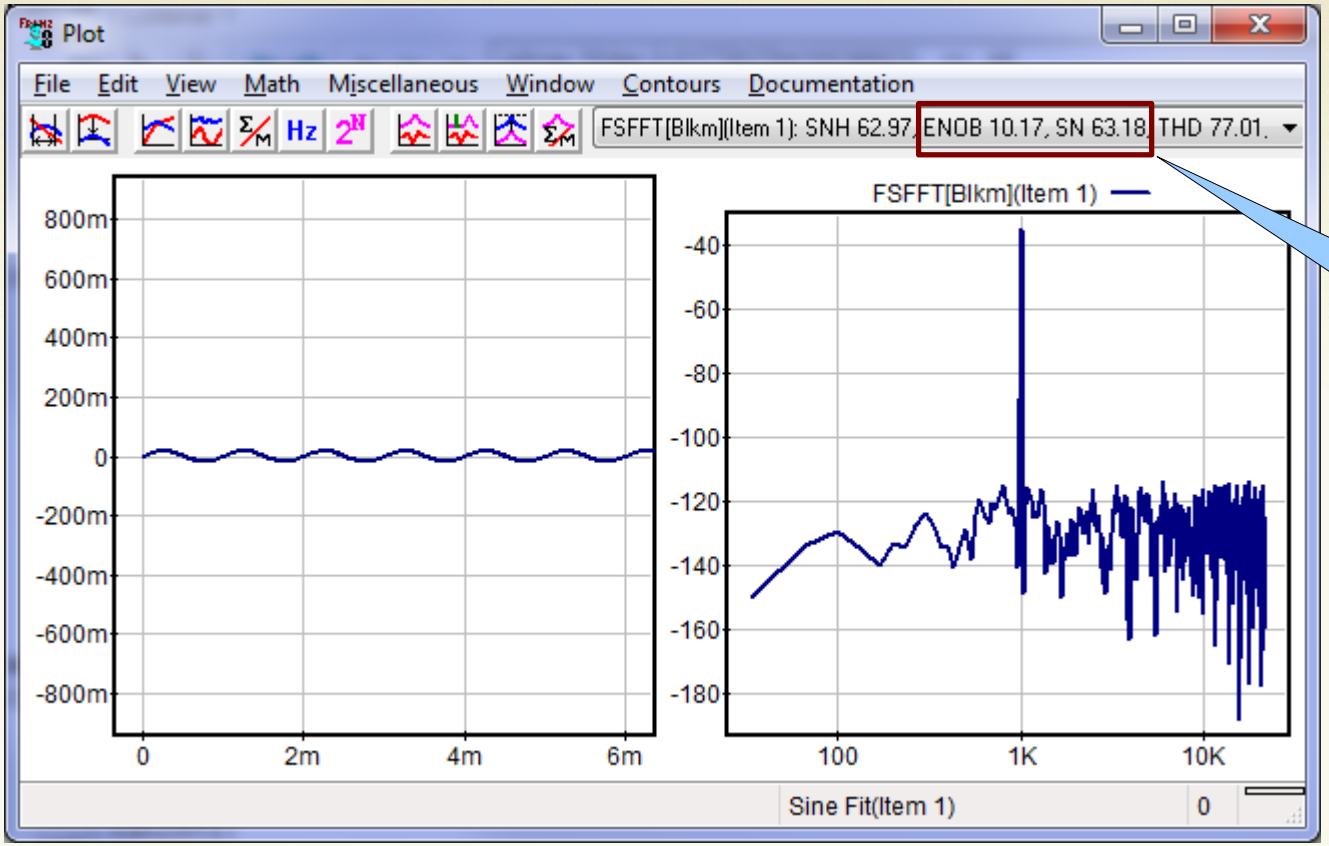


ENOB 14.35
SN 88.51

The amplitude here is -10dB

Digital (Frequency Domain) -35dB

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:

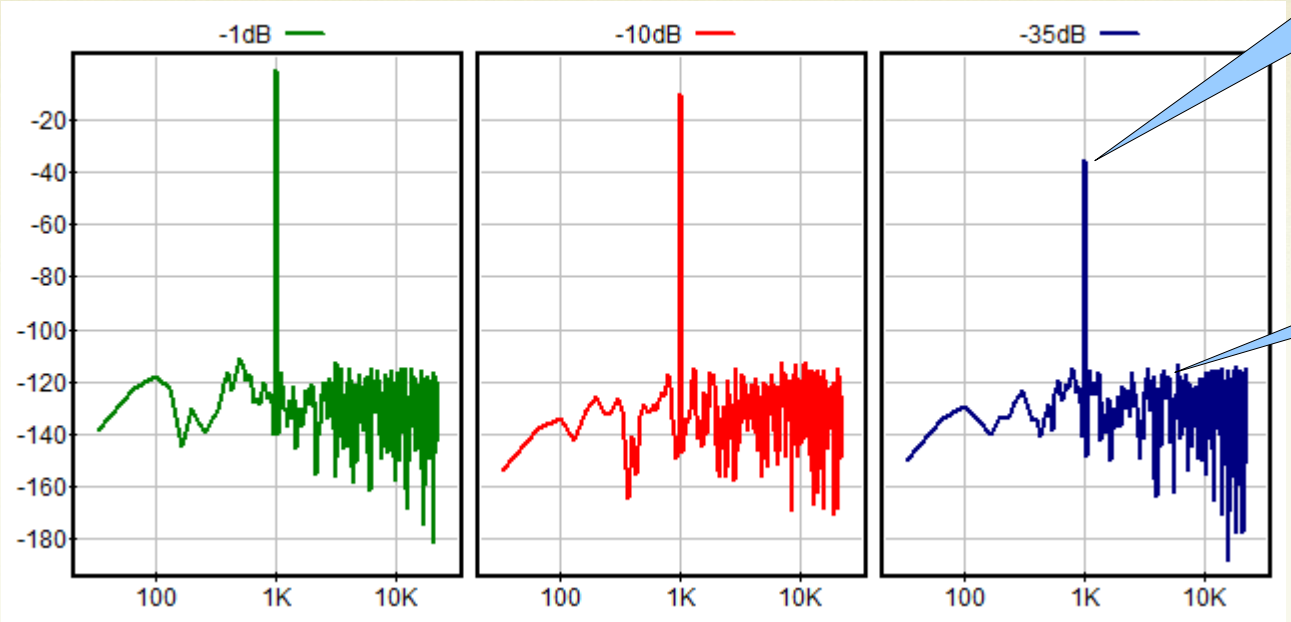


ENOB 10.17
SN 63.18

The amplitude here is -35dB

Digital Volume Control – fixed noise

Clearly, the noise is not moving!



The signal is decreasing as we requested

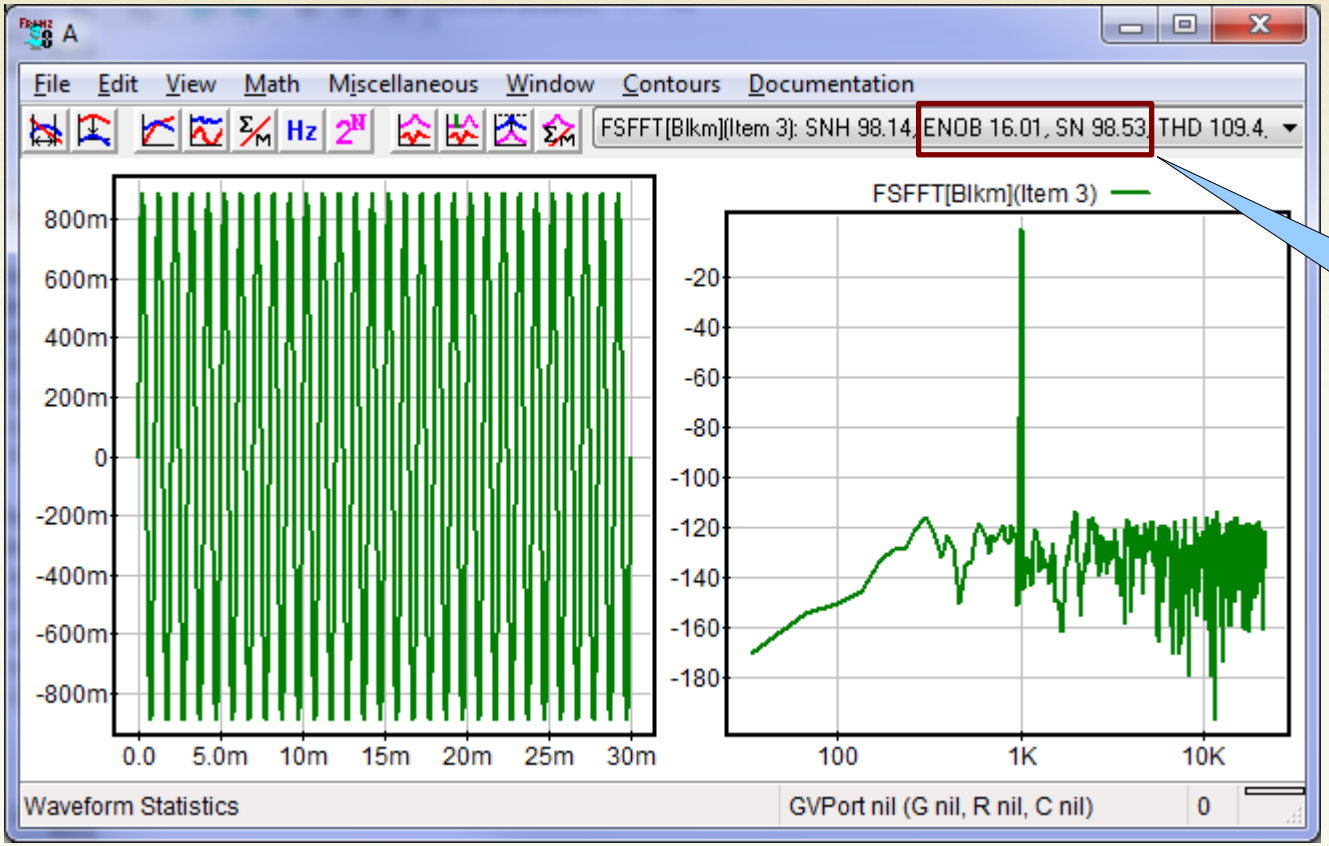
But the noise is not going down!

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

This is why audiophiles generally avoid digital volume control

Analog (Frequency Domain) -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:

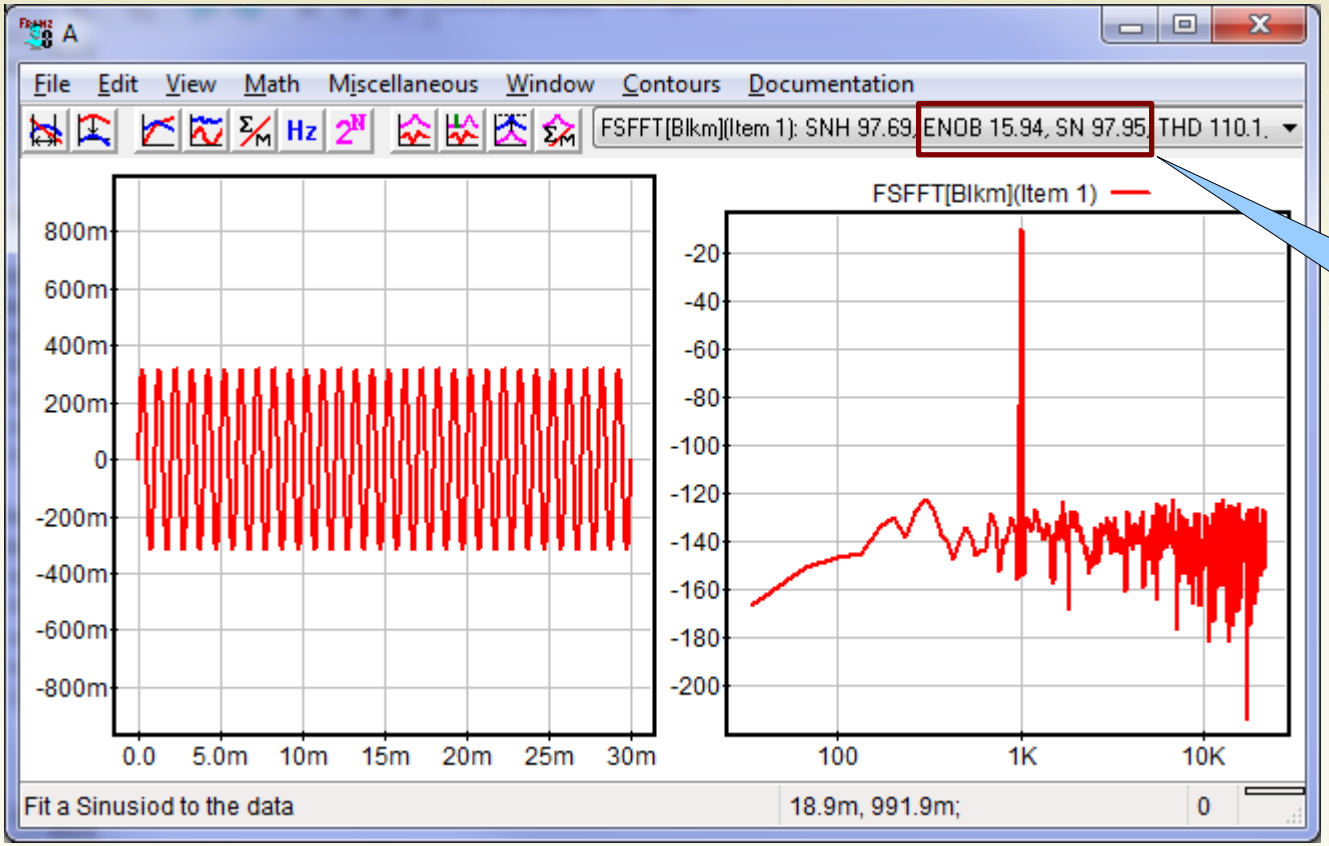


ENOB 16.01
SN 98.53

The amplitude here is -1dB

Analog (Frequency Domain) -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:

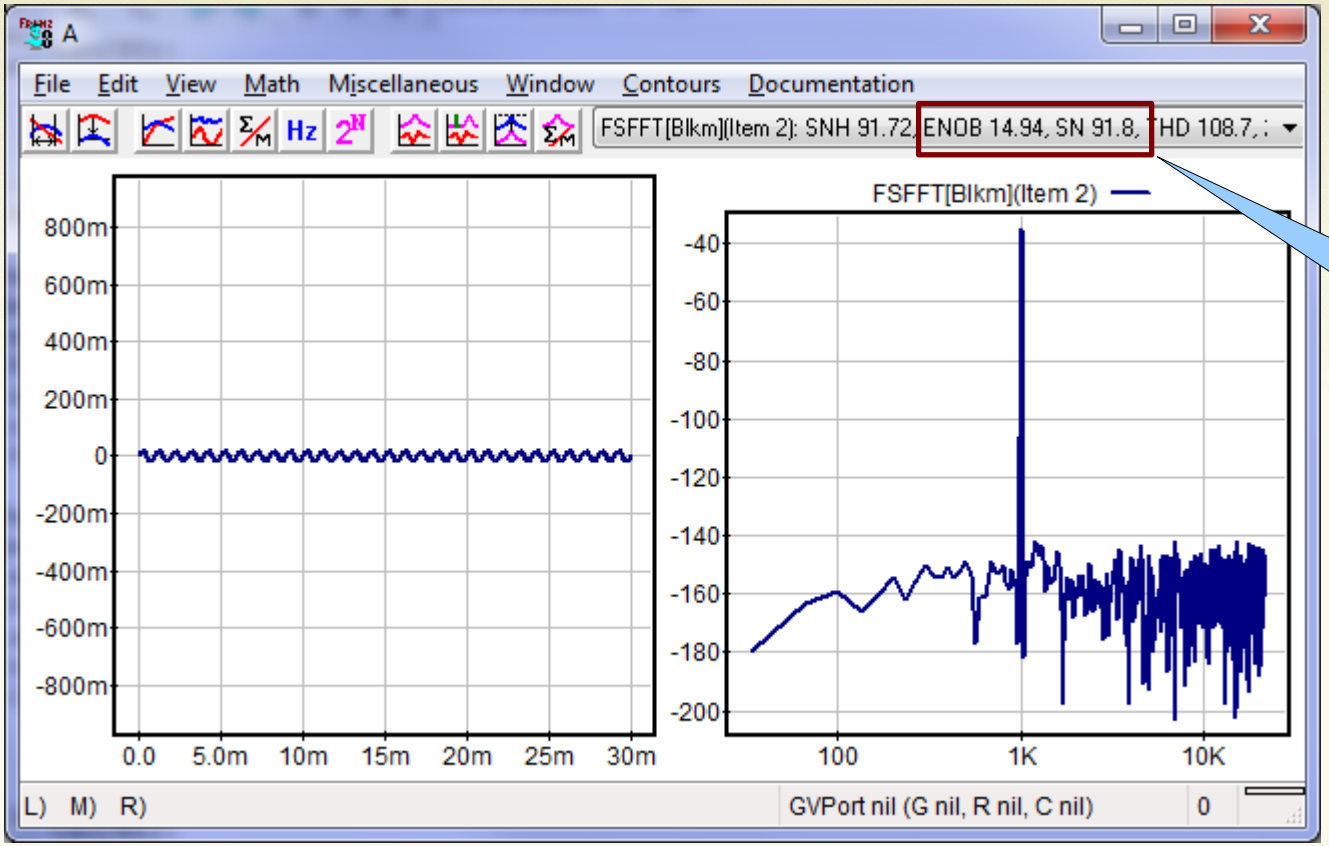


ENOB 15.94
SN 97.95

The amplitude here is -10dB

Analog (Frequency Domain) -35dB

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:

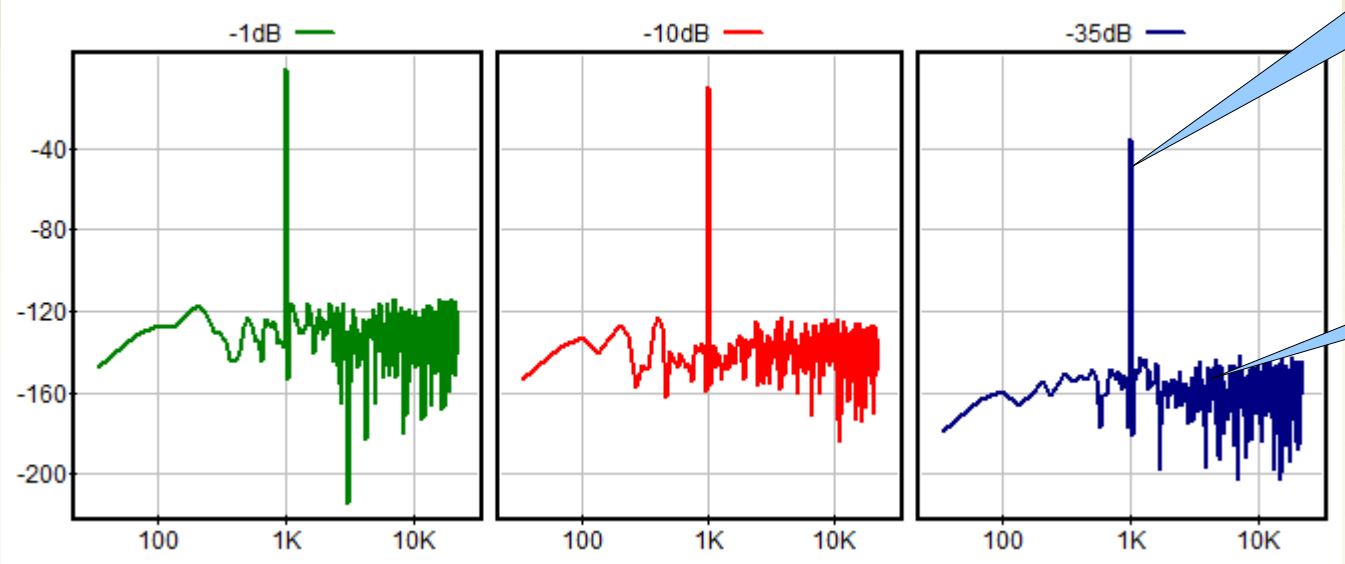


ENOB 14.94
SN 91.8

The amplitude here is -35dB

Analog Volume - variable noise

Now the noise moves down as well



The signal is decreasing as we requested

Now the noise is going down as well

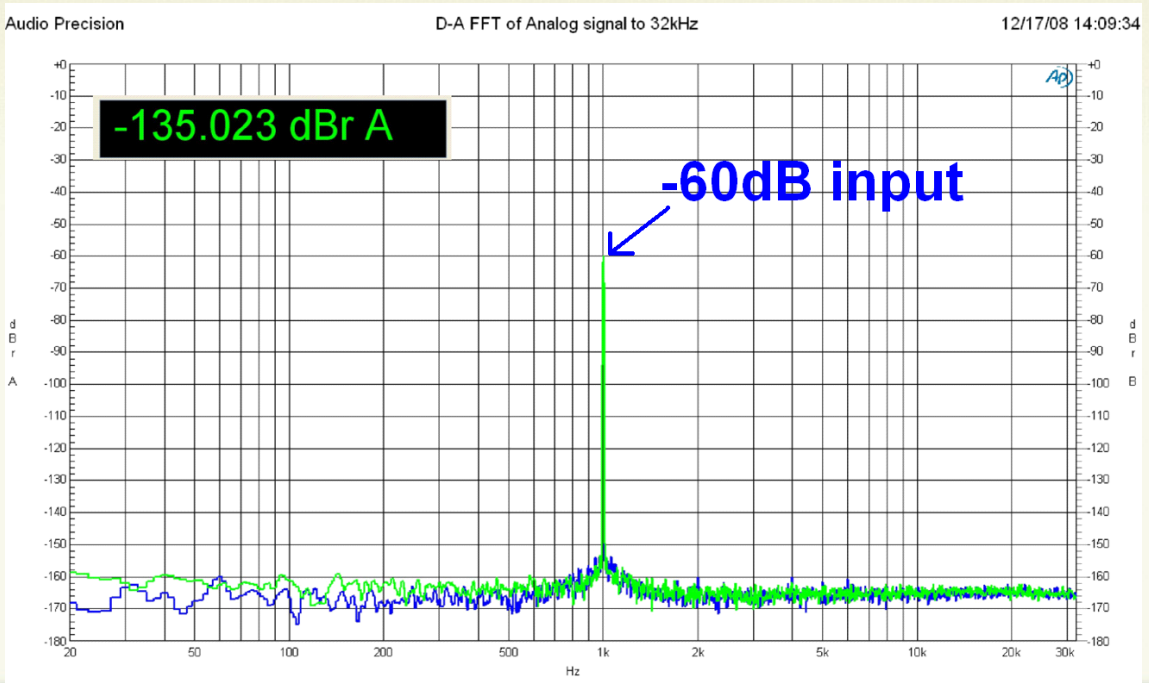
The signal to noise ratio is being maintained

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 16bits.
  - What happens when a 16 bit number is fed to a 32 bit DAC?

Internally 32 bits, externally 16/24



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 * 0.3162 = 533.5372?

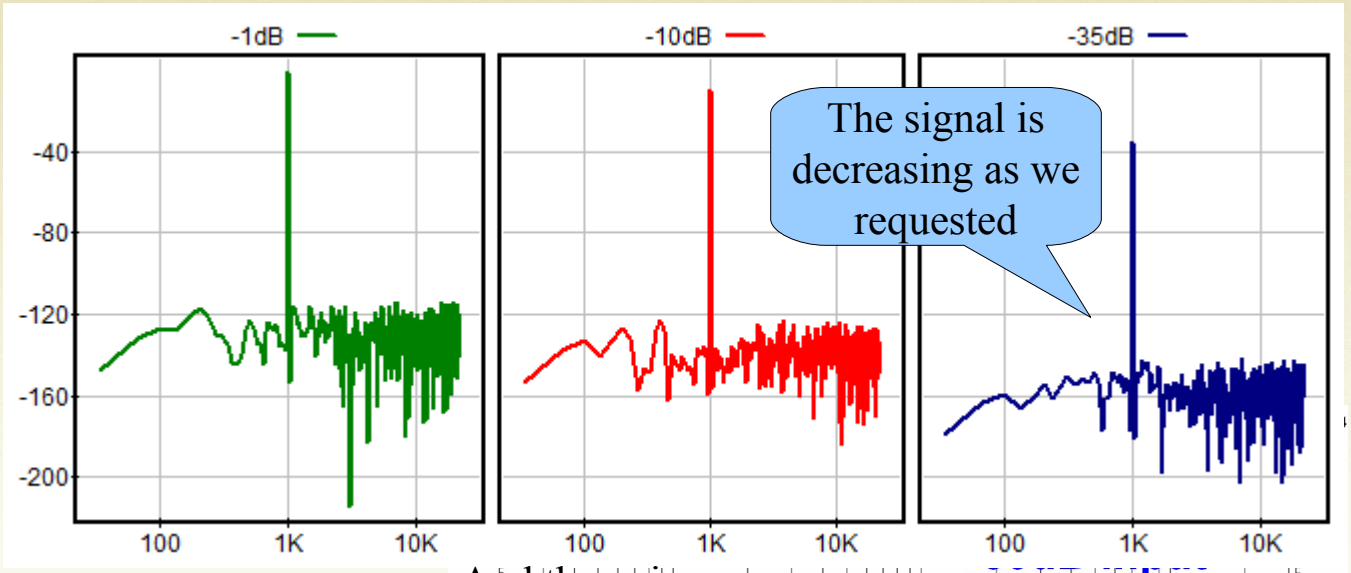
  As indeed it is...

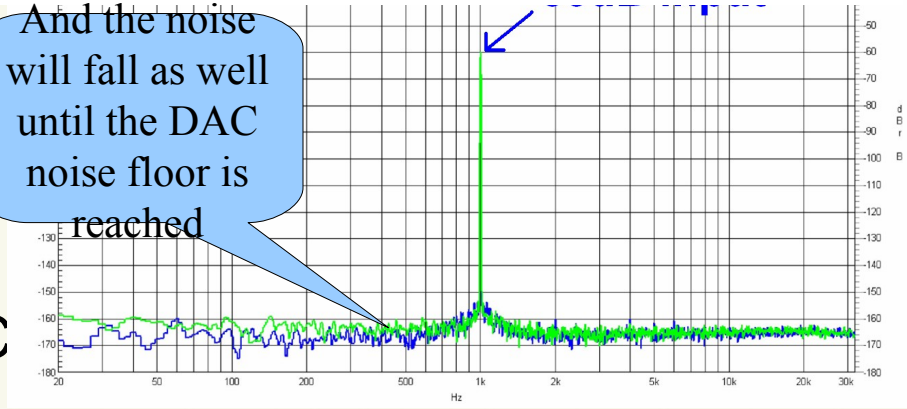
When the volume control has access to the additional bits in the DAC data path, there is no numerical loss of accuracy



Optimum Digital Volume Control

- A Digital volume control with access to the DAC internal data path will behave <u>just like the analog one</u> 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 (ie 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?