

Digital Audio over IEEE1394

Abstract

The paper covers the application of the IEEE1394A (FireWire), IEEE1394B (FireWire 800) serial bus standards and the IEC61883-6 protocol to connect interoperable audio and audio/video (AV) devices. It considers the advantages of using the standards, and their practical implementation today as a method of connecting external hi-fi sound to the latest Apple MAC computers.

Introduction

Digital audio has long promised high quality, auto configuration, interoperability and the option to send AV information arbitrarily from one part of a network to another; for example, to listen to the living-room CD player in the bedroom. There were originally difficulties in fulfilling the early promise of digital audio, but now IEEE1394B (FireWire 800) and IEC61883-6 promote mass adoption by providing the bandwidth, distance and standards for interoperability. Apple has supported the IEC61883-6 audio protocol over an IEEE1394 bridge from OS X v10 onwards, and the first FireWire 800 digital audio amplifier (based on the Oxford Semiconductor OXUF922 silicon reference design) was launched at MacWorld in January 2003.

This paper covers the use of IEEE1394 and IEC61883-6 to implement the FireWire 800 digital audio amplifier. FireWire 800 has the distance to be a usable wiring standard around the home; and the bandwidth for close-range, super high-speed data exchange.

The power available on the bus is relatively high—45 W in power class 2, allowing hi-fi sound at hi-fi volumes without the need for external power supplies. Although the standards specify a minimum of 45 W for power class 2, there is no specified maximum, so any practical amount of power could be delivered by a system designed to source audio data and drive digital audio amplifiers. However, if the power input exceeds 300 W, cable losses may be significant with a typical 30-V supply.

IEEE1394A & IEEE1394B Bus Standards

IEEE1394 is a bus standard for interconnecting AV devices, computers or any equipment that benefits from high data-rate transfer speeds, auto configuration and integrated power. The IEEE1394B (FireWire 800) standard supports speeds up to 800 Mbps and a distance of 100 meters (at 100 Mbps). The older IEEE1394A standard supports speeds up to 400Mbps.

The bus supporting IEEE1394A is branded by Apple as FireWire and by Sony as I-Link (IEEE1394A without power and special connectors), while the bus supporting IEEE1394B is branded by Apple as FireWire 800. However, the patents for the system are pooled and freely available to anyone at the same low cost (around 50c per IEEE1394 product).

IEEE1394 supports both isochronous and asynchronous packets. Asynchronous packets are sent as and when bandwidth is available—the high bandwidth means that the bus is rarely unavailable in normal applications. Asynchronous packets have an ACK and RETRY protocol for end-to-end delivery control. Isochronous packets do not use acknowledgements, but instead offer guaranteed bandwidth on the bus. In addition, isochronous packets allow the transmission of streaming media, such as audio and video data, that require a fixed amount of guaranteed space and a known latency.

The bus supports up to 63 daisy-chained devices; it also allows plug-and-play connection, where the bus handles hot insertion, and the automatic configuration of devices attached to the bus.

Bus power is in the range of 8 V to 33 V, and there are a number of power classes. The power range allows most devices to connect and use bus power without the inconvenience of using extra power supplies for each device.

Bus protocols are fully specified in the IEC61883-1 to IEC61883-6 standards, of which IEC61883-6 is discussed more fully below.

IEC61883-6 Audio & Music Data Transmission Protocol

IEC61883-6 specifies the protocol that handles the isochronous transfer of audio data over IEEE1394 connections. The standard is followed by the Apple MAC and the Oxford Semiconductor OXUF922 reference audio design.

Isochronous Packets

The IEC61883-6 protocol uses IEEE1394 isochronous packets to transfer data across the bus. Isochronous packets negotiate guaranteed bandwidth, giving the transmitter an effectively constant connection to the receiver, with known latency, allowing the transfer of audio streaming data at a constant rate without loss or constriction across the bus.

Synchronization & Time-Stamping

The IEC61883-6 protocol defines the packet headers and contents, including a `SYT` timestamp that is effectively a ‘presentation time stamp’. Because the link latency (`TRANSFER_DELAY`) is known and can be recalculated when peripherals are plugged onto the bus, the calculation of `SYT` is a simple formula, as follows:

$$\text{SYT} = \text{CYCLE_TIME} + \text{TRANSFER_DELAY}$$

Where `CYCLE_TIME` is a base timer used by the IEEE1394 to maintain the bus timing.

In the simplest scenario, the receiver buffers the audio data until `CYCLE_TIME` equals `SYT`. In practice, due to the need to keep jitter to a minimum for high-quality audio, more sophisticated smoothing is required. The `CYCLE_TIME` clock is subject to jitter that, though possibly acceptable for normal applications, is too great for higher-end audiophile applications. In practice, a default link latency is calculated to be the greatest time across all 63 nodes of the bus, which can be used for most circumstances (`DEFAULT_TRANSFER_DELAY=352 μs`).



IEC61883-6 specifies a more complicated formula for `SYT`, that takes into account the processing time and positioning of more than one event within a common isochronous packet; however, the basic principle is the same.

Audio Data Formats

IEC61883-6 allows for many audio data formats that are not explicitly defined; and there is room in the CIP header for future standard and user-defined data formats.

Within IEC61883-6, the code in the FMT field indicates the type of audio format used and the subfield FDF defines subformats within it. The following codes are examples of FMT values:

00₁₆ – DVCR
80₁₆ – MPEG
10₁₆ – AM824

The audio standard referenced in IEC61883-6 is AM824, which contains several subformats and rates allowing for 32-bit and 24-bit audio data which can be IEC60958-conformant, 24-/20-/16-bit raw audio or midi-conformant data, at sample rates of 32 KHz, 44.1 KHz, 48 KHz, and 96 KHz. However, this is not an exhaustive list; refer to the latest copy of the specification for a full definition.



This paper does not attempt to duplicate the detailed information contained in the standard and therefore does not cover the specific operation of packet sequencing, timing etc.

End-to-End Audio-Rate Control & Sample-Rate Smoothing

Rate control is extremely important to the play-out of high-quality audio. Data is transferred from the transmitter at a fixed streaming rate, which might be unknown (because the audio sample rate is encoded in the data headers), and might not match the streaming rate of the receiver. Even a small difference in clock rates results in buffer underrun or overrun at the receiver, and produces an audible break. The receiver and transmitter clocks must be locked together to overcome this problem.

There is a mechanism within IEEE1394 to lock the Tx and Rx clocks, using CYCLE_TIME and the SYT timestamp to ensure that audio samples are always played out correctly. Although this is adequate for ordinary audio, it is not an ideal solution for clock recovery, for the following reasons:

- The clock is not a linear timebase (due to the mechanism used to equate the Tx and Rx clocks)
- The IEEE1394 clocks themselves suffer from jitter, which is transferred to the audio digital-to-analogue converter (DAC) clock and hence modulates the audio output, causing distortion or reduced signal-to-noise ratio from the DACs
- The cycle time is 125 μs or 8 KHz; however, there is no requirement for this to be locked to the audio sample rate

In the Oxford Semiconductor OXUF922 reference design, the problem is handled by using the embedded ARM processor to correct the timing of incoming isochronous packets and present audio data to the DACs with a corrected timebase.

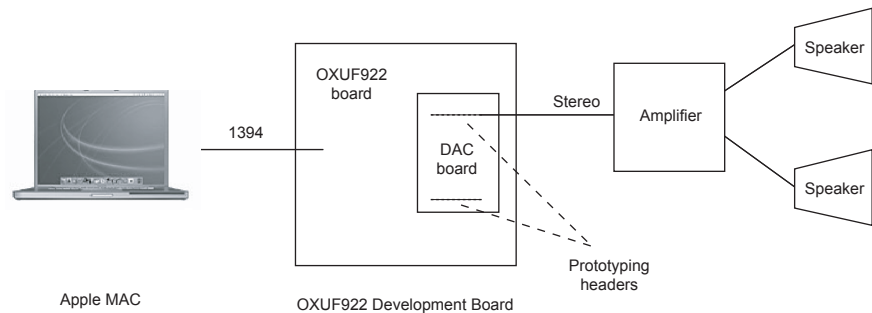
The high-end solution to this problem involves controlling a high-stability external phase-locked loop (PLL), or an array of PLLs. Audio jitter-reducing PLLs are well known in audiophile circles, and solutions compete to reduce jitter below 20 ps for the best-possible reproduction. The Oxford Semiconductor OXUF922 design could be modified to drive such an external circuit for extreme audiophile applications such as an enhanced version of the digital speaker application.

Typical IEEE1394 Audio System

The Oxford Semiconductor digital speaker product demonstrated at MacWorld in January 2003 is based on an OXUF922 reference design that demonstrates a typical IEEE1394 audio implementation.

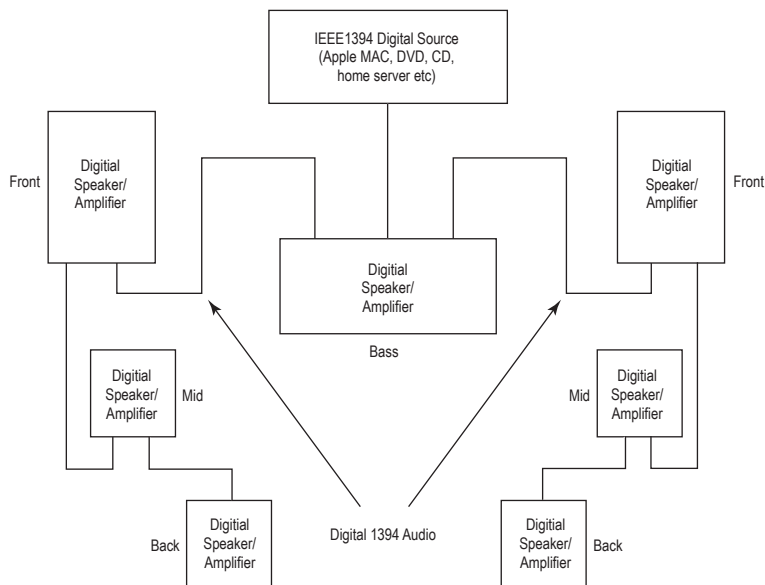
The system uses the OXUF922 (Oxsemi IC) development board with a Wolfson DAC mounted on the prototyping header. The unit is connected to an Apple MAC using the IEEE1394 standard and the IEC61883-6 transmission protocol. The OXUF922 accepts isochronous audio packets from the Apple MAC, handles the buffer management and rate control, and passes the packets to the DACs. The system can be mounted in a surround-sound amplifier system to maximize the power and clarity of the digital audio, as shown in [Figure 1](#).

Figure 1 Typical IEEE1394 Audio Implementation



As shown in [Figure 2 on page 6](#), the IEEE1394 standard can also be used with more sophisticated digital connections to distribute high-quality audio data and power around the network to integrated speakers/amplifiers:.

Figure 2 Using Digital Connections with the IEEE1394 Standard



Advantages of Using IEEE1394

The major advantages of using the IEEE1394 standard are listed below:

- **Easy connectivity**—only one cable needs to be connected between each device, and daisy chaining from one device to another is supported. Current analogue systems require a pair of wires for each and every speaker
- **No extra power supplies**—amplifiers and speakers can be powered from the IEEE1394 bus (minimum 45 W on power class 2 devices, but no upper limit specified in the standard). This removes the need to supply power to every integrated speaker/amplifier—a huge advantage over USB in a simple PC/MAC digital speaker system (USB can only deliver 2.5W, 5 V at 500 mA)
- **Bandwidth**—up to 400 Mbps on IEEE1394A and 800 Mbps on IEEE1394B allows hundreds of audio channels
- **Adaptability and compatibility**—mix audio, video and internet protocol (IP) data etc. on the same network with interoperability. So you could connect, for example, an IEEE1394/DV video camera to a remote node of the system, and be able to access it anywhere
- **Forward compatibility**—IEEE1394 is central to integration into future IEEE1394 AV network devices; audio video control (AV/C) is supported for command and control of VCRs, TVs etc, and other higher level protocols such as HaVi are supported
- **Rationalization**—complicated bespoke digital audio connections such as optical/digital SPDIF are no longer necessary; IEEE1394 audio does this and more with capacity for hundreds of audio channels simultaneously

Summary

With so many standards to choose from for home networking, the home audio/video markets are demanding a real alternative to the many different analogue and digital application specific connections currently in use.

In IEEE1394 we finally have a standard that:

- is supported by a wide range of products
- has superior speed (800 Mbps)
- has maturing AVC control/transmission standards which allow it to be truly interoperable
- does not rely on a central 'master' device, so consumers can buy and connect their home devices one at a time
- does not need a device driver for each attached device

IEEE1394 allows a single cable to daisy-chain from one device to another, allowing hundreds of digital audio channels and combinations of audio/video/data/control to be handled automatically.

IEEE1394 is the only standard that can demonstrate the speed, versatility, and maturing standards to instill confidence of interoperability in the digital home.

Terms & Abbreviations

The following terms and abbreviations are used in the paper:

| Term | Definition |
|-------------|--|
| AV | Audio/video |
| AV/C | Audio video control |
| DAC | Digital to analogue converter |
| HaVi | Home audio/video interoperability standard |
| IP | Internet protocol |
| PLL | Phase-locked loop |
| SPDIF | Sony/Philips digital interface (serial digital audio connection standard IEC958) |
| USB | Universal serial bus |

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