Streaming audio: *Follow the signal chain*

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Abstract

Wireless streaming audio is a rapidly growing and very dynamic marketplace, one that presents attractive opportunities and challenges to equipment manufacturers. The system suppliers best able to capitalize on this opportunity will be those that have adopted an agile, system-wide platform approach to product development, one that focuses on the entire audio signal chain. In the end, this will yield a broad range of robust, feature-rich and highly capable audio systems. This white paper focuses on the system-wide design for the emerging Wi-Fi®-based segment of the streaming audio market.

Introduction

The advent of digital music made streaming audio possible, which made its first appearance on computers with integrated or connected speakers. The computer itself was typically connected by wires to the Internet. Music could be streamed from the Internet and played on the connected speakers. From this rudimentary beginning, streaming audio expanded to home entertainment systems, which were connected by wires to traditional speakers. As wireless connectivity and technologies like *Bluetooth*® and Wi-Fi became more popular and access to them became easier, the convenience and portability of wireless speakers was introduced to the streaming audio marketplace. Locally stored music could be streamed wirelessly to speakers from computers or cell phones, or it could be streamed from the Internet through a local device—like a smartphone with a wireless connection—to one or more speakers in the local network.

From the standpoint of the underlying enabling technologies, as well as consumer demand, the wireless streaming audio market is still evolving and it will continue to do so in the foreseeable future. Wi-Fi connectivity is becoming increasingly popular as the connectivity technology of choice for quality wireless speakers and headphones. Characteristics like its extended range, high bandwidth and robust signaling are advantages for Wi-Fi-based audio streaming systems. In addition to Wi-Fi, other enabling technologies like high-definition audio codecs, as well as high-definition Class-D audio amplifiers and cost-effective high-end digital-to-analog converters (DACs) are also affecting how streaming audio systems are implemented. In between the audio entering through Wi-Fi and exiting through the amplifier the consumers are looking for cleaner audio processing and expanding feature set driving higher performance out of processors and accompanying software. Yet, while the enabling technologies continue to evolve, consumer demand in the marketplace with regards to preferences for services can be quite volatile. For example, a wide range of Internet-based music streaming services are available today, but many more, each with its own special service offering, are expected in the future.

All of these factors contribute to the rapidly changing dynamics of the streaming audio marketplace. Of course, system manufacturers are hard pressed to control consumer demand, but they can control their new product development practices. To maximize their opportunities in such a rapidly changing environment, suppliers of wireless speakers and other types of streaming audio systems must be extremely agile and responsive to the whims of the market, such as newly introduced streaming music services offering high resolution (Hi-Res) or high-definition (HD) streaming audio. The most effective way to do this is to adopt a top-down or system-wide approach to the entire streaming audio signal chain. Each link in this chain is important. In fact, the entire chain is only as strong or as robust as its weakest link. Moreover, the entire chain is stronger when the functionality integrates with and complements that of the others in the chain. In addition, each link must be strategically capable of surmounting all of the challenges that designers face, such as cost, time-to-market, ease of development and others.

Follow the chain

In general, the typical audio streaming signal chain is made up of the following major functional blocks:

- Connectivity
- Processor
- Software
- Digital-to-analog conversion
- Audio amplification

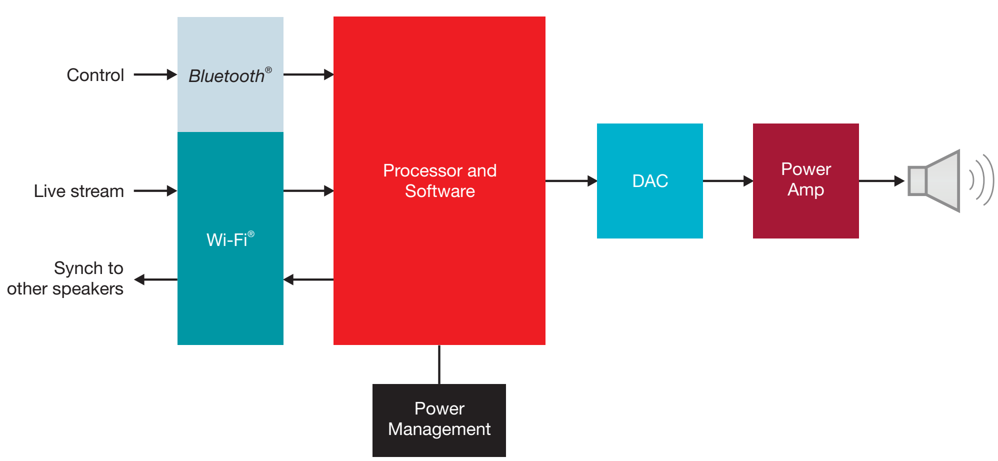


Figure 1: Simplified signal chain Wi-Fi speaker

As the block diagram in Figure 1 indicates, the processing element is central to an audio streaming signal chain. It possesses the intelligence to perform the necessary audio processing like decoding, equalizing and other functions on the digital music stream as it enters the system through the Wi-Fi wireless gateway. What's critical for every processor in every sort of system is the software that runs on it. To ensure rapid development cycles, the software running on the processor in a streaming audio signal chain must, of course, expeditiously process audio streams, but it must also include ready-to-implement interfaces to popular streaming services and streaming devices, capabilities that can be adapted to a broad range of audio quality levels and features that anticipate the next-generation functionalities like multi-speaker, multi-room synchronization that consumers will certainly demand.

In this particular signal chain, the wireless connectivity technology is Wi-Fi. In wireless speakers, the input Wi-Fi interface might be accepting a live digital music stream originating on the Internet, but coming through a smartphone or a home entertainment system that is connected over Wi-Fi with the speaker. The digital music is processed by the speaker's processor and then converted by a DAC into an analog signal. This signal is amplified by an audio amplifier so it can drive the audio to the speaker(s).

A closer look at each element in the signal chain will reveal how an agile and adaptable system can be designed to maximize its opportunities in the marketplace.

Wi-Fi connectivity

Once a new consumer electronics technology becomes established, users soon start seeking next-generation equipment with additional enhancements and higher-quality performance. Such has been the case with live streaming music and the increasing popularity of Wi-Fi as its connectivity technology. Because Wi-Fi access points can be found in most homes, Wi-Fi-based streaming audio equipment is ensured of a high degree of accessibility and ease-of-use for consumers. Additional benefits of Wi-Fi include its greater network capacity, robust signaling and extended radio frequency (RF) range over alternative short-range wireless technologies. Its native support for Internet Protocol (IP) also gives Wi-Fi an advantage in connecting with online music services, many of which have adopted Wi-Fi as a backbone mechanism for their streaming technologies.

Combo connectivity Wi-Fi/Bluetooth

TI's **WiLink™ 8 devices** feature high-throughput, robust co-existence, high integration and seamless compatibility with the Sitara™ family of processors for embedded applications.

Implementing Wi-Fi-based streaming audio systems like wireless speakers will raise a number of considerations. Wi-Fi operates in either the 2.4- or the 5-gigahertz (GHz) bands of the wireless spectrum. A system capable of operating in both bands would ensure higher bandwidth (in case one of the bands is congested) and, therefore, higher throughput for the system. Bandwidth capacity and system throughput will become increasingly critical as more consumers migrate to high-definition audio applications. Antenna diversity will also affect throughput, bandwidth capacity and the range of a local wireless network. This is due to where and how the device is positioned and designed (if one of the antennas is blocked, the other is used). In addition, certain Wi-Fi interface devices have been designed to tightly complement certain processors. This can considerably shorten the development cycle. Other Wi-Fi solutions are more highly integrated, reducing the number of discrete devices in a design and lowering the design's bill of materials (BOM) cost.

Effective co-existence with other wireless technologies like Bluetooth should also be a consideration. For example, the system might utilize Bluetooth for provisioning, as an alternative streaming input, volume control or other control functions, while Wi-Fi provides bulk high-bandwidth connectivity, extended-range Internet access and synchronization with other devices, such as other wireless speakers throughout the house. Since both Bluetooth and Wi-Fi operate in the 2.4-GHz band, co-existence mechanisms should be addressed early in the design phase.

Of course, planning early for more advanced features and capabilities will enable an efficient transition to next-generation products in the future. In the streaming audio market, many consumers are already eyeing equipment capable of supporting true high fidelity HD audio streaming and multi-speaker/multi-room applications. Multiple wireless speakers in one room or throughout a house will require synchronization and advanced networking techniques among the speakers. Unlike wired speakers that receive an audio stream in parallel, a synchronization mechanism is needed for wireless speakers because each speaker will receive an individual unicast of the audio stream. Significant dissonance among the various streams may be perceptible. The more advanced speakers feature tightly integrated Wi-Fi connectivity with audio software processing which is able to synchronize speakers.

Processors

Embedded applications must balance full-featured processing capabilities with low power consumption, peripheral connectivity and cost-effectiveness. In addition, a processor supported by a robust and easily adaptable software environment is critical in fast-paced and still evolving market segments like Wi-Fi wireless streaming audio systems.

The processor is essentially the lynchpin in an audio streaming signal chain. Not only must it have the processing prowess to execute various audio processing functions like decode, signal equalization and others, but it must also simultaneously process the Wi-Fi and/or Bluetooth communications software stacks. Furthermore, the processing performance will take on even greater importance in the wireless streaming audio market in the years ahead as more consumers in the middle and lower segments of the market will demand the equivalent of HD audio equipment that has previously served only the high end of the market. In the past, a 48-kHz CD-quality sampling frequency may have been sufficient for much of the market, but in the future, high-fidelity sound quality in the range of a 192-kHz sampling rate on a 24-bit music signal stream will only continue to increase in popularity. This places additional demands on the processor in the signal chain.

Other important considerations relative to the processor are the resources such as peripheral interfaces and memory which are integrated on-chip. A wide range of integrated resources will facilitate rapid and simple design cycles, and, perhaps just as importantly, these resources will increase the cost-effectiveness of new products by eliminating the need for discrete devices in the design. These integrated resources will speed new designs to market and reduce the BOM cost associated with them.

Since some wireless speakers are designed to

Sitara™ AM335x processors

Powerful, yet low power, the Sitara **AM335x processor** is based on a scalable ARM® Cortex®-A8 core featuring seamless interoperability with the WiLink 8 family of Wi-Fi interface devices. The Sitara AM335x processor is supported by a complete streaming audio software suite.

be portable and operate off of a rechargeable battery, power consumption of the processor and the entire system should be addressed early on. The processor should support low-power and standby power modes, as well as interface to power management supervisory devices for more sophisticated power-saving strategies.

Software environment

A full-featured and robust software environment that tightly supports and addresses the requirements of each hardware block in the audio streaming signal chain process will ensure cost-effective end products and shorten a new product's time-to-market. In some cases, the software supporting the signal chain has been tailored specifically to the hardware. This ensures effective performance for each device in the chain as well as the signal chain as a whole. Additionally, a tight coupling of the software architecture to the hardware in the signal chain can lead to advanced features like precise synchronization of multiple connected devices which, in turn, would enable end-user enhancements such as multiple synchronized wireless speakers in a room, multiple speakers throughout a house on segmented sub-networks or advanced networking techniques that extend the coverage range of a typical residential Wi-Fi access point.

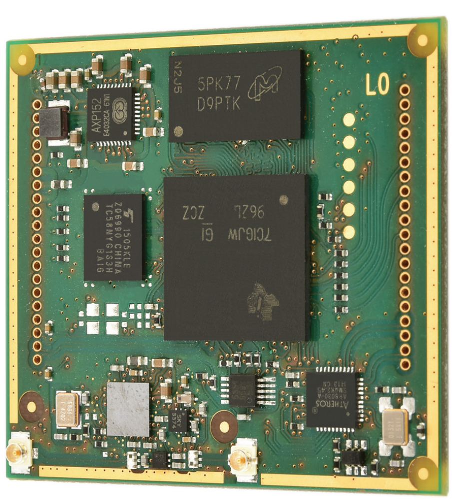
Integrated interoperability in the software subsystem of a variety of popular music streaming services will also simplify new product development. In addition, some software subsystems for streaming audio processing already include certain enhanced high-end capabilities like the Dirac Live Room Correction Suite™ which is able to correct the acoustic defects caused by the listening environment.

Some audio streaming software subsystems have adopted a modular platform approach so that developers simply select the software blocks that are tightly coupled to the requirements of the hardware in a new product's signal chain. Of course, a software subsystem based on mainline Linux® will also accelerate new product software development by enabling the integration of open-source software and the validation of a new product's software against the community.

Versatility is also critical in a software subsystem so that end products with differentiated features and capabilities can be quickly rolled out. The ease with which the user interface can be customized and compatibility with both the iOS and Android™ user operating environments are important considerations.

StreamUnlimited

Ported to Sitara processors, the **StreamUnlimited StreamSDK** is a complete software ecosystem featuring integrated support for popular streaming services and flexible functional blocks for a wide range of products.



High-performance audio DAC

The **PCM5242** is a stereo differential-output audio DAC with the industry's lowest out-of-band noise levels. It is plug-and-play compatible with certain audio TI Class-D power amplifiers.

Converters

Neglecting to deploy the appropriate high-performance digital-to-analog converters (DAC) and, if needed, analog-to-digital converters (ADC) in a streaming audio signal chain would essentially place bottlenecks in the system. Conversely, DACs with high-dynamic performance, good tolerance to clock jitter and low out-of-band noise can form a stable basis for streaming systems serving all segments of the market. The cost-effectiveness of some audio stereo differential output DACs will be essential for many high-end streaming audio systems like sound bars that are transitioning to the upper-middle and middle of the audio equipment market in response to the increasing number of consumers who have shown a keen interest in high-fidelity streaming audio. High-performance DACs will be required to maintain the minimum 96-kHz sampling rate for HD audio.

High-definition Class-D audio amplifiers

The high-definition Class-D high-performance audio amplifier is the last link in the live streaming audio signal chain, just prior to the sound being passed through the speaker and experienced by the human ear. At this point, some of the most beneficial characteristics of the high-definition Class-D audio is that it provides true premium sound by providing ultra-low distortion across the audio band and superior audio quality. This is enabled by high-definition Class-D amplifiers that exhibit ultra-low Total Harmonic Distortion (THD) as well as very low output noise and a Signal to Noise Ratio (SNR) of greater than 110dB. Other key traits include amplifiers that can provide both high power efficiency and very low power stage idle losses below 1 W, as well as seamless compatibility with the rest of the high-definition signal chain.

In general, Class-D audio amplifiers are smaller in size and more energy efficient than Class-A/B amps. Greater power efficiency can eliminate the need for additional thermal management mechanisms like heat sinks, reducing again the physical size of the system. The latest generation of Class-D amplifiers feature very low output noise and low total harmonic distortion, key criteria for processing an HD audio signal.

Class-D audio amps can be deployed in a wide range of products since they can support levels from 35 Watts (W) up to 325 W stereo as well as 600 W in monaural systems. Moreover, they feature advanced feedback loops that ensure high-quality audio by reducing distortions to the lowest level possible across the audio band.

The seamlessness of operation between the audio amplifier and DAC in the signal chain will also have

True high-definition (HD) Class-D audio amplifier

The **TPA3251**, the industry's highest performing monolithic Class-D amplifier, was designed from the ground up for high-definition (HD) audio system development. It exhibits the highest audio performance for a monolithic class-D amplifier, with an ultra-low 0.005% THD+N at 1 W into 4 Ω and an industry leading <60 μV of output noise, while providing 175 W of stereo power. Integrated fault and protection features simplify system design and complete the package offered by the TPA3251.

effects on the performance of the system as well as the time-to-market for new products. Some Class-D amplifiers and high-performance audio DACs have been optimized for seamless plug-and-play operations so that additional engineering is not required every time the two devices are deployed in the same signal chain. A highly integrated amplifier that incorporates much of the support circuitry that must often be implemented in discrete devices can increase the power efficiency of the signal chain by reducing power losses through the amp as well as reducing the overall BOM costs for the design.

Conclusions

As consumer expectations for features in streaming audio continue to grow, system design becomes even more critical to meet the demands. Flexible, agile system design is a total that is greater than the sum of its components. Whether each link in the streaming audio signal chain meets the designer's cost-effectiveness and feature requirements rightfully demands considerable attention. Designers cannot assume that simply meeting these requirements individually will translate into a differentiated experience for the consumer. Indeed, how each aspect of the signal chain functions—as well as how easily and quickly the entire chain comes together in an operating environment—are just as critical, if not more so, than performance parameters taken in isolation. The Wi-Fi connectivity enables speakers unrestricted by unsightly wires, the processor with accompanying software enables expandable streaming services and audio processing, and the converters and class-D amplifiers enable clean and crisp audio playback with increased signal-to-noise ratio. From the moment the audio enters the system through Wi-Fi, to when the processor decodes and analyzes the audio, to when the music gets converted to analog domain and played through the amp, a well-designed system provides an improved experience for the growing need of streaming audio devices.

To learn more, download the **streaming audio TI Design**.