Keywords: integer, non-integer, MAX9850, master clock

APPLICATION NOTE 3735

Audio-DAC Performance Investigation

By: Adrian Rolufs
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Abstract: The MAX9850 audio DAC can operate from a wide range of master-clock frequencies with varying levels of performance. By selecting different master-clock frequencies, designers can balance performance with ease of design. This application note analyzes the performance of the MAX9850 with various master-clock to sample-rate ratios, showing how the master-clock frequency affects performance.

The MAX9850 is an audio DAC that features unique clocking circuitry that allows it to achieve good audio performance from a wide range of master-clock frequencies. Typical audio DACs require a master clock that is an exact multiple of the sample rate in use. For example, if the sample rate is 48kHz, the most common master clock is 48kHz x 256 = 12.288MHz. The MAX9850 can operate from standard audio clock rates, but it will also operate from commonly available system clocks, such as 12MHz, with reduced performance. With a wide range of acceptable master-clock frequencies, the MAX9850 allows designers select a master-clock frequency that appropriately balances audio performance with ease of design.

Integer Modes[1]

To achieve maximum performance, both the master and slave integer modes are available. These modes require a master clock that is an exact integer multiple of the sample rate in use. Master mode sets the MAX9850 to output word and bit clocks; slave mode sets the MAX9850 to input word and bit clocks. **Figure 1** shows an FFT of the MAX9850 operating in master-integer mode. The input signal is a full-scale 1kHz sine wave sampled at 48kHz. The master clock is a synchronous 12.288MHz signal.

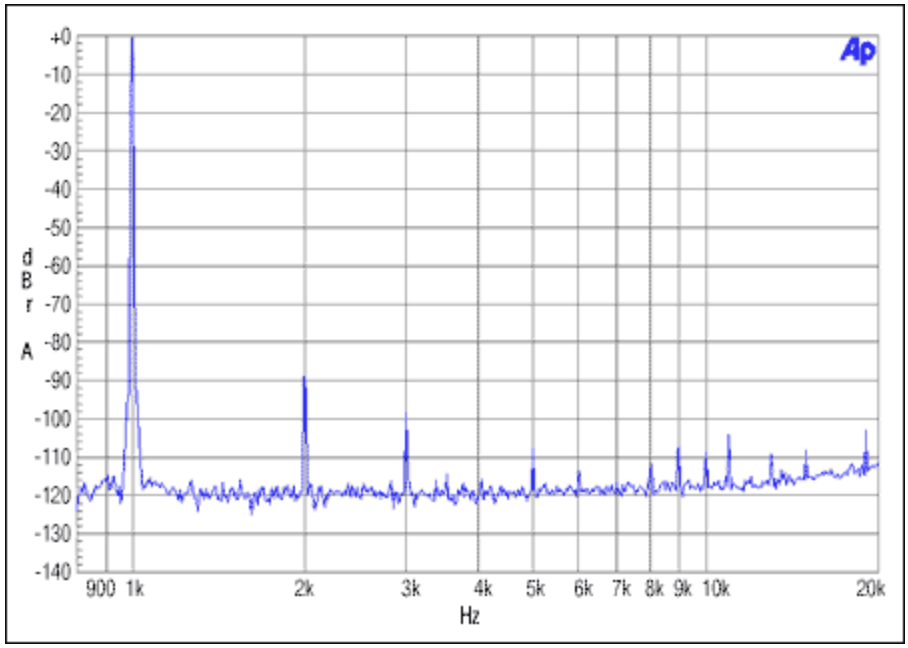

Figure 1. Master-integer mode. MCLK = 12.288MHz, F_S = 48kHz, 0dBFS.

The amplitude of the distortion in master-integer mode is at or below -90dB at all frequencies. The resulting THD+N is -85dB. The distortion that does appear is all harmonic, and is at such a level that it is likely to be masked from audibility to most listeners. As the MAX9850 is intended for use in playback systems reproducing audio that has already been encoded by a lossy algorithm, such as MP3, the distortion created in this mode is not likely to be the limiting factor in the sound quality of the replay chain.

In **Figure 2**, the MAX9850 operates in slave mode with the same clock, sample rate, and input signal as in Figure 1. The performance is unaffected because all the clocks are synchronous and exact integer multiples of each other.

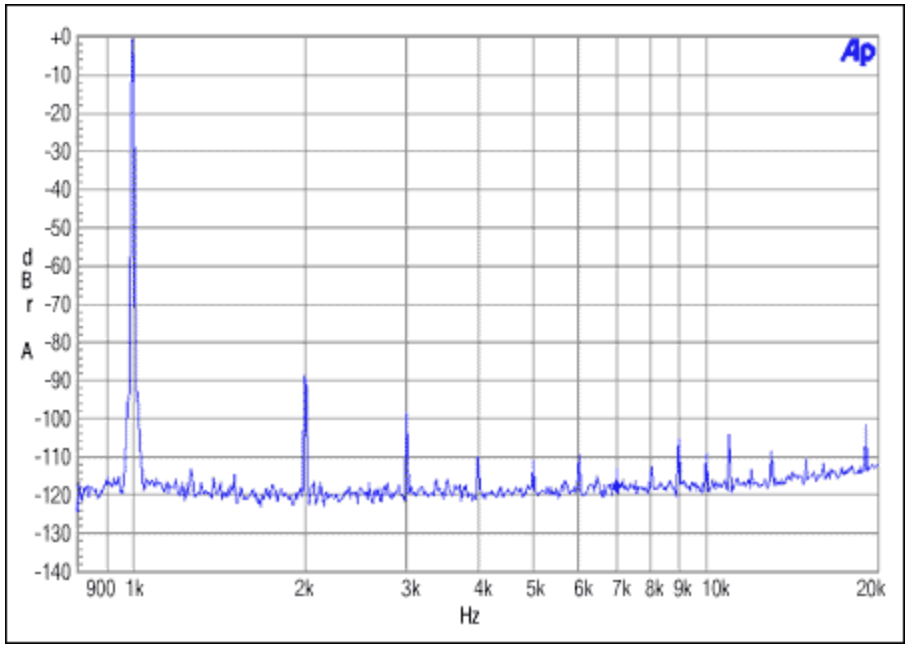

Figure 2. Slave-integer mode. MCLK = 12.288MHz, F_S = 48kHz, 0dBFS.

Noninteger Modes

While integer mode provides the best performance, it requires a clock frequency that is an exact integer multiple if the sample rate (F_S—an exact multiple of 16 x F_S, to be exact). Clock frequencies that are compatible with integer mode are not commonly used by other parts of a system. In many portable-audio systems, a commonly available clock frequency is 12MHz, because it is used by USB. Because this clock is already available in the system, it is simpler to use this clock for audio rather than a dedicated clock. Although 12MHz is not an exact multiple of 16 x F_S for any audio sample rate, it is an integer multiple of 48kHz. As a result, although integer mode cannot be used, the noninteger circuitry can easily create appropriate internal clock rates. **Figure 3** shows the frequency spectrum of a system using a 12MHz clock to reproduce a 1kHz signal sampled at 48kHz. The performance of the MAX9850 in this mode is degraded—but not significantly—from the performance obtainable in integer mode. The largest harmonic is still roughly 90dB below the signal amplitude, but now additional nonharmonic distortion elements appear in the signal. The THD+N is only slightly reduced to -83dB.

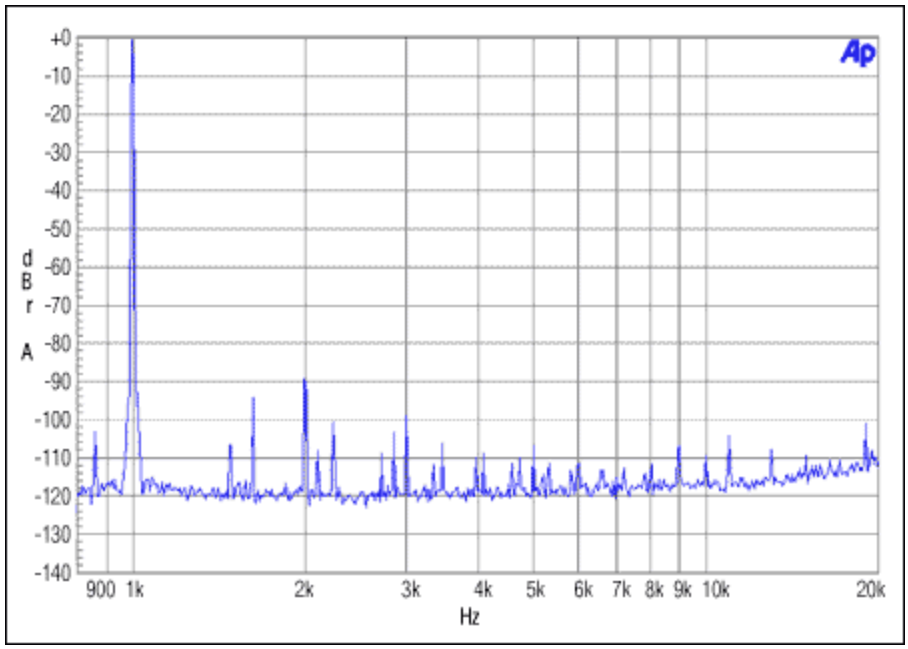

Figure 3. Master noninteger mode. MCLK = 12MHz, F_S = 48kHz, 0dBFS.

Switching to slave mode (**Figure 4**) eliminates the nonharmonic distortion elements and provides performance comparable to integer mode.

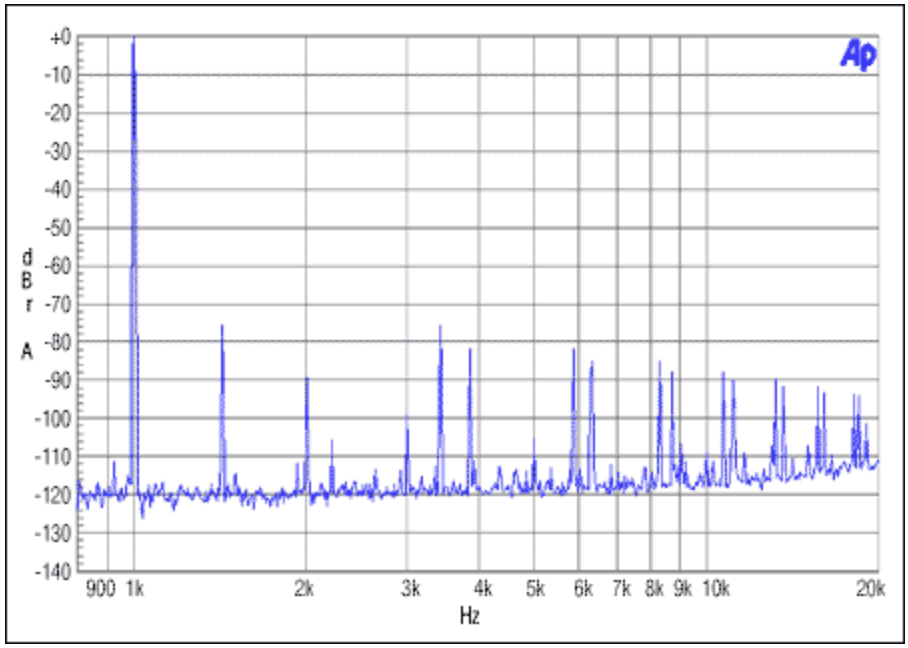

Figure 4. Slave noninteger mode. MCLK = 12MHz, F_S = 48kHz, 0dBFS.

Figure 5 shows an FFT of the MAX9850 output operating from a 12MHz clock in master noninteger mode with input data sampled at 44.1kHz. The MAX9850 is able to reproduce the 1kHz sine wave, even though the sample rate and master clock are not integer related. The performance hit comes in the form of higher distortion. The distortion is also no longer all harmonic distortion, due to the data and clock manipulations required to make the DAC operate from a noninteger clock. The THD+N is measured at -71dB in this mode.

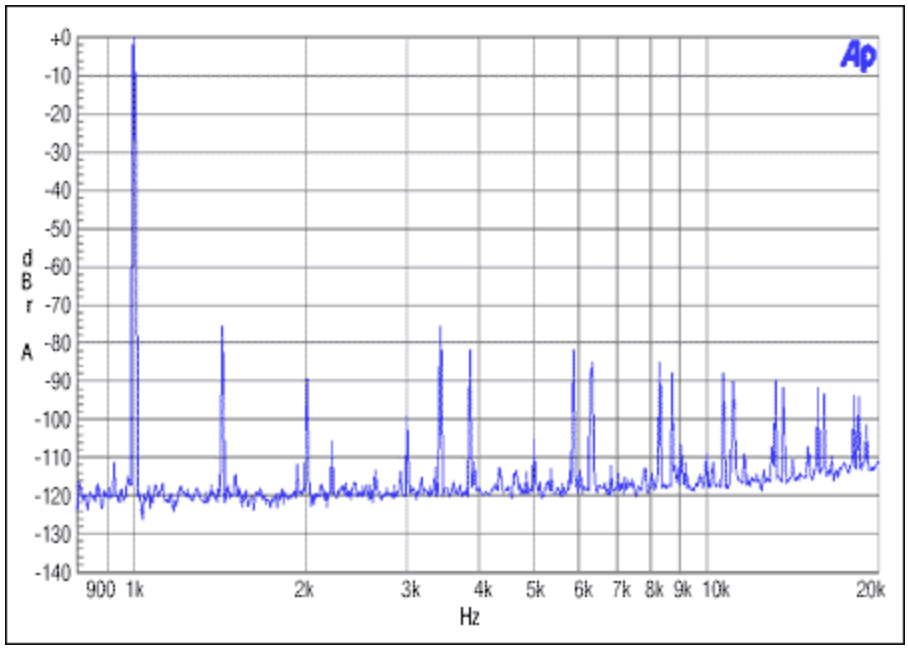

Figure 5. Master noninteger mode. MCLK = 12MHz, F_S = 44.1kHz, 0dBFS.

Although in integer mode, switching between master and slave mode has no effect on the performance; in

noninteger mode, this is no longer the case. Switching from master to slave operation now further reduces the performance of the converter, as shown in **Figure 6**. The THD+N increases to -65dB.

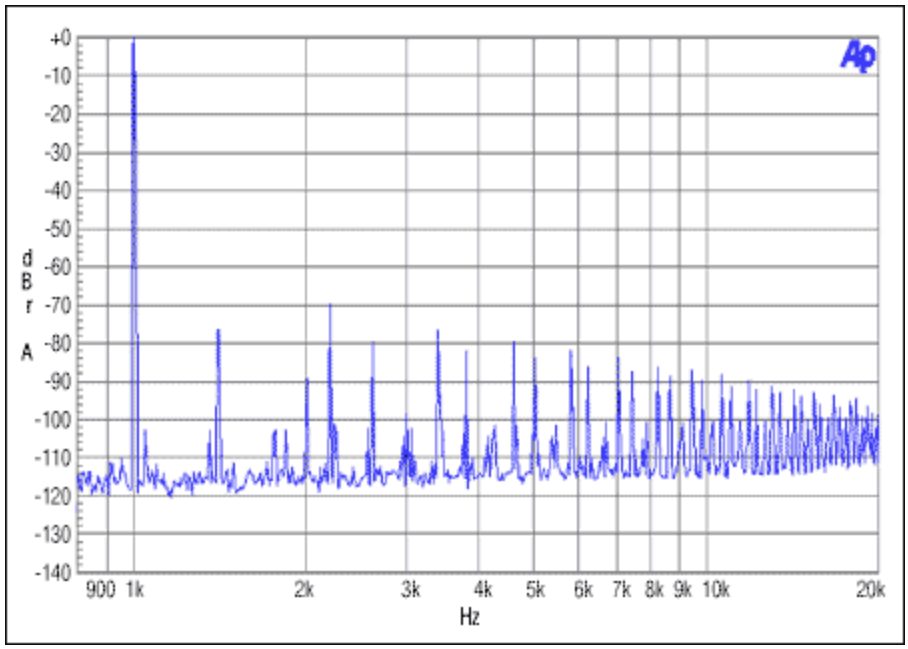

Figure 6. Slave noninteger mode. MCLK = 12MHz, F_S = 44.1kHz, 0dBFS.

Distortion as a Function of Input Amplitude

While at large signal amplitudes, the signal can mask some distortion. As the signal amplitude decreases, the distortion must decrease as well to maintain good sound quality. **Figures 7** to **11** show the MAX9850's output spectrum for -30dBFS and -60dBFS signal levels. For the modes where there is an integer relationship between the master clock and the sample rate, all distortion elements are below the noise floor at signal amplitudes of -30dBFS. For noninteger-related sample rates and master clocks, such as 44.1kHz and 12MHz, only low amplitude distortion remains. At -60dBFS levels, distortion that is inherent in the architecture becomes visible in the spectrum. This distortion is not directly related to the sample rate or master clock, so as a result is identical in all modes.

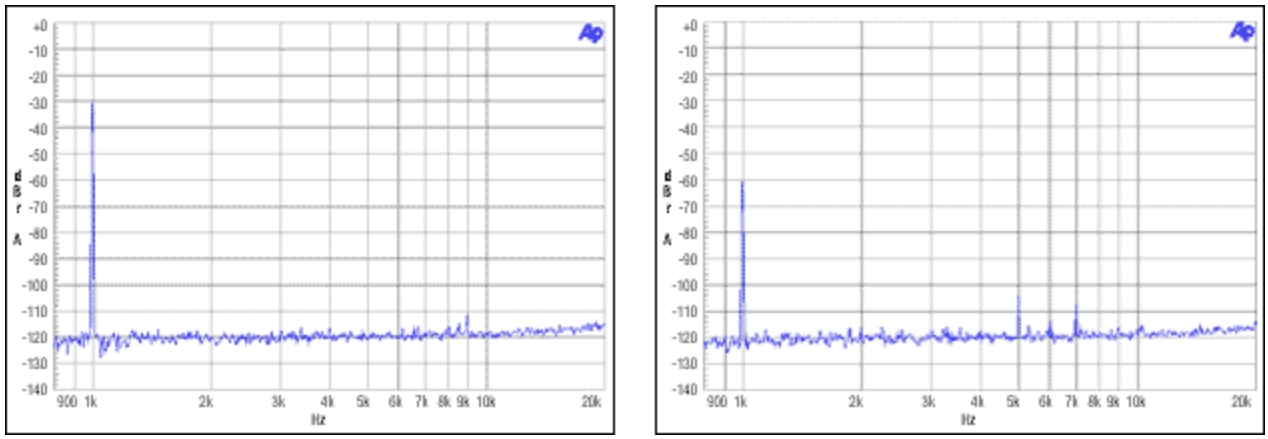

Figure 7. Master/slave integer mode. MCLK = 12.288MHz, F_S = 48kHz, -30dBFS and -60dBFS.

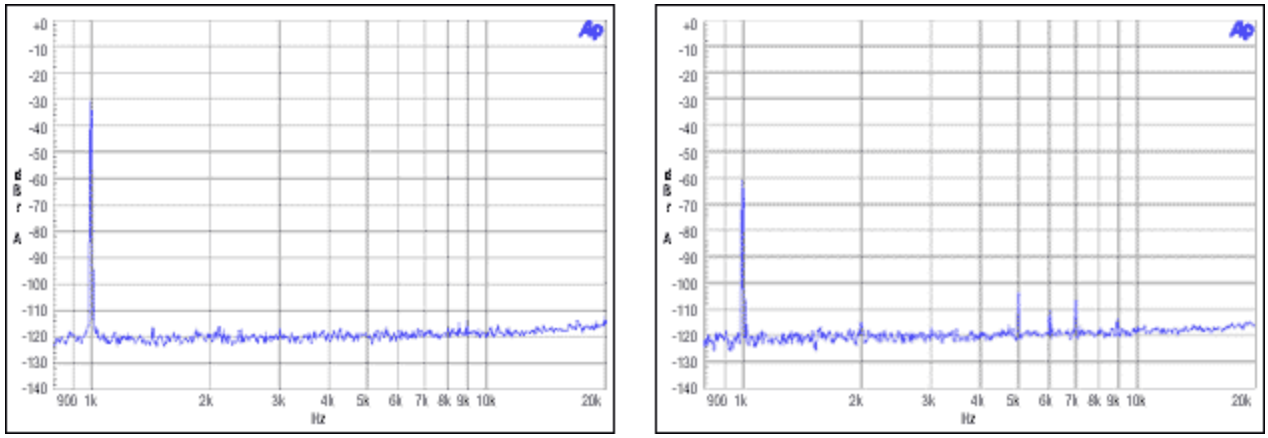

Figure 8. Master noninteger mode. MCLK = 12MHz, F_S = 48kHz, -30dBFS and -60dBFS.

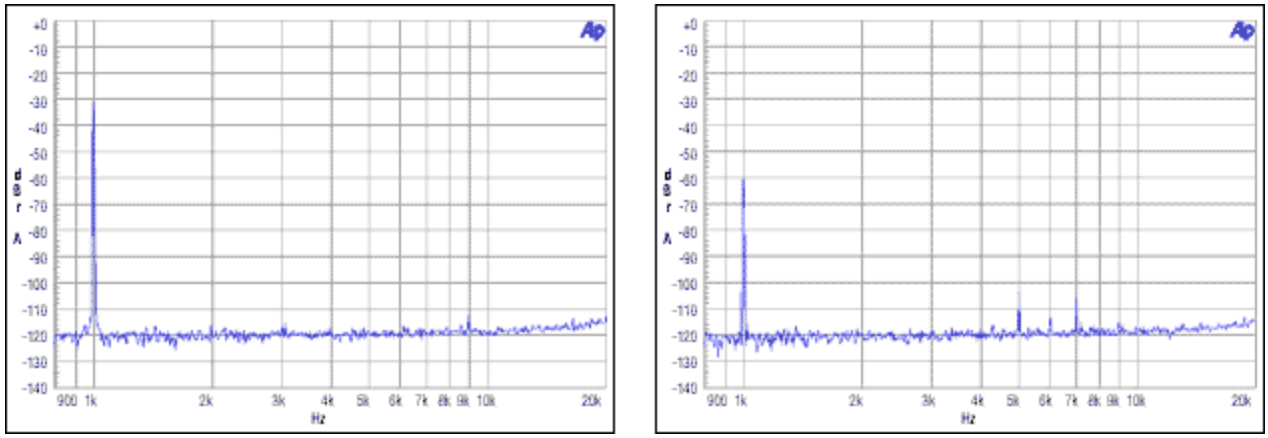

Figure 9. Slave noninteger mode. MCLK = 12MHz, F_S = 48kHz, -30dBFS, -60dBFS.

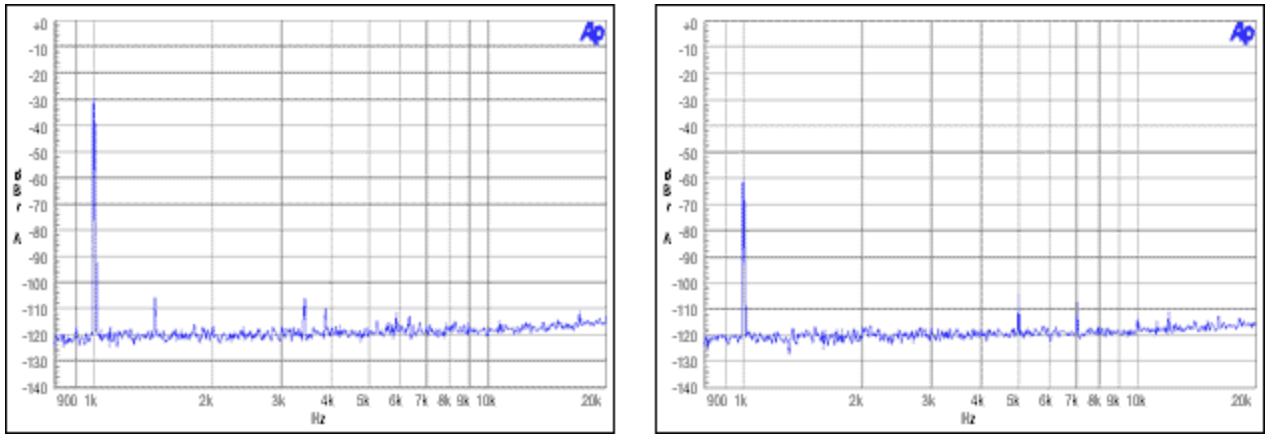

Figure 10. Master noninteger mode. MCLK = 12MHz, F_S = 44.1kHz, -30dBFS, -60dBFS.

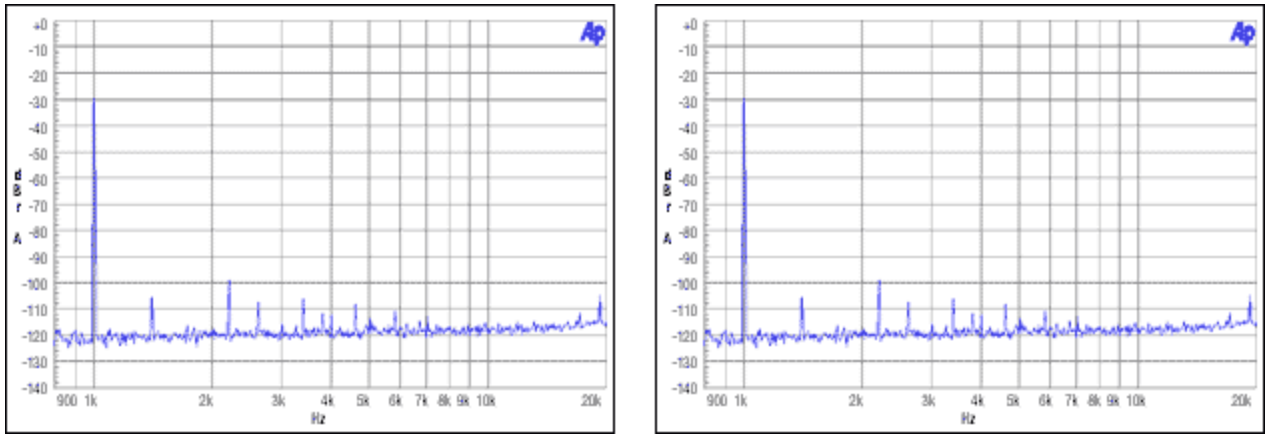

Figure 11. Slave noninteger mode. MCLK = 12MHz, F_S = 44.1kHz, -30dBFS, -60dBFS.

Conclusion

At full-scale single levels, significant distortion can be measured in some of the modes. Although it is measurable, it is not particularly audible because the human ear picks out the loud signal and the quieter distortion elements are ignored. This same concept is used in many lossy compression algorithms (such as MP3 and AAC) where part of the compression is achieved by eliminating signals that are masked by more powerful signals. In both cases, significant amounts of data can be eliminated without significantly sacrificing sound quality. Similarly, a converter can create some amount of distortion without adversely affecting sound quality.

When the human ear listens to low-level signals, it is much better at detecting distortion in the signal, as there is no longer a large signal to provide masking. At these lower levels the MAX9850 produces distortion near or below the noise floor, maintaining good sound quality.

The MAX9850 also achieves good signal-to-noise ratio and dynamic range, regardless of operating mode. Because the spectra created by a -60dBFS input signal are the same regardless of operating mode, the dynamic range is identical for all modes. Similarly, the noise floor is the same for all operating modes, so the signal-to-noise ratio is the same in all modes.

Even in the lowest performance mode, the MAX9850 is able to achieve useful results. In systems where sound quality is not of paramount importance, any available system clock can be connected to the device and it will function. For systems that demand better audio quality, the option still exists to provide a dedicated audio clock and operate the DAC in a fully synchronous mode.

Appendix: Measurement Settings

Circuit Board	MAX9850EVKIT
Signal Generator	Audio Precision SYS-2722 with PSIA-2722Bit depth: 16 bits
Signal Analyzer	Audio Precision SYS-2722 with PSIA-2722 22Hz to 22kHz bandwidth A-weighted filtering FFT input A/D: HiRes A/D @ 65536 FFT Samples: 32768 FFT Window: Blackman-Harris Averages: 4

Power Supply	Agilent E3630A triple-output DC power supply A_{VDD} = 3.0V, P_{VDD} = 3.0V
Clock Source	12.288MHz generated by the PSIA-2722 12MHz generated by the EV kit's crystal oscillator

[1]Refer to the MAX9850 datasheet for complete details on configuring the MAX9850.

Related Parts		
MAX9850	Stereo Audio DAC with DirectDrive® Headphone Amplifier	Free Samples
MAX9851	Stereo Audio CODECs with Microphone, DirectDrive Headphones, Speaker Amplifiers, or Line Outputs	
MAX9853	Stereo Audio CODECs with Microphone, DirectDrive Headphones, Speaker Amplifiers, or Line Outputs	

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