Clock Jitter and Clock Accuracy for Digital Audio

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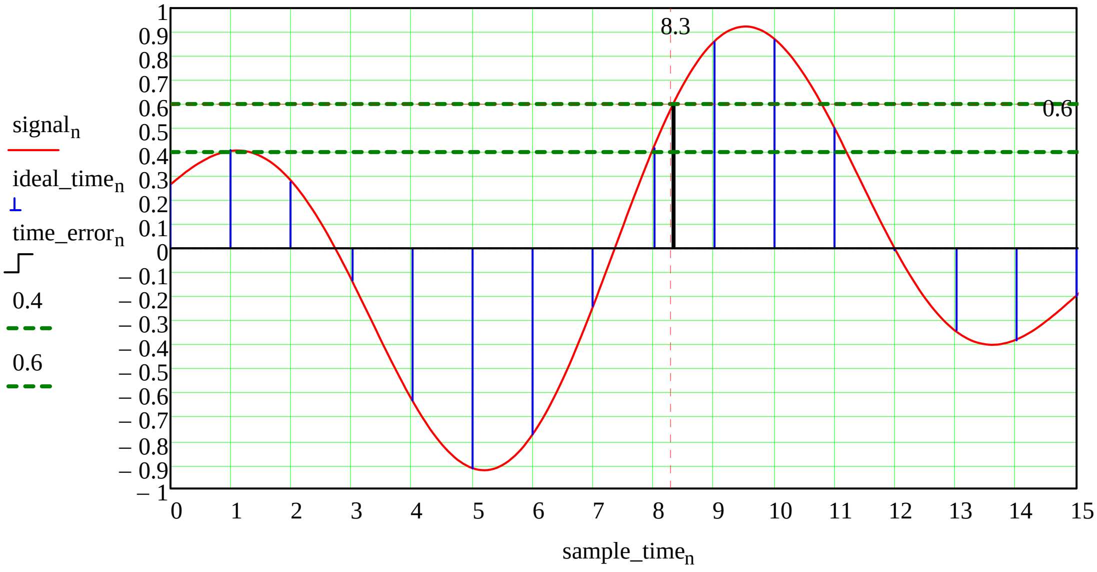
For a theoretically perfect clock, each cycle lasts exactly the same time as all other cycles. Real life clocks have two separate imperfections: absolute accuracy (including long term drift) and short term variations (jitter).

Jitter

Digital audio relies on serial data formats where each bit has a given time duration. For example, the bit duration for a 192KHz stereo signal (AES or SPDIF) is 81 nanoseconds. A few nanoseconds of jitter will not be enough to impact most digital operations such as processing, memory operations, or data transfer. However, converters are impacted by lower jitter levels. For audio production it is best, if possible, to reduce the impact of jitter on converters to levels below human perception.

Digital audio is based on sampling.The plot below shows a wave signal (red), the correct sample values (blue), and one sample with time error (black). Sample 8 has a signal value of 0.4. A 0.3 time error at sample 8 results in a signal value of 0.6. In this example the time error caused 0.2 error in the sample value - which is 10% of full scale.

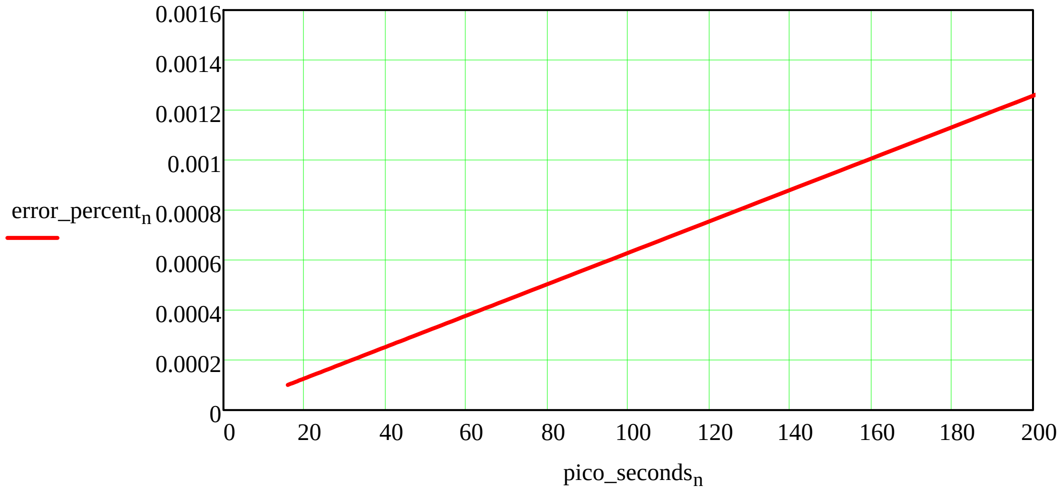


The steeper the slope of the wave, the bigger the error will be. The slope depends on two factors: amplitude and frequency. Louder, higher frequency signals yield larger errors.

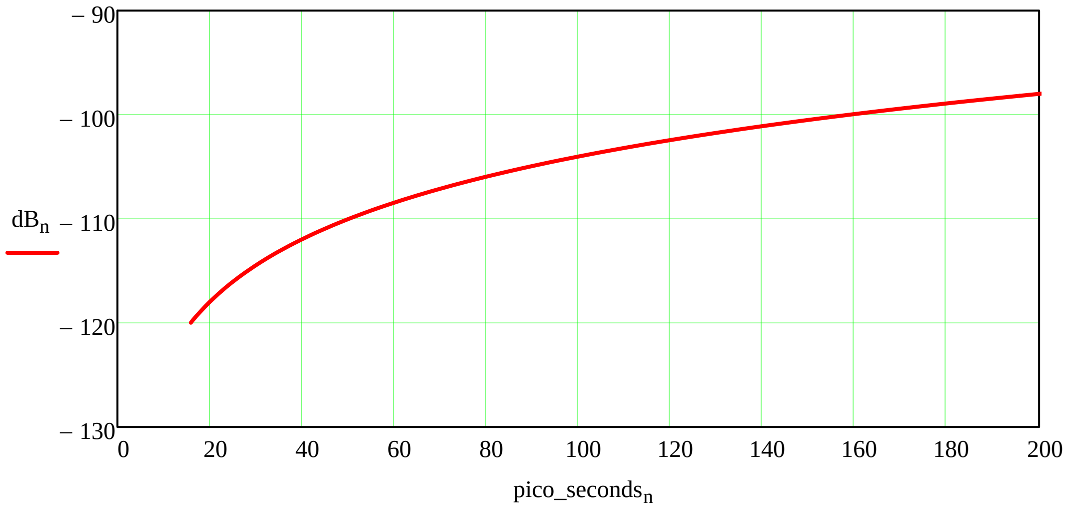
Real life sampling is never perfect; virtually all samples have some time error, also known as jitter. The signal errors due to jitter distort the waveform. For audio, the goal is to keep the resulting distortions below audibility.

For 20KHz audio bandwidth, the maximum theoretical slope (relative to full-scale signal) is a known value. The plots below are based on that value in order to cover worst case senario.

The plot below shows the relationship between jitter and the corresponding percent error relative to full scale.
At 200 pico-second jitter, the distortions are better than perfect CD quality audio. State of the art analog technology distortions are large enough that the impact due to 20 pico-second jitter is negligible.



The plot below shows the relationship between jitter and signal error in dB (relative to full-scale).



Note that -120dB represents one part per million accuracy (0.0001%). At high amplitude and frequency, this level of accuracy is difficult to achive, even with a single stage analog circuit .

Ultimately, jitter matters at the converter. Even assuming a theoretically zero-jitter clock source, the real life signal path to a converter includes some electronic circuitry, which adds jitter; In most cases locking to a clock requires a PLL circuit (inside the converter), which becomes the major contributor of jitter.

There are four common methods for quantifying jitter:

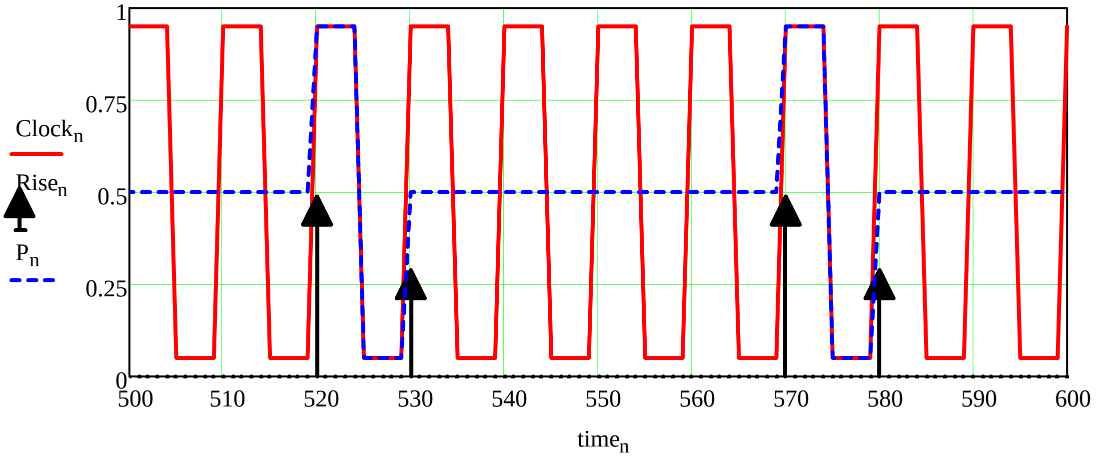
1. EBR (error bit rate) is an indirect measurement of jitter. A comparison is made between data before and after transmission. This method is widely used in high-speed data communication. EBR yields the least information about the nature of the jitter of any of the four methods.

2. A wide bandwidth oscilloscope enables a measurement referred to as an "eye pattern". This method is effective at high frequencies, but not effective at audio sample rates.

3. Spectral analysis is often used by timing device manufacturers to examine the relationship of jitter to frequency. The result is often presented as a detailed plot (dBc vs. frequency).

4. Cycle-to-cycle measurement (single-shot) accumulates many individual cycle time measurements. The data is used to generate statistical information. The average value yields the sample rate, and the data yields standard deviation (jitter information) and more. This method provides the most detailed information about the nature of the jitter.

The plot below shows a 100KHz clock (red), and two selected cycles (blue). One cycle starts at 520usec and ends at 530usec. The other is from 570 to 580usec.



Note: The ear is not very sensitive to a single sample error, it is sensitive to groups of errors that occur over a few milliseconds. The nature of auditory processing is a subject known as psychoacoustics and is beyond the scope of this paper.

Clock Accuracy

Clock accuracy is a measure of the difference between theoretical and real hardware sampling rates. Engineers express frequency accuracy in "parts per million" (ppm).

Example 1: A clock operated dishwasher timer is set to 1 hour, but the process lasts 1 second too long. This time deviation (278 ppm), would be more than acceptable.
Example 2: Measuring a ten minute duration sports event with 0.01 second accuracy requires 17ppm accuracy.

Humans can't perceive one second time error over an hour duration (278ppm). Today's technology makes it easy to achieve much better then 100ppm accuracy. Increasing an audio clock rate by 100 ppm will make an hour performance shorter by 0.36 seconds. Slowing a three minute song by 100ppm adds 0.018 seconds - which is not perceptible.

Audio production requires that all the sound tracks start, drift and end together to avoid possible conflicts. The ear is very sensitive to time mismatch between tracks. In some cases a few microseconds of mismatch causes audible impact (comb filtering). Processing tracks with unsynchronized independent clocks imposes an unrealistic requirement on clock accuracy.

Restricting drift between two tracks to within 1 microsecond over 3 minutes requires a total error to within 0.0056ppm. Maintaining the same drift over longer durations requires increasing accuracy, which makes independent clocking impractical. Adding more tracks increases the problem. In contrast, using a single clock provides sample-by-sample synchronization with no restrictions on duration and number of tracks.

Clock inaccuracy also manifests as pitch shift. The ear has limited pitch sensitivity; A shift of 1 cent (less than 500ppm) is below that limit. Even 100ppm is a trivial requirement to meet with today's technology.

Using independently clocked tracks can introduce audible pitch shift related issues. A pair of tones with slight pitch separation may produce audible beat frequencies. Synchronizing tracks to a single clock guarantees that any shift in pitch is common to all the tracks, thus preventing audible effects.

Clock accuracy and clock jitter are separate issues. Achieving high accuracy does not guarantee low jitter and vice versa. For example, atomic clocks offer extreme accuracy, but are not made for audio frequencies. They operate at 10MHz or other general purpose frequencies. The circuitry required for converting to audio clock rates (typically PLL) adds jitter.

From a technology standpoint, meeting and exceeding clock accuracy requirements for audio is not particularly challenging. However, meeting the jitter requirements is a challenging task. Understanding the concepts of accuracy and jitter, and how they impact audio enables an engineer to secure better results.