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Bluetooth Applicability in High-Fidelity Audio Systems

Garrett Scheiber

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Do the abilities of Bluetooth technology allow for its use as a transmission medium for high quality audio?

Music enthusiasts have sought the highest quality audio playback since audio recording technology was developed. Amplification techniques and speaker constructions have been improved to give clearer sound. Despite these advances, transmission has continued primarily through wire. Developments in wireless technology have the possibility to change transmission of audio between speakers, amplifiers, and other audio devices. Bluetooth has the potential to solve this transmission problem, but the abilities must be investigated before any conclusions are made. Bit rates and other characteristics of common Bluetooth versions must be analyzed and compared to the bit rate of high-fidelity music to assess Bluetooth's suitability.

Bit rate is a common measurement of music quality. It consists of a sampling rate, a level measurement, and a classification of loss. This is illustrated in Figure 1. The black waveform is the original recording waveform of the music. The time between each vertical line is the sampling rate (a higher sampling rate translates to a lower delay between samples, which increases the accuracy). The level measurement is the position of the wave at a certain point (the height of each horizontal line). A higher number of bits devoted to level will result in an increased level accuracy. Loss classification is either lossless (no audio data loss during compression) or lossy (audio data is lost during compression). For example, CDs have a sampling rate of 44.1 kHz with 16 bits devoted to the output level which gives a bit rate of 1,411.2 kbps (which is considered lossless) for two channel audio. For this investigation, CD quality (1,411.2kbps) will be considered the lowest possible quality for high-fidelity music.

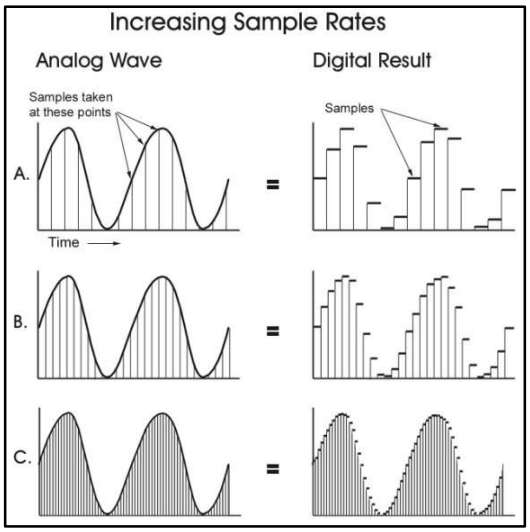
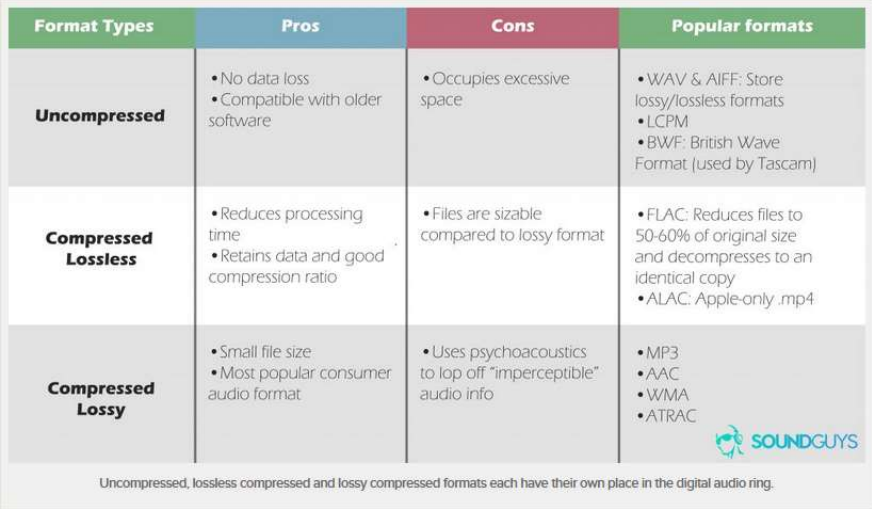


Figure 1: The difference between different bitrates and the effect on sound accuracy.

Wired transmission's bit rate is limited solely by the sending node, the receiving node, and the source quality of music (e.g. streaming services, records, or CDs). This gives different

audio qualities the opportunity to be transmitted at their native bit rate (the source quality). Alternatively, wireless transmission uses radio waves to transmit data between nodes, which is limited by the transmission rate of the nodes

Bluetooth 5.0 (the latest version of Bluetooth) has a transmission rate of approximately 1,400kbps, which seems to meet the requirements for transmitting CD quality audio (the established baseline for high-quality audio). Solely analyzing the transmission rate gives a misleading outcome. The "other characteristics" mentioned above must also be considered. Bluetooth version differences and congestion can have a negative impact on the transmission rate. Although compatible, using different versions of Bluetooth at the sending and receiving nodes will restrict the transmission rate to the lower rate of the two nodes. Congestion in the radio frequency wavelength (other active Bluetooth transmissions) will also limit the transmission rates. The only potential positive factor to consider is the codec used in transmission.



Format Types	Pros	Cons	Popular formats
Uncompressed	• No data loss • Compatible with older software	• Occupies excessive space	• WAV & AIFF: Store lossy/lossless formats • LCPM • BWF: British Wave Format (used by Tascam)
Compressed Lossless	• Reduces processing time • Retains data and good compression ratio	• Files are sizable compared to lossy format	• FLAC: Reduces files to 50-60% of original size and decompresses to an identical copy • ALAC: Apple-only .mp4
Compressed Lossy	• Small file size • Most popular consumer audio format	• Uses psychoacoustics to lop off "imperceptible" audio info	• MP3 • AAC • WMA • ATRAC

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Uncompressed, lossless compressed and lossy compressed formats each have their own place in the digital audio ring.

Figure 2: Different Bluetooth codecs with advantages and disadvantages.

Codecs compress data before transmission (some audio codecs are shown in Figure 2). Most common codecs are lossy, being optimized for lower quality audio streaming services (Spotify, Apple Music, Pandora, etc.). As shown, only one codec exists which is both compressed and lossless (FLAC). Practically, FLAC is not a standard codec in most devices, and therefore would not be beneficial to common users. Considering the factors of version difference, congestion, and codec applicability previously described, Bluetooth is not currently applicable to high-fidelity music transmission.

Although current versions of Bluetooth are not applicable to high-quality audio transmission, changes in future versions can be made to rectify this. Advances in transmission speeds will likely be offset by increased use of Bluetooth in a wider variety of applications, making transmission rate improvements negligible. Despite this, codec modification and priority frequencies could deem Bluetooth applicable in high-fidelity audio transmission. Widely using lossless compression codecs similar to FLAC would decrease the bit rate necessary to transmit high-quality audio, while preserving the original signal. The transmitter would analyze the audio source, classifying it as high or low- quality and communicating this to the receiving node. Both nodes would then transition to the high-quality codec and begin the transmission.

"Priority" frequencies could be implemented, which would reserve a certain fraction (of the 79 different frequencies illustrated in Figure 3) for designated uses (these could be audio or professional related). The use of priority frequencies would reduce the congestion in these

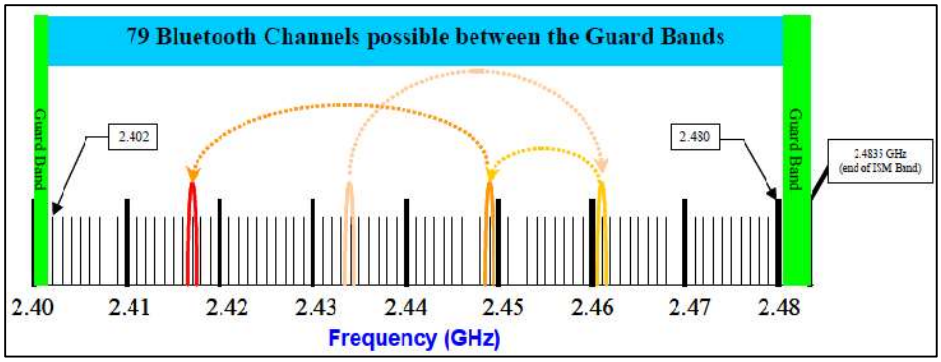

Figure 3: A graphical representation of the frequencies used in Bluetooth transmission.

frequencies, allowing for higher transmission rates where desired. Both of these changes (to codec use and priority frequency allocation) could improve Bluetooth's viability in high-fidelity audio transmission.

Bluetooth versions do not currently exibit the abilities for high-fidelity music transmission. Transmission speeds are adequate, but limitations related to codecs, congestion, and differing Bluetooth versions prevent Bluetooth from being a realistic alternative to wired audio transmission. As shown, modifications to codec availability and frequency allocation could theoretically make Bluetooth a viable method of audio transmission.

Figure 1: https://www.izotope.com/en/learn/digital-audio-basics-sample-rate-and-bit-depth.html

Figure 2: https://www.soundguys.com/understanding-bluetooth-codecs-15352/

Figure 3: https://sites.google.com/site/nearcommunications/adaptative-frequency-hopping