A New Era in Computer-Based Audio

Computer-based audio offers us new ways to organize, purchase, and listen to music. Following is an overview of the various methods one can use to connect a computer to one's audio system, including the advantages and disadvantages of each. Just to let you know that we know what we're talking about , here is some background on our experience with digital audio.

Ayre's Digital Expertise

Ayre has been building ground-breaking digital products that have defined the state-of-the-art since the introduction of the D-1 DVD player ten years ago. Our list of accomplishments is extensive:

- World's first audiophile grade DVD player to provide support for 96/24 audio discs.
- World's first disc player to provide user-selectable digital filter responses, including "slow roll-off" algorithm with improved transient response.
- World's only DVD player to provide total galvanic isolation between audio and video circuits.
- World's first production progressive-scan DVD player.
- World's first DVD player with 14-bit video DACs.
- Consultant to Analog Devices on bringing 12- and 14-bit video DAC chips to the mass market.
- World's first audiophile grade CD player to use a ROM transport mechanism—joint project with Resolution Audio.
- World's first CD player to use both "upsampling" and oversampling for a data rate of 1.4112 MHz at 24 bits.
- World's first audio-only universal stereo player to play all available optical disc formats.
- World's first disc players to provide user-selectable "Minimum Phase" digital filter responses, including both "slow roll-off" algorithm with improved transient response and "apodizing" algorithm for removal of ringing from digital filters used to produce the disc.
- World's first disc players to implement 16x oversampling in a single-pass path rather than the conventional cascade of 2x filters.

These innovations paid off in terms of performance—both measured and audible. Each of Ayre's digital audio products has won multiple awards from various magazines world-wide.

D-1xe DVD Player
Product of the Year – Stereo Sound, Japan
State-of-the-Art – Audiophile, Germany
Editor's Choice Award – Stereophile GHT
Product of the Year – Hi-Fi Review, Taiwan
Reviewer's Choice – Soundstage
Product of the Year – Home Theater Sound
Reviewer's Choice – Home Theater Sound
Golden Eye Award – The Perfect Vision
Golden Ear Award – The Absolute Sound
Editor's Choice Award – The Perfect Vision
Editor's Choice Award – The Absolute Sound
Class A Recommended Component – Stereophile

CX-7e CD Player
Product of the Year – Hi-Fi +, United Kingdom
Best of the Year – Enjoy the Music
Source Component of the Year – Enjoy the Music
Editor's Choice Award – The Absolute Sound
Class A Recommended Component – Stereophile

C-5xe Universal Stereo Player
Product of the Year – Stereophile
Digital Source Product of the Year – Stereophile
Reviewer's Choice – Soundstage
Diapason d'Or – Gramophone, France
Class A+ Recommended Component – Stereophile

Jitter and Audio Performance

Since introducing the radically innovative Ayre D-1 DVD Player in 1999, we've been a leader in digital audio technology for the succeeding ten years. Yet in all that time Ayre has never offered an outboard D/A converter box, instead concentrating on one-box disc players. The reason for this is quite simple—the standard S/PDIF (Sony/Philips Digital Interface Format) digital connection used with two-box solutions is flawed, unavoidably and needlessly introducing jitter into the audio playback system.

A low-jitter master audio clock is essential for attaining high performance levels of digital audio reproduction. But that low jitter only matters at one critical point—at the D/A chip itself. Jitter-induced timing errors create artifacts that audibly degrade the music signal. Therefore a well-designed one-box disc player places a fixed-frequency master audio clock right next to the D/A chip for the best possible performance.

In contrast, a two-box system splits the system into a disc transport box and a D/A converter box. The two are normally connected with the industry-standard S/PDIF connection which places the master audio clock in the transport box, where it is mixed together with synchronization codes and the audio data and transmitted to the D/A converter box. The D/A converter box must then attempt to recover the critical master audio clock from this jumble of signals for delivery to the D/A chip itself.

The standard solution for a two-box disc player is to use a PLL (Phase-Locked Loop) to control a VCO (Voltage-Controlled Oscillator) in the D/A box, generating the master audio clock. The VCO varies its frequency in order to lock onto the incoming signal sent from the transport box. Unfortunately, a variable-frequency oscillator simply cannot achieve the low-jitter performance of a fixed-frequency crystal oscillator.

Over the years many schemes have been implemented by various manufacturers in attempts to improve the jitter performance of the S/PDIF connection, including dual PLL's, VCXO's (Voltage-Controlled Crystal Oscillators), frequency synthesizers, FIFO (First-In, First-Out) buffers for the audio data, external re-clocking ("jitter reduction") devices, and so forth. While all of these methods are able to reduce the jitter levels, they cannot eliminate the jitter that is inherently added by the S/PDIF connection.

Another approach to reduce jitter that has become increasingly popular in recent years is to use an ASRC (Asynchronous Sample Rate Converter) chip. The idea is that the original audio data is replaced with newly calculated data that represents what the audio data would have been if the incoming signal had most of the jitter filtered out. The technical theory behind this method is sound, as demonstrated by the measured performance, which is generally quite good. However the audible performance of these devices is controversial, and Ayre has avoided this approach as it completely discards the original audio data.

The only correct solution is to place the critical master audio clock in the D/A converter box, next to the D/A chip itself. This has been done in a few products using separate transports and D/A converters, but there have been drawbacks to these solutions. One scheme added a separate cable that carried the master audio clock signal back upstream to the transport box. While able to achieve low levels of jitter, this new interface was no longer compliant with the S/PDIF standard. Instead a closed system was created that only worked with specific pairs of transport and D/A converter boxes from a single manufacturer.

A well-designed one-box disc player avoids these problems completely. The master audio clock is placed immediately adjacent to the D/A chip, and the rotational speed of the disc is adjusted so that the audio data is read at a rate to match the master audio clock—a simple and elegant solution. Therefore, for a full decade, Ayre only offered one-box disc players.

A New Chapter in Digital Audio

The personal computer has become ubiquitous, and its flexibility allows for many new solutions to existing problems. It is extremely convenient to store one's music collection on the hard drive of a personal computer, where the entire musical library can be organized and easily played.

The problem occurs when transferring the music from the computer to a high-performance sound system. Once again the master audio clock is in the wrong place—the computer, now acting as the disc transport. The D/A converter must lock onto the signal coming from the computer and reconstruct a new master clock using a variable-frequency oscillator, which cannot achieve the low jitter levels of a fixed-frequency master clock.

The original way to play the audio via a computer was with a soundcard that was mounted directly within the computer itself. However, a more hostile environment for high-quality audio could scarcely be imagined. Low-quality switching power supplies and a chassis full of RF interference made it virtually impossible to achieve high-performance analog outputs. Digital outputs on a soundcard allowed the conversion to analog in a more friendly external environment, but the only standard is the jitter-prone S/PDIF connection.

One solution is to use an Ethernet D/A converter, thereby avoiding the S/PDIF connection altogether. An Ethernet D/A converter can have a fixed-frequency master audio clock inside of it, sending commands to the computer to request more audio data to fill the D/A converter's buffer. Technically, this is an excellent approach and is able to provide true low-jitter performance. (A similar approach can be taken with Firewire, although most computers do not provide the hardware support for this connection.)

The difficulty with these systems is similar to the difficulty with non-computer D/A converters that use a proprietary interface to their matching transports—they are closed systems. For Ethernet and Firewire D/A converters, the hardware and software are inextricably linked, so both must perform up to the customer's expectations. Unfortunately, very few (if any) companies are capable of creating both a state-of-the-art D/A converter, and state-of-the-art computer software that is required.

Currently the most common way to bring the audio data out of the computer to a high-performance audio system is via the USB port. In recent years, there has been an explosion of external USB D/A converters. The advantage of this approach is that any music player software may be used—iTunes, J. River, Windows Media Player, Foobar, WinAmp, et cetera—so the customer is able to select the application that fits his needs the best. And most of these software applications are either free or offered at a very low cost.

What has enabled this proliferation of USB-based D/A converters is a series of parts from Burr-Brown (Texas Instruments) called the PCM270x series. These parts are inexpensive (only a few dollars), very easy to use, and require no programming skills. They are similar enough to conventional D/A chips that any digital audio engineer can easily design a product around them.

The problem with all of the chips in the Burr-Brown PCM270x series is that they have high levels of jitter. A fixed-frequency master audio clock is not employed. Instead a variable-frequency master audio clock is generated based on the timing of the incoming audio data. The computer sends packets of audio data at one millisecond intervals across the USB connection. The Burr-Brown chips have internal circuitry that measures the interval between the audio packets, and then uses this information to generate a new master audio clock that matches the rate at which the computer sends packets.

This system, called "adaptive" USB mode, creates several opportunities where jitter will be added to the D/A converter's master clock:

1) Any variable frequency clock will intrinsically have more jitter than an equivalent fixed-frequency clock. In the "adaptive" USB mode, the clock in the D/A converter must "adapt" to match the rate that the computer sends out audio packets. In the case of the Burr-Brown PCM270x parts, the master audio clock comes from a VCO and inherently exhibits high levels of jitter.

2) The computer cannot send audio packets at a perfectly fixed rate. Firstly, the computer's internal clock is not designed to have low jitter. In a market segment where costs are literally shaved to the fractions of a cent, it would add too much the cost of a computer to use a high-performance, low-jitter clock. Secondly, the inside of a computer is filled with RF interference, making it impossible for even the best of clocks to maintain their spectral purity.

3) The Burr-Brown USB-enabled D/A converter chips update (change) the frequency of the master audio clock each time a packet of audio data is received. This happens once a millisecond so there will be a strong jitter component at 1 kHz, right in the middle of the audio band. Typical measurements of the PCM270x chips exhibit jitter levels in the thousands of picoseconds, orders of magnitude worse than a well-designed one-box player.

Finally, it should be noted that D/A converter boxes based on the PCM270x series parts are limited to a maximum sample rate of 48 kHz and a maximum word length of 16 bits. So while they can transfer CD-grade audio from one's computer, they are incapable of playing higher resolution files.

Another Approach

The question remains—is there any practical method of using one's personal computer to enjoy the convenience and power of the computer, yet at the same time achieving true audiophile-level performance? Therein lies a story.

At the same time that Texas Instruments was developing the PCM270x USB-enabled D/A converter chips, they also developed an obscure part called the TAS1020B Stereo USB Audio Interface chip. This chip integrates multiple functions into one part—a USB transceiver, a microprocessor, a memory controller with a FIFO buffer, and an I^2S interface to allow easy connection to A/D and D/A converter chips.

Obviously this chip is very powerful and offers great potential to the digital audio designer. The difficulty is that this chip is a blank slate—completely unusable unless programmed. The TAS1020B offers the potential for improved performance, but it is no easy task to write the necessary software code for this part. To give an idea of the complexity of the chip, the datasheet is no less than 110 pages long—and it doesn't even tell the full story. Let us just say that tackling a project with the TAS1020B is not for the faint of heart.

A "third-party" company has been certified by Texas Instruments to develop software for the TAS1020B. This company mainly works with manufacturers in the "pro" audio business, but also supplies their software solution to several audiophile-oriented companies. Their code allows high-resolution audio data (up to 96/24) to be transmitted across the USB port. While this approach offers the advantage of allowing the transfer of high-resolution audio data, it does little to address the jitter problem inherent in the PCM270x chips.

Their software averages the timing interval of four audio data packets instead of measuring each individual packet, but the master audio clock still changes frequency 250 times per second. And unlike the analog PLL used in the PCM270x parts that can continuously change the frequency of the master audio clock, the TAS1020B has a frequency synthesizer that can only change in discrete steps, exacerbating the jitter problem. However, as the D/A chip is now separated from the USB receiver, many audio companies use some sort of jitter reduction circuitry between the two, often in the form of an ASRC chip. But whatever approach is used, these circuits can only reduce jitter and not eliminate it.

A Step Forward

Clearly a new approach was called for if the full sonic potential for computer-based audio was to be achieved. Enter one J. Gordon Rankin, Chief Scientist and Owner of Wavelength Audio, best known for his sweet-sounding amplifiers and preamplifiers using directly-heated single-ended triodes. (He also has a thriving business supplying custom guitar amplifiers with the same design philosophy to a growing list of ecstatic customers.)

But before Gordon founded Wavelength, he had a past life nearly 180 degrees in the opposite direction—he was the Chief Engineer at the 6th-largest manufacturer of PC's in the world. While employed there, he built his vacuum-tube based designs as a sideline. And when he won a Product of the Year award from The Absolute Sound for one of his amplifiers in 1995, he knew it was time to change careers.

Now the right ingredients existed to take advantage of the performance possibilities of the TAS1020B chip—a serious audiophile design engineer who also had extensive knowledge of computers and programming. Gordon's first approach was to use the expanded memory buffer of the TAS1020B to reduce the jitter while still using the "adaptive" USB transfer mode.

Recall that the previous "adaptive" solutions changed the frequency of the master audio clock at least 250 times per second. In contrast, Gordon wrote software code for the TAS1020B that allowed the chip to calculate the average data transfer rate of 250 audio packets, and then make minute corrections to a low-jitter, crystal-based external master audio clock only 4 times per second. The jitter was radically reduced and naturally the sonic benefits were commensurate. Wavelength began to establish a strong reputation for their line of USB D/A converter boxes.

A New Era

As with all successful audio designers, Gordon was not content to rest on his laurels. He continued to pursue new methods to achieve even higher performance from the TAS1020B chip. The key was to use an obscure method of USB audio data transmission that was hidden in one of the lengthy USB audio standards documents. The name for this mode is “asynchronous” USB data transmission.

The “asynchronous” part of the name should not be confused with Asynchronous Sample Rate Converters. Instead, it simply means that the master audio clock in the D/A converter box need not be synchronized with any of the clocks in the computer. This was the breakthrough that finally allowed for the jitter of an external D/A converter box to be as low as a one-box disc player.

With the “asynchronous” mode, the master audio clock is in the D/A converter box, where it belongs. A buffer in the D/A converter box stores the incoming audio data from the computer and the TAS1020B controller chip tells the computer to send more audio data as the buffer empties during playback.

It sounds simple, but Gordon spent nearly two years developing the software that allowed the TAS1020B to work in “asynchronous” mode with both PC’s and Mac’s, using only the native drivers included in their standard operating systems. This ensures full compatibility with all music playback programs and connecting the USB D/A converter becomes simple and easy. Naturally, Gordon took advantage of the TAS1020B’s capabilities to ensure that it will support all sample rates up to and including 96/24.

The radically lowered jitter of the “asynchronous” mode was a key ingredient in improving the sonic capabilities of USB-based computer audio. Wavelength’s cutting-edge USB D/A converters using Gordon’s custom “adaptive” operation took a giant leap forward in overall musical performance when he upgraded them to “asynchronous” mode.

The Ayre QB-9

Ayre is proud to be the first licensee of Wavelength Audio’s new “asynchronous” USB technology called Streamlength software. For the first time ever, Ayre can make an external D/A converter box that has the critical master audio clock where it belongs—right next to the D/A chip itself, and without resorting to a non-standard interface.

This external D/A converter box can be connected to virtually any computer running either Windows or Mac operating systems via the standard USB port. One can choose his favorite music playback program and enjoy all the power and flexibility that computer-based audio offers, while still enjoying state-of-the-art sound from his music system.

Wavelength Audio makes a full lineup of tube-based USB D/A converters using the Streamlength software. These offer wonderful sound for the music lover that prefers the sound of tubes. And for the music lover that prefers the freedom from maintenance and sound qualities offered by solid-state designs, Ayre is pleased to offer the QB-9 USB D/A converter using the Streamlength software.

In addition to the ultra-low jitter achieved by putting our own custom-designed master audio clock in the D/A converter itself, the Ayre QB-9 offers a host of other features that make it a true breakthrough product for computer-based audio. As with all other Ayre products, the analog circuitry is fully-balanced and zero-feedback for a natural sound with the correct pace and timing.

Taking a chapter from the design of our D-1xe DVD player, the USB receiver section is isolated from the rest of the audio circuitry with high-speed opto-isolators. This means that the RFI generated by the multitude of clocks operating inside the PC and its noise-generating switching power supply is completely kept out of one’s music system. Finally, we’ve included our new “MP” minimum-phase digital filters for exquisite tonal accuracy and musicality.

Our sincere thanks go out to J. Gordon Rankin who developed the technology that finally allowed Ayre to build an external D/A converter box that achieves the same high level of performance as our disc players.