Wireless Digital Audio Quality For Portable Audio Applications

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Introduction

This whitepaper discusses the impact of wireless audio technology on audio quality, with emphasis on portable audio applications, and some of the factors that should be considered in selecting a wireless audio technology.

Battery Life & Form Factor

Before getting into an analysis of the factors directly affecting audio quality, it is necessary to introduce some of the other factors that indirectly affect audio quality by placing constraints on the selection of digital wireless technology. These additional factors include battery life (power consumption), form factor, and cost.

The selection of audio Analog to Digital Converter (ADC), audio Digital to Analog Converter (DAC) and headphone/speaker driver has a major direct impact on audio quality metrics such as Dynamic Range, Signal to Noise Ratio (SNR) and Total Harmonic Distortion (THD). This impact is independent of whether a wired or wireless link is used.

However, in a wireless solution battery life (power consumption) becomes an important consideration that influences the selection of ADC and DAC. When power is no object, high performance solutions can achieve SNR of > 110dB and THD of < -100dB using 24-bit resolution and 192KHz sampling while consuming on the order of 100mW. The solutions typically used by battery-powered wired portable audio devices today achieve around -70dB THD+N/S and >90dB SNR for <10mW power consumption. These codecs will migrate to the headphone/earphone in a wireless solution and therefore wireless audio technology should be selected to allow the full performance of these codecs to be realized. In other words, the wireless audio technology selected should not limit audio quality to anything worse than -70dB THD+N/S and 90dB SNR.

Long battery life is one of the key metrics that consumers look for in choosing a portable audio player. Consider a player with a 400mAHr Li-ion battery that provides 27 hours of playtime between charges when used with a wired configuration. This player is consuming approximately 55mW during playback. Approximately 10-15mW can be attributed to the audio DAC and amplifier driving the headphone. Ideally, the addition of a radio would have no impact on the battery life of the player. In order to achieve this, the power consumption of the radio should also be on the order of 10-15mW, since the audio DAC/amp on the player can be powered down when the radio is being used.

In the case of a wireless earphone, an attractive battery form factor is a coin cell with a diameter of less than 15mm. A rechargeable Lithium Ion battery of this size has a capacity of approximately 70mAHr. To achieve 10 hours of playtime, the power consumption of the entire wireless solution must be less than 26mW including the radio and the audio DAC. Once again, the power consumption of the radio alone must be on the order of 10-15mW.

Audio Quality

One of the most important factors influencing the selection of wireless audio technology is impact on audio quality. Generally, users want the same audio quality from their wireless solution that they get from a wired solution. Four key factors are discussed below.

Digital Wireless Transmission Capacity

The goal of the digital wireless transmission technology should be completely lossless audio transmission. Uncompressed, 16-bit, 44.1KHz-sampled stereo audio (full CD quality) requires 1.4112Mb/s. Lossless audio compression can reduce this to approximately 1Mb/s on average, but the short term compression ratio depends on characteristics of the music such that the radio still needs to support the full 1.4Mb/s to achieve lossless full CD quality audio streaming. Anything less, and lossy compression is required and audio quality is reduced. Some excess capacity is required for the retransmission of packets corrupted by interference. In general, a radio capacity of approximately 2Mb/s provides an optimum trade-off between audio quality, interference robustness and power consumption.

Digital Audio Compression for Wireless Transmission

The primary purpose of digital audio compression is to reduce the data rate of the audio stream to fit within the capacity supported by the digital wireless transmission technology. There are two main categories of digital audio compression; lossy compression and lossless compression.

Lossless compression only eliminates redundancy from the audio stream such that no information is lost. The original audio stream can be exactly reproduced by decompression, such that there is no reduction of audio quality, and the simple encoding/decoding circuitry consumes negligible power.

Lossy compression includes well-known formats such as MP3, WMA, OGG, AAC, and others. Lossy compression targets a specific compression ratio (e.g. 4:1, 10:1, etc.) or data rate (e.g. 128Kb/s, 192Kb/s, etc.) and eliminates as much information as is necessary to achieve that amount of compression. Perceptual encoding is used to minimize the audibility of the information loss. Relatively high compression ratios can be achieved at the expense of audio quality and at the cost of complexity and power consumption of the circuitry performing the encoding and decoding.

Figure 2 shows the impact of lossy Bluetooth SBC compression relative to Kleer lossless compression using a multi-tone test. Bluetooth SBC compression results in a noise floor that is at least 40dB higher than lossless compression, with a corresponding reduction in SNR and dynamic range.

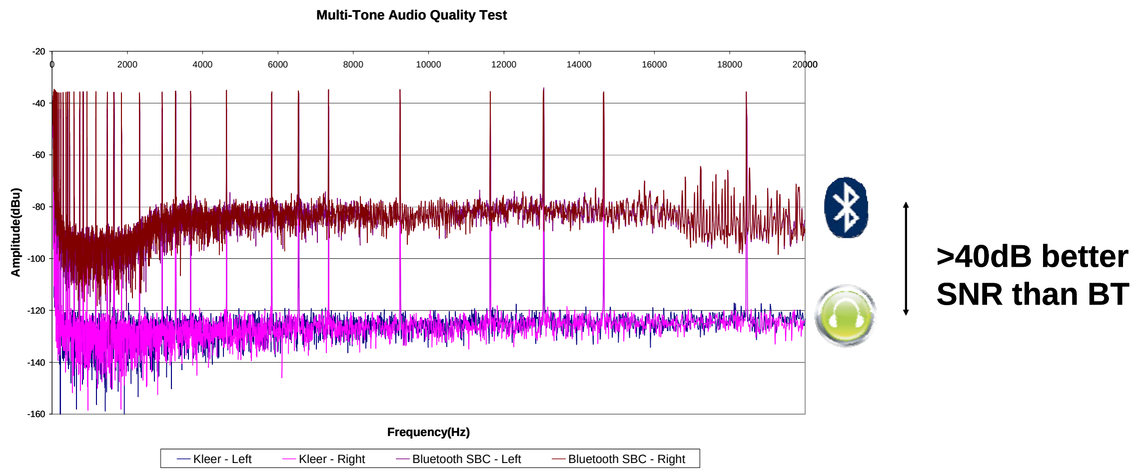

Figure 1. Multi-Tone Test: Kleer versus BT

An argument often used to rationalize the use of lossy compression in digital wireless audio applications is that the music itself is usually stored using lossy compression and therefore the wireless transmission compression is not causing any additional reduction in audio quality. There are several problems with this argument. The first problem is that the audio quality associated with compression formats used for wireless transmission is not as good as that associated with digital storage compression. This is because the compression used for wireless transmission must take into consideration the power consumption and latency associated with real-time compression and decompression. The second problem with this argument is that combining digital storage compression in series with wireless transmission compression (sometimes referred to as transcoding) may reduce the audio quality more than either compression method individually. The third problem with the argument is that portable audio devices are evolving towards using lossless storage compression as the cost of storage comes down. Portable audio devices are becoming the primary storage vehicle for entire music collections that are then played in the home and car, as well as on the portable device. This is driving a demand for higher quality (lossless) storage, in which case the wireless transmission compression will be the limiting factor in audio quality.

Recognizing the problems mentioned above of using separate wireless transmission compression, some Bluetooth providers are offering the ability to transport the music in the format used for storage, e.g. MP3. This approach may eliminate the requirement for transcoding in the player, but it forces the headphone/earphone to support the superset of possible storage compression formats which simply transfers the complexity and power consumption from the player to the headphone/earphone. Furthermore, it does not address the situation where there is uncompressed music on the player if the radio does not have sufficient capacity.

Interference Robustness

Digital radios for consumer electronics, including wireless LAN (802.11b/g), Bluetooth, Zigbee, cordless telephones, and baby monitors, all use unlicensed radio spectrum, known in the US as the Industrial, Scientific and Medical (ISM) bands. Any device wishing to communicate in this band must be able to deal with the interference generated by these other devices.

A robust overall solution must be able to re-transmit data corrupted by interference at another time and possibly on another channel when and where there is no interference. The ability of a wireless digital audio solution to do this depends on several factors;

a) The **size of the audio buffer** determines how long the system can wait for interference to clear up before the audio stream is affected. Although larger buffers can deal with more interference, they also introduce more latency that can be unacceptable in certain applications. The size of Kleer's audio buffer is configurable, supporting over 100msec for applications that may face severe radio interference, or as little as 20 - 45msec for video applications.
b) **Minimum bandwidth requirement** refers to the amount of spectrum required by the wireless solution. Figure 3 illustrates the bandwidth requirements of WLAN (3 x 22MHz), BT (20 x 1MHz) and Kleer (3MHz). In this environment, Bluetooth cannot find 20 channels (as mandated by the Bluetooth standard) that do not overlap with WLAN, and therefore will have difficulty supporting a single audio stream. Kleer, on the other hand, can find at least 4 channels, any one of which is sufficient to support the audio stream.
c) **Dynamic frequency diversity** refers to the ability of the wireless audio solution to quickly move to another frequency, or channel, if the current channel is experiencing poor performance. Speed is critical. For example, Kleer can scan the entire ISM band to find a good channel before audio is impacted. Tests of Bluetooth devices show that when a new interferer is encountered, audio is affected before the Adaptive Frequency Hopping (AFH) mechanism adapts to avoid the interferer.

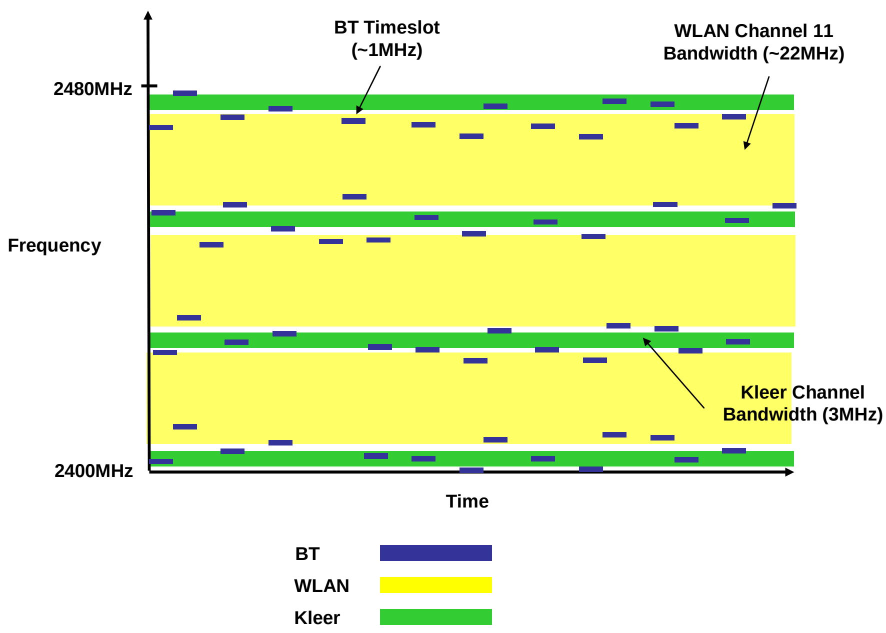

Figure 2. Minimum Bandwidth Requirements

Audio Latency

Audio latency is the total delay that the audio stream experiences. Applications that involve a video component and multi-channel sound systems are sensitive to latency.

Application	Maximum Acceptable Latency
Portable Audio	> 100msec
Video Soundtrack	45-70msec
Multi-channel audio rear speakers	< 20msec

There are several possible sources of latency in a wireless audio solution. Two key sources of latency are; a) audio compression; and b) audio buffering.

Lossy audio compression, such as Bluetooth SBC, requires sufficient audio data stored to allow frequency domain processing. This can add as much as 40msec of latency. In contrast, lossless compression can operate on much smaller blocks, achieving full performance with less than 5msec of latency.

As discussed earlier in this whitepaper, audio buffers are also required to hold the incoming audio at the source, and continue the flow of audio at the sink, while the radio is experiencing corruption. The size of the audio buffer, and thus the amount of latency, required to deliver interference robustness in a wireless audio solution that has dynamic frequency diversity is dependent on how quickly the system can detect a bad channel, and switch to a good channel. Kleer's channel switching is extremely fast, allowing 16 channels to be scanned in less than 40msec, thus allowing total latency (audio buffer plus compression buffer) to not exceed 45msec for video applications. In addition, Kleer is enhancing its channel switching to make it even faster, in order to target total latency of 20msec.

Summary

The success of wireless technology in the portable audio market depends on audio quality, battery life, form factor and cost. This paper has discussed the various factors in a wireless audio solution that affect audio quality, and proposes minimum requirements for some of the key technology selection considerations.

Kleer's wireless audio technology is the first such technology to combine high quality audio and robust ISM band coexistence with low power consumption to address portable, home and automotive audio markets. Kleer's Audio LP technology is ideally suited for OEMs of portable audio players, iPod and other player accessories, home audio/theater systems, earphones, headphones and speakers.

Kleer's patented sub-sampling radio architecture communicates lossless CD-quality digital stereo audio over a robust 2.4GHz radio link, while achieving 10 times the battery life of a comparable Bluetooth solution. Kleer's dynamic narrowband channel selection with configurable latency offers unprecedented interference immunity and ISM band coexistence, while our 2.37Mb/s capacity allows lossless transmission of the audio signal with ample room for retransmission.