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APPLICATION BULLETIN
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THD+N VERSUS FREQUENCY CHARACTERISTICS AND SPECTRA OF THE PCM1717/18/19/20/23/27

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The following application bulletin describes the theory and actual performance of THD+N versus frequency characteristics for the PCM1717 series which include on-chip digital filters. The contents of this article apply to the PCM1717 and other devices which use the same digital filter architecture and ΔΣ DAC, such as PCM1718, PCM1719, PCM1720, PCM1723, and PCM1727.

THEORY OF A DIGITAL FILTER

There are four basic characteristics of a digital filter:

- Passband Frequency
- Passband Ripple
- Stopband Frequency
- Stopband Attenuation

The passband frequency and passband ripple only affect audio band characteristics, while the stopband frequency and stopband attenuation do not influence THD+N versus frequency characteristics directly because these are out of the audio band. But depending on the test condition, the appearance of THD+N versus frequency characteristics is decreased so that the out of audio band spectrum remains in the measurement band.

Figure 1 shows the digital filter frequency response. This is an example of 8x oversampling, but stopband attenuation against the $f_S/2$ of the passband depends upon the signal frequency.

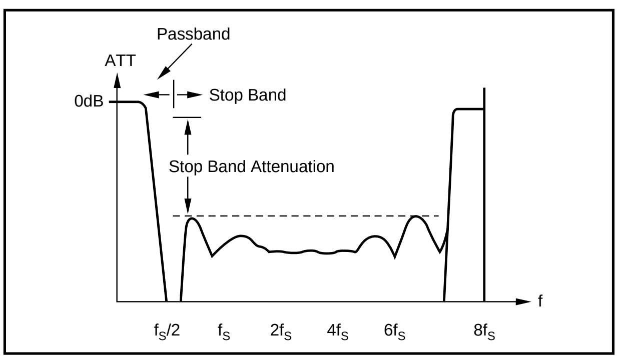

FIGURE 1. Digital Filter Attenuation.

SIGNAL FREQUENCY AND SAMPLING SPECTRA

Given a signal frequency (f_A), the sampling spectra of digital-to-analog conversion is then $f_S \pm f_A$. This is not caused by the DAC architecture, it is a result of sampling theory. This is shown in Figure 2.

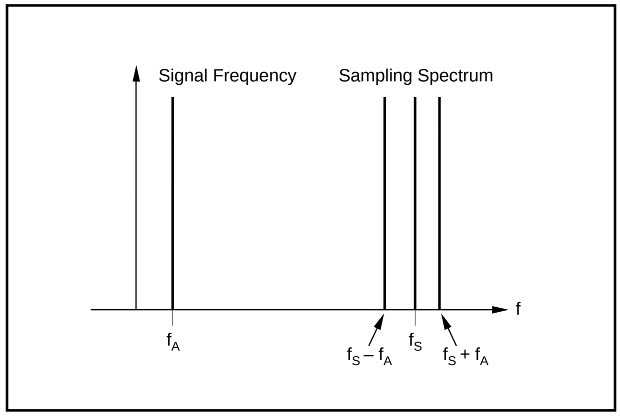

FIGURE 2. Sampling Spectrum.

SUPPRESSION OF THE SAMPLING SPECTRA BY DIGITAL FILTERING

A sampling spectra level is given by the stopband attenuation response of the D/A converter combined with the oversampling signal filter. Figure 3 shows this relation. When signals f_{A1} and f_{A2} are input into a digital filter with stopband attenuation like Figure 3, the sampling spectrum distributes on $f_S \pm f_{A1}$, $f_S \pm f_{A2}$ (only the lower frequencies of spectrum). If attenuation at $f_S - f_{A1}$ and $f_S - f_{A2}$ frequencies are P_1 and P_2 respectively, then each spectra level should be P_1 and P_2. Notice that this attenuation level depends upon the input signal frequency f_A.

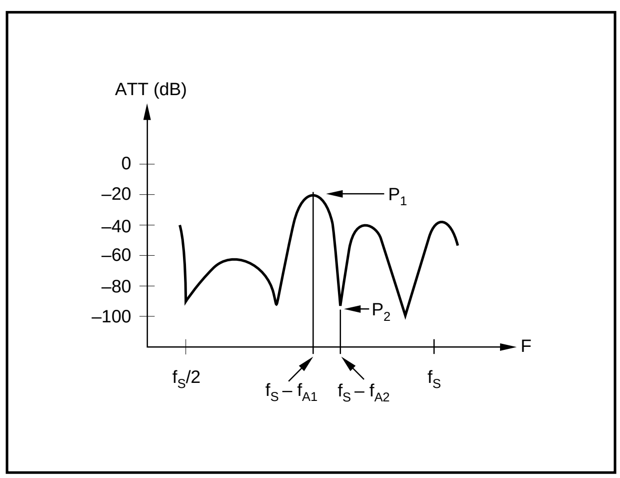

FIGURE 3. Digital Filter Attenuation with Spectrum.

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DIGITAL FILTER RESPONSE OF THE PCM1717/18/19/20/23/27

Figure 4 shows the digital filter response of PCM1717, PCM1718, PCM1719, PCM1720, PCM1723, and PCM1727. Although the minimum stopband attenuation is –35dB on the specification, Figure 4 shows that there is over –80dB attenuation in specified frequency range. This means that the sampling spectra level is varied by the input signal. The stopband frequency is $0.555f_S$ on the specification.

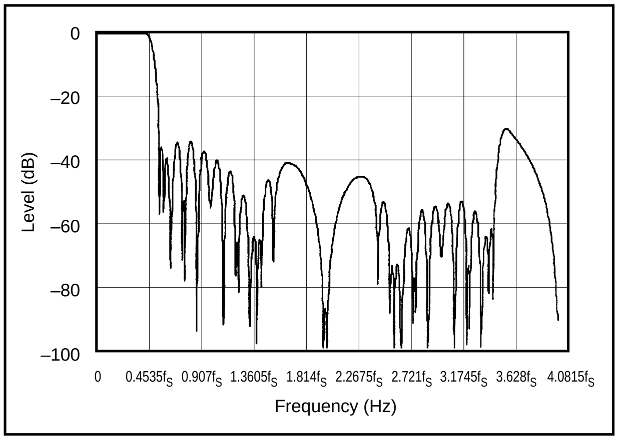


FIGURE 4. Digital Filter Characteristic of PCM1717.

ACTUAL SPECTRUM MEASUREMENTS

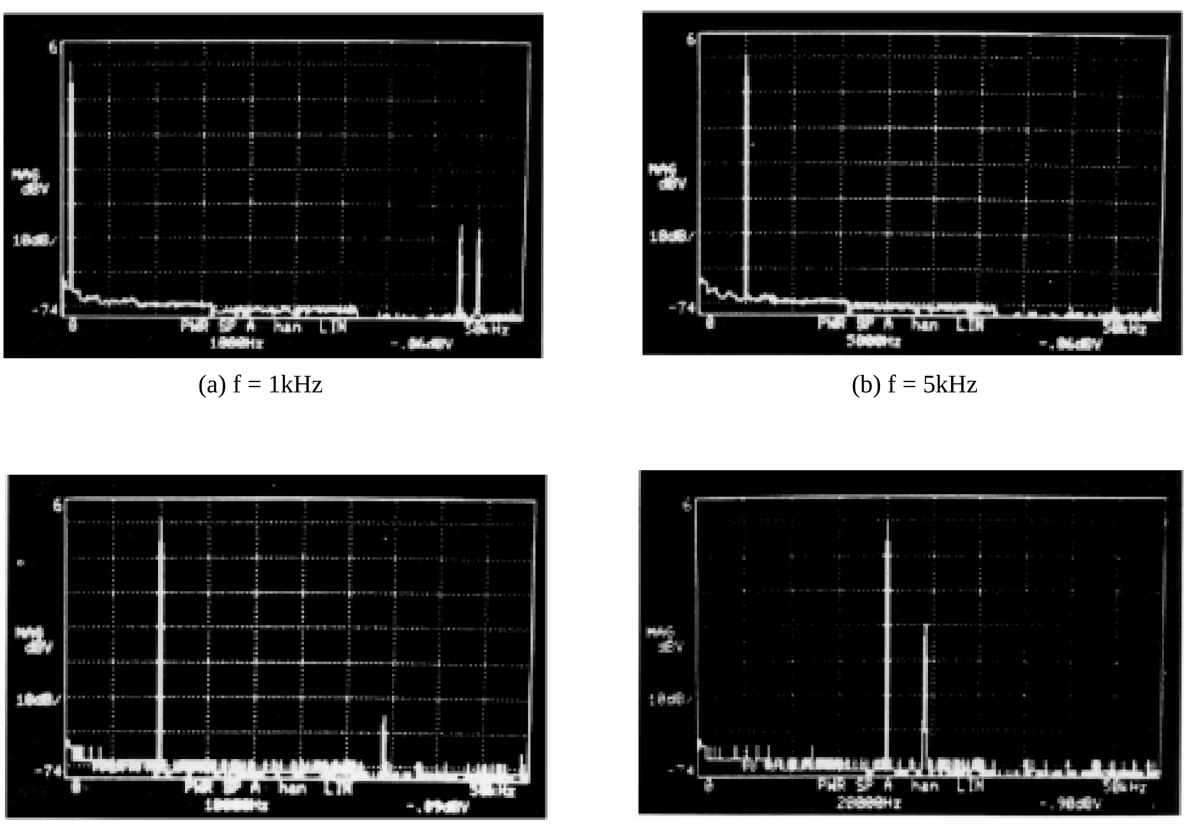
In this section, we show the actual sampling spectrum distribution with various input frequencies (measurement bandwidth is 50kHz, f_S = 44.1kHz). Figure 5a shows the $f_S \pm f_A$ = 44.1kHz ±1kHz, –45dB spectrum with a 1kHz input frequency. Figure 5b shows no spectra with a 5kHz input frequency because the measurement equipment has only –70dB to –80dB dynamic range and could not measure any out of audio band signal. Figure 5c shows the $f_S \pm f_A$ = 44.1kHz –10kHz = 34.1kHz, –55dB spectrum with a 10kHz input frequency. Figure 5d shows the $f_S \pm f_A$ = 44.1kHz – 20kHz = 24.1kHz, –30dB spectrum with a 20kHz input frequency.

From this data, the spectra level is different from input signal frequency, (f_A), and this level is determined by the digital filter attenuation response shown by Figure 4.

In Figure 4, for example, if f_A = 5kHz, $f_S – f_A$ = 44.1kHz – 5kHz = 39.1kHz and its conversion frequency of f_S is 39.1kHz/44.1kHz = $0.887f_S$. The attenuation level at $0.887f_S$ (about –80dB) which can not measured as spectra.

THD+N VS FREQUENCY CHARACTERISTICS

Proper measurement of THD+N for digital audio applications require band limitation by a 20kHz ideal LPF. If the out of audio band spectrum is suppressed insufficiently, the measurement is not for THD+N, but actually for an out of



(a) f = 1kHz

(b) f = 5kHz

(c) f = 10kHz

(d) f = 20kHz

FIGURE 5. Actual Measurement Result of PCM1717 Output Spectrum.

audio band spectrum measurement. Especially since the THD+N versus frequency measurement is directly affected by the out of audio band spectrum, and one will not measure proper results. This means that out of audio band spectrum level compared to the input frequency, (f_A), depends on the digital filter attenuation which is not stable in the whole stopband. That is, the spectrum level in the measurement band is extremely different at –36dB and –80dB attenuation levels, at a frequency of (f_S –f_A). If a 20kHz LPF is used, and out of audio band spectra is sufficiently suppressed, it is possible to measure a proper result because the influence of out of the band spectra can be ignored. Figures 7 and 8 show the actual THD+N performance with/without a post LPF. A test block diagram is shown in Figure 6.

The measurement equipment used is the "SYSTEM-ONE" from Audio Precision with an internal 22kHz or 30kHz LPF. The PCM1717 is measured on Burr-Brown's evaluation board, DEM-DAI1717 which accepts a digital audio (S/PDIF) input signal from the SYSTEM-ONE and output an analog signal to:

- Output of the DAC Directly
- Output of the 2nd-Order LPF

The output analog signal can be measured under the following test conditions (which can be selected by switching):

- With 20kHz band limitation LPF
- With 22kHz or 30kHz band limitation LPF in the Audio Precision

As shown in Figures 7 and 8, THD+N performance varies with frequency, if the out-of-band spectra is not suppressed sufficiently (20kHz band limitation LPF is not used). This result is not THD+N performance, but THD+N out of band spectra, because it is caused by the out of band spectra level. For precise measurement of THD+N performance it is necessary to remove the out of band spectra using a 20kHz band limitation LPF.

An Application Bulletin called "Dynamic Performance Testing For Digital Audio DAC's" is also available. Please refer to it for related information.

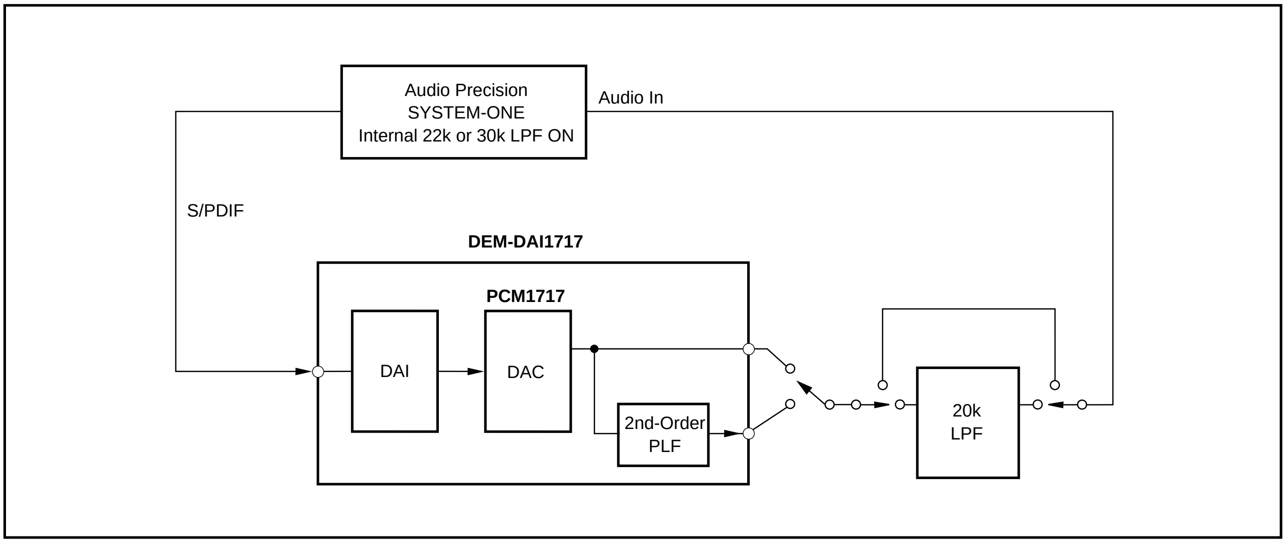


FIGURE 6. THD+N versus Frequency Test Block Diagram.

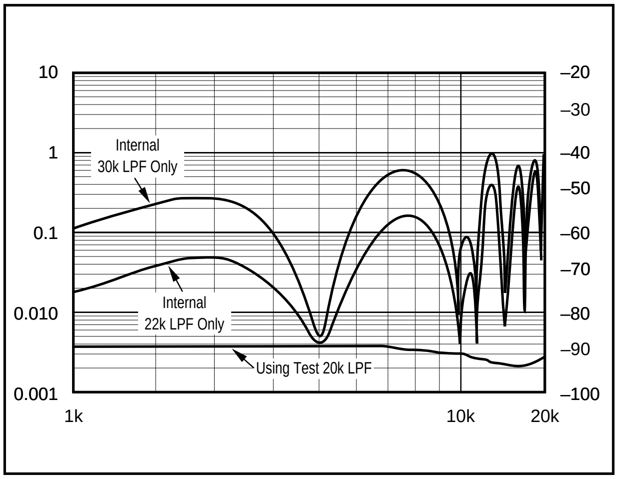


FIGURE 7. THD+N versus Frequency Characteristics with 2nd-Order Post Filter.

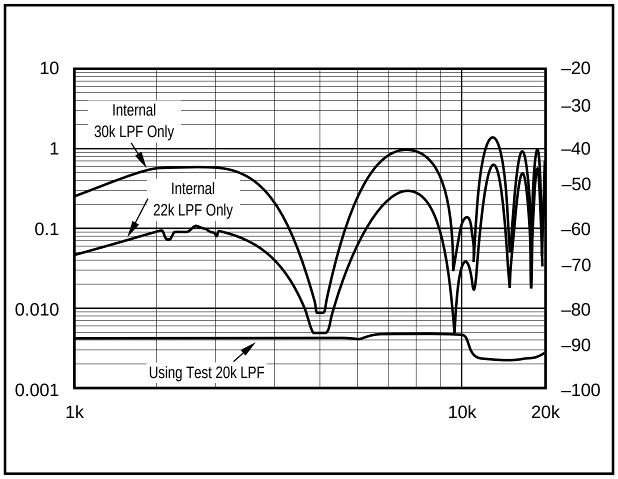


FIGURE 8. THD+N versus Frequency Characteristic without any Post Filter.

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