Application Report
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Out-of-Band Noise and Filtering for PCM DAC

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ABSTRACT

This application report is discussing out-of-band noise issue by delta-sigma type audio DAC, it shows simply CR passive post LPF solution and OVER function solution with actual measured spectrum data and audio performance.

Applied PCM DAC family model on this application report is PCM1753, PCM1754, PCM1755, PCM1602, PCM1604, PCM1606, and PCM1608.

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1 Theory of Out-of-Band Noise

Figure 1 shows quantization noise spectrum of the delta-sigma modulator section of the applied PCM DAC family model. The delta-sigma modulator is operated by 64fs sampling rate in default condition (fs: normalized sampling frequency). Quantization noise level in audio band, up to fs/2, is low level, it can achieves specified 107-dB dynamic range. Otherwise, quantization noise level from fs/2 to 8fs frequency band is around –60 dBFS, this application report defines it as out-of-band noise. This quantization noise spectrum performance is given by designing of delta-sigma modulator, DAC family in this case uses 4th-order, 8-level quantizer delta-sigma modulator.

This quantization noise is converted to analog signal, then, thorough internal analog LPF of DAC.

Figure 2 shows frequency response of DAC internal analog LPF, it has 100-kHz pass bandwidth, noise spectrum from fs/2 to fs band could not removed.

Therefore, DAC outputs converted audio signal with out-of-band noise which is given as total performance of delta-sigma quantization noise and internal analog LPF performance.

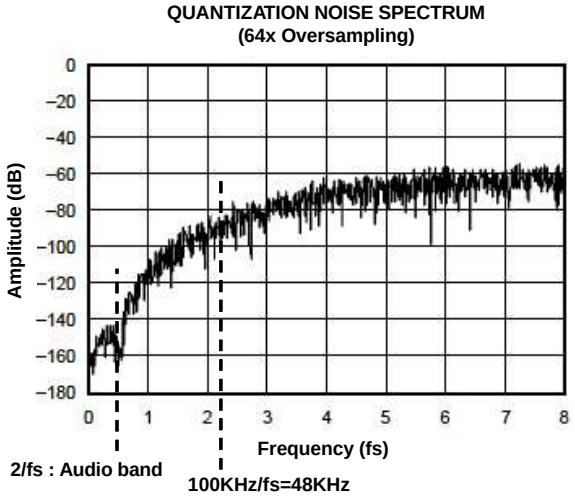


Figure 1. Delta-Sigma Quantization Noise

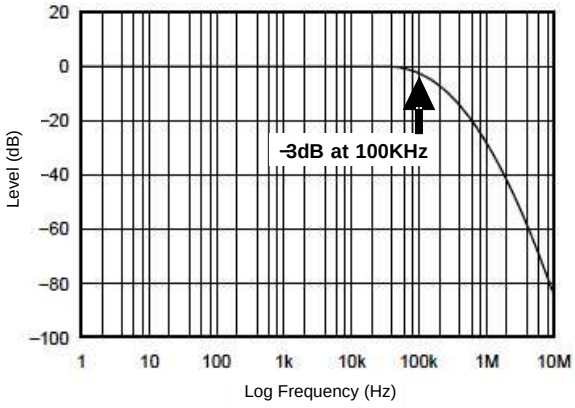


Figure 2. Internal Analog LPF Response

2 FFT Measurement

Figure 3 shows 100-kHz bandwidth FFT spectrum data by DAC output direct.

Measurement condition is:

–60-dBFS, 1-kHz sine wave signal

fs = 48 kHz, 64fs (default)

It shows around –82 dB level out-of-band noise at 100 kHz.

Figure 4 shows 100-kHz bandwidth FFT spectrum data with 2nd-order post LPF.

Measurement condition is same as above.

It shows around –92 dB level out-of-band noise at 100-kHz, it is 10 dB lower than direct output.

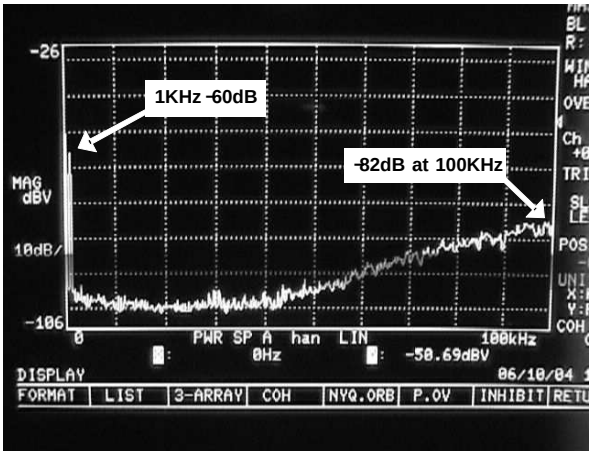


Figure 3. FFT Measurement, DAC Out Direct

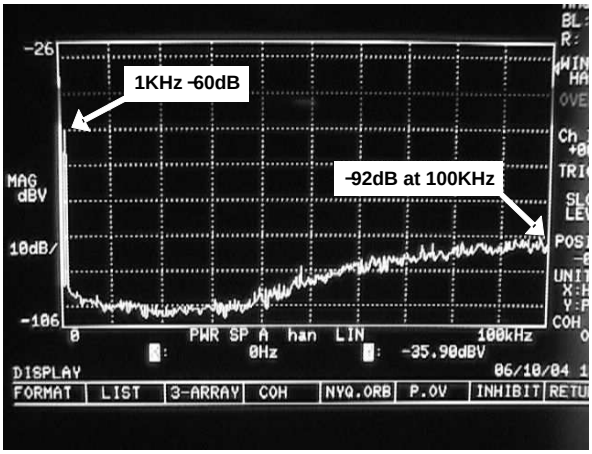


Figure 4. FFT Measurement, 2nd-Order LPF

3 Post LPF

In general applications, this out-of-band noise can be removed by active type 2nd-order or 3rd-oder post LPF which have around 40-kHz to 80-kHz cut-off frequency performance as shown in Figure 4.

Typical application circuit of post LPF is shown in each data sheet, almost application uses 2nd-order post LPF with gain amp function to achieves 2-Vrms CD/DVD standard line output level.

In case of cost sensitive applications, even a dual OpAmp IC for stereo post LPF should be considered to save material cost of application.

But, out-of-band noise should be removed to avoid any nonestimated operation of connected analog amp section such as inter-modulated noise in audio band, one of solution for this issue is simply CR passive post LPF.

Figure 5 shows an application circuit for post LPF by simply CR passive filter.

Cut-off frequency fc is given by fc = 1/ 2π C_2R_1 (Hz)

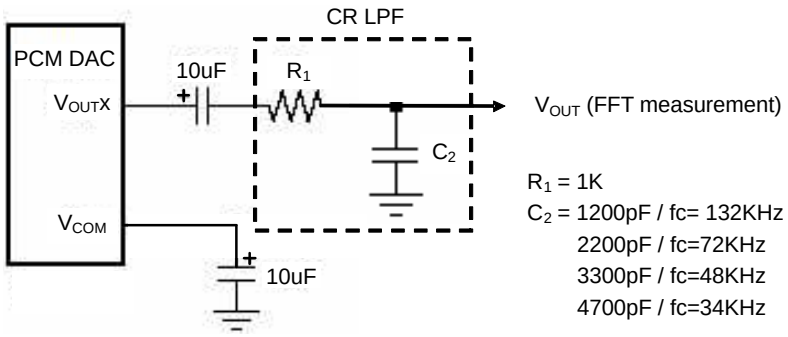


Figure 5. CR Passive Post LPF Circuit

4 FFT Measurement by CR Post LPF

Figure 6, Figure 7, Figure 8, and Figure 9 shows 100-kHz bandwidth FFT measurement data by four type CR passive post LPF.

Removed noise level at 100 kHz is 2 dB to 8 dB, but, it is better than DAC output direct, without any post LPF.

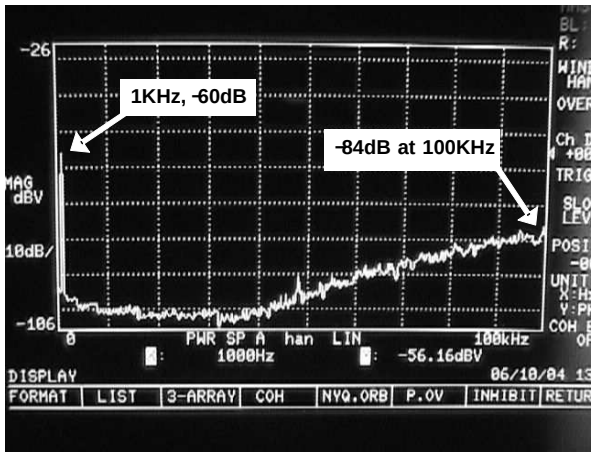


Figure 6. FFT Measurement C = 120 pF, fc = 132 kHz

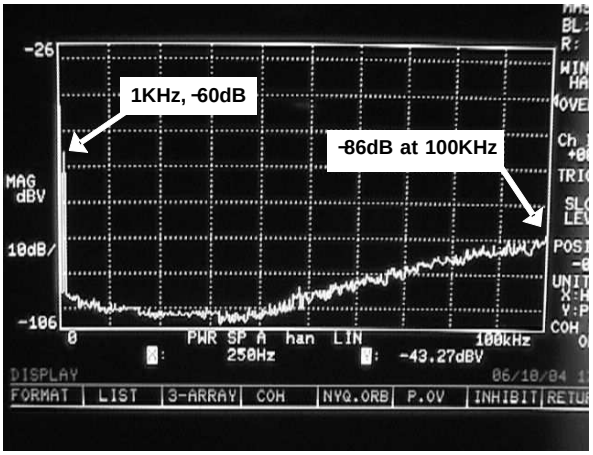


Figure 7. FFT Measurement C = 2200 pF, fc = 72 kHz

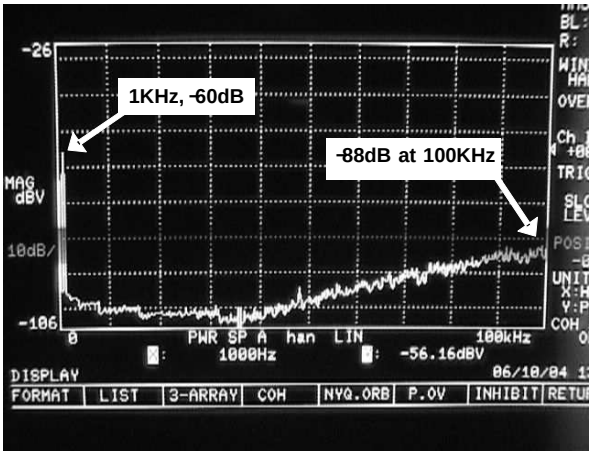


Figure 8. FFT Measurement C = 3300 pF, fc = 48 kHz

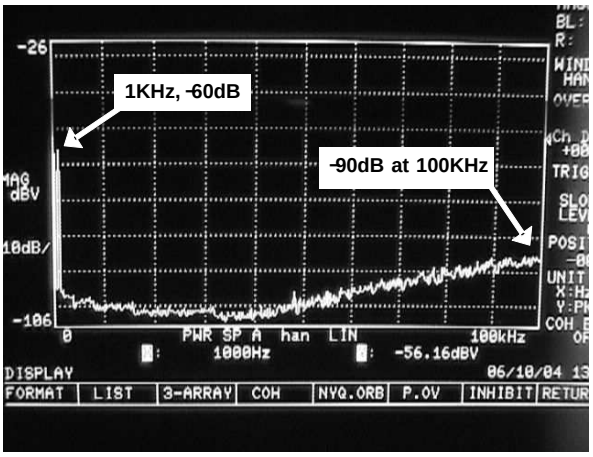


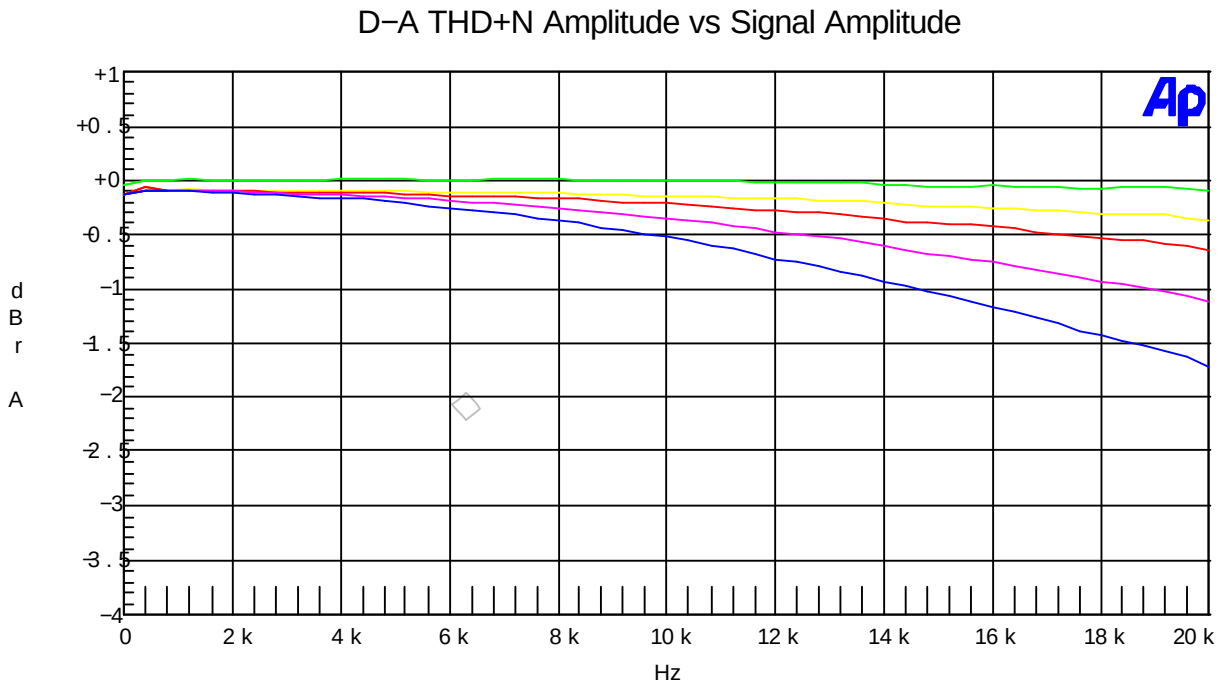
Figure 9. FFT Measurement C = 4700 pF, fc = 34 kHz

5 Frequency Response by CR Post LPF

On the other hands, audio band signal frequency response should be considered so that CR passive LPF have slow roll-off characteristics for audio band.

In general, –1 dB or –0.5 dB frequency response at 20 kHz is required.

Figure 10 shows frequency response by four type CR post LPF and DAC direct.



Sweep	Trace	Color	Line Style	Thick	Data	Axis	Comment
1	1	Green	Solid	1	Anlr.Level A	Left	Vout Direct
2	1	Yellow	Solid	1	Anlr.Level A	Left	C=1200pF(fc=132kHz)
3	1	Red	Solid	1	Anlr.Level A	Left	C=2200pF(fc=72kHz)
4	1	Magenta	Solid	1	Anlr.Level A	Left	C=3300pF(fc=48kHz)
5	1	Blue	Solid	1	Anlr.Level A	Left	C=4700pF(fc=34kHz)

Figure 10. Frequency Response by CR LPF

6 OVER Function

Software control (serial register control) DAC family have OVER function, this OVER is selectable function for operating sampling rate, fs of delta-sigma section.

Figure 11 shows register MAP by PCM1608 for OVER function.

Default operating is 64fs (OVER = 0). Otherwise, this operation can be switched to 128fs by setting OVER = 1, then boost frequency of quantization noise can be shifted to more higher frequency as shown in Figure 12.

Figure 13 shows 100-kHz bandwidth FFT measurement by DAC output direct. As you can see from FFT data on Figure 13, out-of-band noise up to 100 kHz could be much improved around -102 dB at 100 kHz by operation of OVER = 1.

FUNCTION	RESET DEFAULT	REGISTER	BIT(s)
Digital attenuation control, 0 dB to -63 dB in 0.5 dB steps	0 dB, no attenuation	16 and 17	AT1[7:0], AT2[7:0]
Soft mute control	Mute disabled	18	MUT[2:0]
Oversampling rate control (64fs or 128fs)	64fs oversampling	18	OVER

System Clock Rate = 256, 384, 512, or 768 fs:

Over = 0 64x Oversampling (default
Over = 1 128x Oversampling

Figure 11. OVER Register

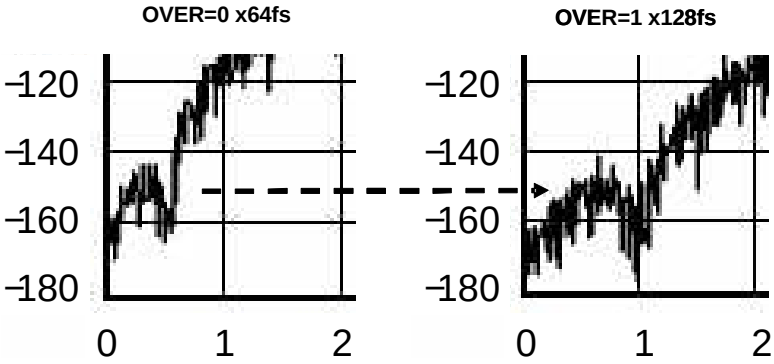


Figure 12. Quantization Noise by OVER Function

-60dB Direct Output by OVER=1, x128fs (without LPF)

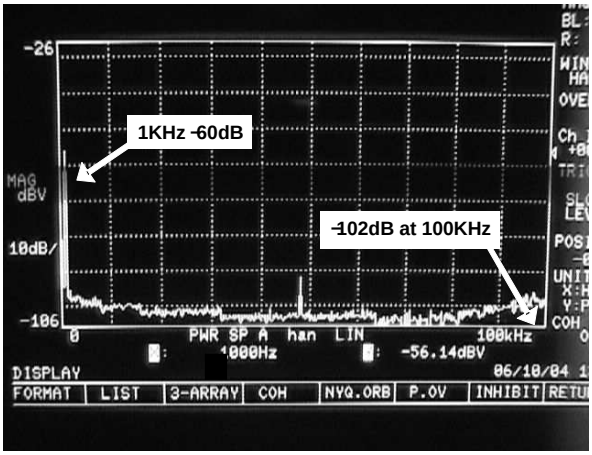


Figure 13. FFT Measurement by OVER = 1, 128fs

7 Audio Performance by CR Post LPF

Key audio performance is THD+N, Dynamic Range, and SNR in typical digital audio application, this section shows actual measured key audio performance by post LPF condition.

Figure 14 shows test block diagram for audio performance measurement, it uses Audio Precision AP2722 with AES-17 LPF.

AES-17 LPF in AP2722 is 20-kHz band limit filter, it have –60-dB attenuation at f = 24 kHz, any out-of-band noise can be removed ideally.

Table 1 shows actual measured audio performance of the PCM1608 (as typical model of multi-channel DAC family) by two post LPF condition.

Table 2 shows actual measured audio performance of the PCM1754 (as typical model of 2ch DAC) by two post LPF condition.

Both test result says that audio performance is not influenced by post LPF type condition with 20-kHz band limit by AES-17 LPF for testing.

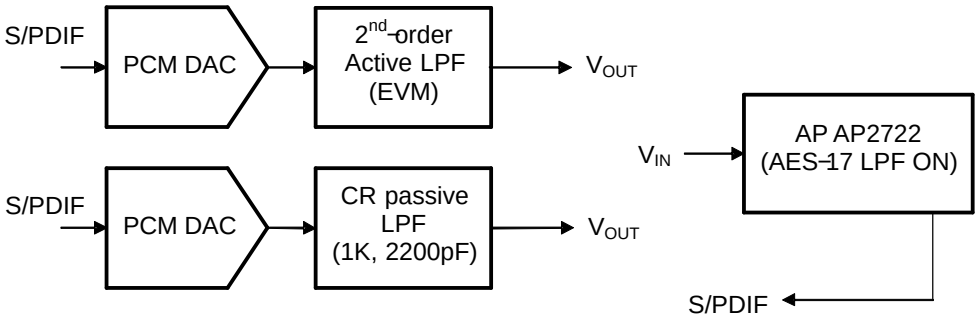


Figure 14. Frequency Response by CR LPF

Table 1. PCM1608 Measured Audio Performance by LPF

Performance/LPF	2nd LPF	CR LPF
V_{OUT}, Lch	2.013 V	1.091 V
V_{OUT}, Rch	2.014 V	1.094 V%
THD+N, Lch	0.00157%	0.00151%
THD+N, Rch	0.00182%	0.00189%
D.Range, Lch	103.6 dB	104.1 dB
D.Range, Rch	103.8 dB	104.3 dB
SNR, Lch	103.8 dB	104.2 dB
SNR, Rch	103.9 dB	104.5 dB

Table 2. PCM1754 Measured Audio Performance by LPF

Performance/LPF	2nd Active LPF	CR Passive LPF
V_{OUT}, Lch	2.58 V	1.41 V
V_{OUT}, Rch	2.59 V	1.41 V
THD+N, Lch	0.00288%	0.00297%
THD+N, Rch	0.00283%	0.00301%
D.Range, Lch	104.7 dB	105.2 dB
D.Range, Rch	104.7 dB	105.1 dB
SNR, Lch	106.7 dB	107.2 dB
SNR, Rch	107.0 dB	107.5 dB

8 Audio Performance by OVER Condition

OVER function is effective to remove out-of-band noise up to 100 kHz, but, operation speed at OVER = 1 is 128fs, switching speed for DAC internal circuit would be double, then, it makes higher noise over default 64fs operation.

This section shows audio performance difference by OVER function.

Figure 15 shows test block diagram for audio performance measurement, it is almost same as Figure 14.

Table 3 shows actual measured audio performance of the PCM1608 by OVER = 0, 1.

Table 4 shows actual measured audio performance of the PCM1754 by OVER = 0, 1.

In case of operation by OVER = 1, there is very small performance degrading over OVER = 0.

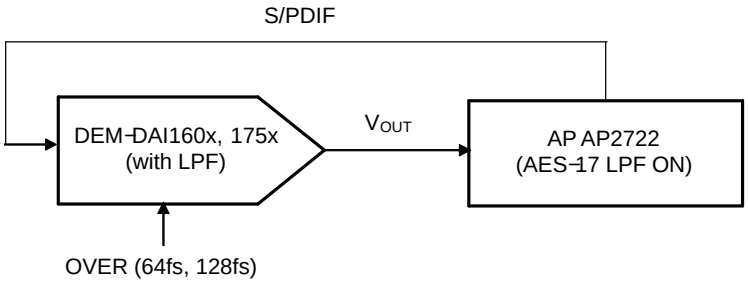


Figure 15. Audio Performance Test by OVER

Table 3. PCM1608 Measured Audio Performance by OVER

Performance/OVER	64fs	128fs
THD+N, Lch [%]	0.00138	0.00177
THD+N, Rch [%]	0.00168	0.0028
D.Range, Lch [dB]	104.8	103.0
D.Range, Rch [dB]	104.9	104.1
SNR, Lch [dB]	104.8	104.8
SNR, Rch [dB]	105.0	104.9

Table 4. PCM1754 Measured Audio Performance by OVER

Performance/OVER	64fs	128fs
THD+N, Lch [%]	0.00229	0.00278
THD+N, Rch [%]	0.00241	0.00297
D.Range, Lch [dB]	106.5	105.9
D.Range, Rch [dB]	106.5	106.0
SNR, Lch [dB]	107.7	107.2
SNR, Rch [dB]	108.1	107.6

9 Conclusion

Acceptable out-of-band noise level is depends on application, this report shows a couple of solution with actual measured data.

In general applications, to remove out-of-band noise:

- 2nd-order active post LPF is recommended.
- Simply CR passive post LPF is one of solution without any performance degrading.
- OVER = 1 (128fs) function can be much removed out-of-band noise.

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