Intel Audio '98 Roadmap

revision 1.01

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1. Introduction

This paper presents Intel’s audio roadmap vision for 1998 and beyond, and highlights trends and specific developments impacting PC audio architecture. The appendixes give more details.

- **Appendix A** details specific AC ‘97 recommendations for high quality, feature rich, cost effective PC audio subsystems in 2H97 and 2H98. Recommendations made at this time for 2H97 are primarily intended to benefit OEMs in selecting parts which meet specific platform requirements. Recommendations for 2H98 provide IHVs and OEMs with input at the beginning of their design cycles.
- **Appendix B** details specific recommendations for Power Management of AC ‘97 audio devices.

The discussions and recommendations presented here are most applicable to high-volume OEM audio solutions (not retail and upgrade solutions) for the following PC categories:

- Home Desktop Multimedia PC
- Home Interactive PC Theater (IPCT)
- Corporate Desktop PC configured w/ audio capabilities
- Mobile PC

Note: Due to unavailability of data on feature requirements, cost, extensibility, and backwards compatibility for several new PC categories, the following recommendations may or may not be applicable to:

- $999 Consumer PC
- Corporate netPC

1.1. Audience

This paper is primarily for IHVs and OEMs who have detailed working knowledge of the current PC audio architecture. You should also be familiar with the Audio Codec '97 (AC '97) Component Specification, technical FAQ, and System Design Guide[1], available on the AC ‘97 web page at:

http://developer.intel.com/pc-supp/platform/ac97/

You may also wish to read the Universal Serial Bus specifications. USB audio peripherals extend the built-in audio capabilities of mainstream *Digital Ready*[2] PCs, and may even replace built-in audio with *Digital Only*[2] solutions for certain emerging market segments:

http://developer.intel.com/design/usb/

[1] The AC ‘97 System Design Guide includes several important white papers originally published in 2Q96:

- Introduction and Overview of AC '97
- AC '97 Controller/Codec/System Recommendations
- Implementing Legacy Audio on the PCI Bus
- Audio/Telephony Integration
- Digital Audio and the 1997 Desktop PC
- Hardware Acceleration and Re-direction of Audio Streams
- AC '97 Controller / AC '97 Interoperability Design Considerations

[2] *Digital Ready* and *Digital Only* PCs are described in section 4 of this paper.

2. General Audio Trends

This section presents several highly visible and interrelated trends impacting PC audio:

- Increasing processor performance
- Integration of functionality
- External expansion busses

2.1. Increasing processor performance

As processor performance increases, more functionality is accomplished in software. This is an industry-wide trend and can be observed across all platforms and CPUs. Hardware implementations face competition with software-only implementations and need to demonstrate a functionality, performance or quality advantage. There currently exist high quality software-only implementations of HRTF 3D, wavetable MIDI synthesis, and Dolby* AC-3* decode. By 2H98 or 1H99 there may be enough concurrency to perform more than one of these functions in software on mainstream platforms, but for high performance 3D computing and gaming platforms, hardware acceleration will continue to be desirable. It is becoming increasingly important that hardware acceleration be implemented in a scaleable manner (i.e. baseline software capability with a compatible hardware acceleration option).

The Intel audio is providing the industry with recommendations and supporting data on hardware vs. software partitioning (such as those which appear in **Appendix A**).

2.2. Integration of functionality

As the attach rate for a function goes up there is more incentive for integration onto the system motherboard or even into the SuperIO or chipset logic. This is also an observable industry trend. Full featured PCI-based SoundBlaster compatible and Digital Ready audio components will be available as standalone motherboard components in 2H97. The next potential points in this evolutionary trend could be to:

- combine the high performance audio controller with another motherboard device.
- incorporate a low cost baseline audio interface into the superIO (SIO) or similar device.

Many IHVs are proposing combination PCI devices for 1H98. This allows the IHV to amortize the PCI bus mastering controller support across multiple devices, saves pins, and potentially provides cost and layout size benefits. Mobile platforms and add-in cards are immediate beneficiaries of these integration efforts. IHVs proposing combination devices face the additional complexity of needing to secure design wins for each subsystem device. OEMs and IHVs who choose to work together still face these issues relating to motherboard adoption of combination devices:

- It is difficult to project exact feature requirements 12-18 months in advance.
- There are diverse attach rates for the various audio, comm, graphics, and video functions.
- Scalability of hardware acceleration is often a requirement.
- Some subsystems face additional certification requirements (modem communications, for example).

A low-cost baseline audio interface (without hardware legacy compatibility or acceleration) might address the entry point of a fully scaleable architecture by 2H98. These interrelated issues must be considered:

- For which segments will baseline audio deliver adequate performance and compatibility?
- Is a fixed 48K or a dual (44.1/48K) rate Codec adequate support for Microsoft's WDM* digital audio?
- Should the implementation also support combined audio/comm or scaleable hardware acceleration?

2.3. External expansion buses

External expansion buses offer PC OEMs system design and configuration flexibility, and PC customers user friendly upgrades. The gradual replacement of ISA add-in cards with USB is under way, and IEEE 1394 is also expected to gain momentum within the next couple of years. However, the transition to external digital audio is expected to be gradual because initial implementations will probably appear first at the mid- to high-end and cost more than highly-integrated motherboard audio solutions which make use of existing low cost analog peripherals. In addition, external solutions do not support specific capabilities currently required for many mainstream platforms, such as:

- hardware legacy compatibility (100% SoundBlaster* compatibility)
- internal analog connectivity (legacy CD-ROM audio, TV tuner, Video Capture audio in)
- some DirectSound* audio acceleration features (such as MIDI w/ DLS and multi-stream HRTF 3D)

For these reasons Intel recommends that in 2H98 external audio be viewed as an extension of the built-in Digital Ready audio capabilities, rather than as a complete system audio replacement.

However, on specific platforms, the PC OEM may choose to implement a Digital Only audio subsystem (entirely based on external audio components). For these cases Intel recommends that digital speaker and digital monitor implementations be selected so as to maintain maximum compatibility with existing (and emerging) PC applications which demand full-duplex audio capabilities by supporting both speaker output *and* mic input. External analog connectivity is also desireable, and can be met by providing line out, line in, and mic in connectors directly on the digital monitor or speakers.

3. Specific Audio Developments

This section briefly discusses the following developments:

1. Microsoft WDM digital audio infrastructure
2. SoundBlaster compatibility
3. Power management
4. DVD-ROM drives and PC to CE connections
5. Audio/communications integration
6. Digital “push audio” sources

3.1. Microsoft WDM digital audio infrastructure

The current release of Windows* 95 (OSR2.1) has limited support for USB devices, and does not put in place the necessary infrastructure to support a complete external audio solution. Enhanced audio support is targeted to be a future OS feature. Microsoft first described the WDM digital audio infrastructure in their September ‘96 Windows Hardware Newsletter. Hardware designs for 2H97 are nearing completion, but WDM audio potentially impacts hardware and device driver designs for 2H98 and beyond:

Key potnetial WDM audio features include

- low latency audio services
- ring 0 sample rate conversion and mixing
- streaming CD/DVD support
- SoundBlaster emulation (SoundBlaster Pro, MPU 401, software MIDI)

The low latency nature of the WDM audio services potentially enables Digital Ready audio implementations which employ PCI to USB (or IEEE 1394) re-direction using the multi-trip acceleration model[3], as well as Digital Only external USB (or IEEE 1394) based audio solutions.

3.2. SoundBlaster compatibility

SoundBlaster compatible DOS games write directly to 4 hardware devices (no APIs)

- SoundBlaster Pro or SoundBlaster 16 compatible registers
- OPL*-compatible FM music synthesizer
- MPU 401* compatible MIDI UART for General MIDI synthesis
- gameport (game pad or joystick)

The Microsoft DirectX* (Win9x) APIs have achieved significant momentum, but the reality is that SoundBlaster is still a significant standard for PC games, and includes well known CD-ROM titles such as Quake*, Doom*, Descent*, Duke Nukem 3D*, and Wing Commander*. A popular “Games on the Internet” web page shows (as of 3/7/97) that 907 out of the 1351 games catalogued (~67%) are DOS titles[4].

By Holiday 1997 DirectX games with 3D graphics & audio may outship DOS games. However, existing DOS games will not disappear overnight. Games have one life “on the (retail) shelf” and another one “in the (home) cabinet”. PC buyers typically expect last year’s best-selling CD-ROM titles to run on their new machines. Another example, those 10 CD-ROM game retail packs at the neighborhood superstore are often recycled DOS games. Last year’s bestsellers, as well as shareware, freeware, and demoware games are also handed down within families, and/or traded via the internet and BBS.

[3] Discussed in the AC ‘97 Design Guide paper “Hardware Acceleration and Re-direction of Audio Streams”.
[4] **http://happypuppy.com/games/lordsoth/index.html**

No one disputes that SoundBlaster compatibility is a requirement for '98 systems. The only debate revolves around the viability of two alternate approaches to achieving compatibility:

- hardware SoundBlaster compatibility on ISA or PCI
- SoundBlaster compatible software emulation

Intel expects that both of these approaches will be evident in 1998, each with significant market share.

3.2.1. Hardware SoundBlaster compatibility on ISA or PCI

To date, OEMs have been adamant about requiring 100% hardware SoundBlaster compatibility for 2H97 systems — they don't want disappointed customers or to incur costly support calls. In terms of hardware cost, it is estimated that hardware SoundBlaster compatibility adds ~$2-3 to the total Codec cost in 2H97. With support calls costing an estimated $20 or more, it may be unrealistic to expect the majority of OEMs to commit to a software emulation capability until it has been successfully introduced into the marketplace, or been widely demonstrated and tested for compatibility and robustness by an independent software test house. Without this kind of data the level of exposure is unknown and the risks are not quantifiable. Many OEMs can be expected to choose the known quantity: 100% hardware compatibility. This means ISA- or PCI-based designs which implement ISA resources using various compatibility techniques.

SoundBlaster compatible single-chip ISA Codecs are currently mature and are inexpensive, but have limited features. Intel expects ISA-based audio to be phased out for add-in, and perhaps for motherboard components as well, by the end of 1998 for a number of reasons:

- generally lower audio and music synthesis quality (not all)
- limited multi-stream capabilities
- less configurability and manageability compared w/ PCI and USB
- obstacle to enabling Digital Ready audio
- growing momentum for ISA elimination

Intel has published detailed recommendations for one method of implementing 100% hardware SoundBlaster compatibility on PCI. The PC/PCI chipset implementation has been proven compatible by a generation of PCI-based mobile systems which support ISA SoundBlaster compatible cards in the dock, and is now available on desktop chipsets. "Implementing Legacy Audio on the PCI Bus" version 2.1 is available for download at:

http://developer.intel.com/pc-supp/platform/ac97

Intel expects PCI-based SoundBlaster compatible designs (including many first generation AC '97 designs) will be introduced in 2H97 and remain available until SoundBlaster emulation has been widely adopted (estimated by mid-1999).

3.2.2. Software emulation of SoundBlaster functionality

WDM digital audio proposes to support software SoundBlaster emulation with the following features:

- SoundBlaster Pro register emulation
- MPU 401 UART emulation
- software wavetable MIDI synthesis (via emulated MPU 401)

OPL-compatible FM music synthesis is not proposed, but most current DOS games offer a choice of FM or General MIDI device (MPU 401) for music synthesis. The game port may be eliminated in systems without a SoundBlaster compatible Codec, but the analog joystick or gamepad can be emulated by a USB joystick.

The number of popular DOS games which cannot be supported via emulation is currently unknown, but expected to be small. No software emulator can deliver 100% SoundBlaster compatibility, because emulation is not expected to support the following:

- real mode operation
- DOS games which use proprietary memory extenders
- DOS games which require OPL-compatible FM for music synthesis
- DOS games which do not work w/ USB emulation of analog joystick or gamepad
- DOS games with hardware dependent features, timing, or performance
- legacy game controllers (analog joysticks and gamepads)

A viable SoundBlaster emulation option as an alternative to hardware would offer significant potential benefits to the PC audio architecture:

- enables cost reduced native PCI audio interfaces
- facilitates Digital Ready audio output via USB or IEEE 1394 by eliminating bus dependent SoundBlaster hardware

Intel expects standalone or combination PCI-based designs which utilize software emulation of SoundBlaster functionality will be introduced beginning in 1H98. These designs are still expected to provide high quality hardware wavetable MIDI w/ DownLoadable Samples (DLS), WDM-compatible DirectSound acceleration capabilities, and Digital Ready output. These designs are expected continue into 1999 and perhaps beyond.

3.3. Power management for audio devices

There are two architecturally consistent specifications for power managing audio currently under development. These are the *Advanced Configuration & Power Interface* (ACPI), and the *PCI Bus Power Management Interface Specification* (PPMI). The choice of which specification to support is dependent upon the intended deployment of the audio subsystem. Any audio subsystem that is only targeting motherboard integrated implementations should ensure that their design can be implemented with an ACPI compliant motherboard/BIOS. On the other hand, if audio vendors wants to sell their audio solutions into the retail add-in market as well, the design must conform to revision 1.0 of the *PCI Bus Power Management Interface Specification*. The reader is encouraged to download one or both of these specs which are available at:

Advanced Configuration & Power Interface (ACPI)

http://www.teleport.com/~acpi

PCI Bus Power Management Interface Specification (PPMI)

http://www.pcisig.com

A more comprehensive discussion of the power management issues for audio appears in **Appendix B** of this paper.

3.4. DVD-ROM drives and audiophile PC to CE connections

DVD-ROM drives introduce new high-quality digital content into the PC environment. Potential digital audio formats include:

- DVD movies with high quality multi-channel audio formats: MPEG2*, Dolby Digital* AC-3*, etc.
- DVD audiophile music formats: 48 or 96 kHz sample rate, 20- or 24-bit audio, multi-channel
- DVD multimedia content specific to the PC: audio formats TBD

The PC and Consumer Electronics (CE) industries are working to enable the exchange of digital audio for audiophile quality movie and music playback, as well as high quality authoring. The Interactive PC Theater (aka Family Room PC), and eventually all PCs, will support digital, as well as analog interconnects to CE. But CE has a much longer average life cycle than PC equipment, and there is a significant installed base of recently purchased Dolby Surround* Pro Logic* (analog) home theater equipment. In the 1997-2000 time frame, universal backwards compatibility needs to be preserved via analog line out (stereo mini or RCA jacks) somewhere in the PC system. Higher performance and richer features can be enabled via digital audio output:

- S/P-DIF* or IEC958 support two-channel LPCM (up to 24-bits at 44.1 or 48KHz) or AC-3 encoded bitstream and are available on existing CE equipment
- USB or IEEE 1394 offer bi-directional exchange of multi-channel data and control and will be available on future CE equipment

The typical household is most likely to create a home theater in the Family Room. The home theater is a 10-foot social experience built around a large screen display and a high quality consumer A/V Receiver with six or more speakers. The typical Interactive PC Theater (Family Room PC) can be expected to deliver multi-channel audio output to the A/V Receiver in analog or digital form:

- Dolby Surround Pro Logic (or equivalent) encoded stereo, via stereo RCA jacks
- Dolby Digital AC-3 (or equivalent) encoded or decoded, via S/P-DIF, USB, or IEEE 1394

The home office or den is less likely to be used as a home theater. The office or den PC is a 2-foot personal experience more compatible with two speakers plus optional subwoofer (but nothing prevents the use of a larger display and/or more than two speakers). The typical baseline DVD enabled PC can be expected to deliver the following two-channel audio outputs:

- Dolby Surround Pro Logic (or equivalent) encoded stereo to a pair of analog or USB speakers
- HRTF 3D virtual multi-channel to a pair of analog or USB speakers

3.5. Audio/communications integration

The current Audio Codec '97 specification offers no specific recommendations for the integration of audio and communications functionality. There has been substantial interest in developing a potential interoperable specification for integrating the audio and communications functionality. This would potentially enable a future generation of interoperable audio/communications designs which use AC-link (in addition to the proprietary AC-link designs which are currently being developed). Standalone audio only designs would not be affected. Shown below is one possible architecture that is under preliminary evaluation. Such an effort would require extensions to the baseline AC '97 specification, hence DC/AC'98 nomenclature. The Codec package may also have to be expanded to provide additional functionality that currently is not addressed in the AC '97 specification.

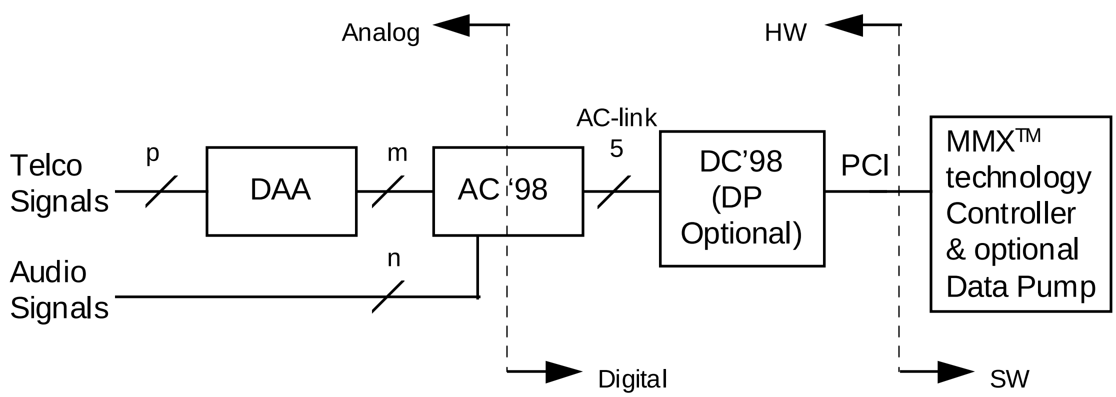

Figure 1. Potential combined audio/communications architecture

Desirable goals for audio/communications integration are:

- Optional extensions to existing AC '97 Codec specification (in the form of an appendix)
- Interoperable specification for portions of the Digital Controller (DC '98) functionality
- No changes to current AC-link timing and slot definitions
- No additions to baseline audio functionality, negligible impact on audio quality
- Support for software or hardware data pump via stuffing option (same DC '98 footprint)
- Definition includes support for one or two lines
- Support for low-cost "no telephony" stuffing options (easy upgrade from audio to audio/comm)

3.6. Digital "push audio" sources

Direct Broadcast Satellite and similar technologies are expected to introduce new high quality "push audio" sources into the PC environment which potentially deliver digital audio data at a rate which differs (slightly) from the time base of the DACs built into the system. Several potential mechanisms need to be evaluated as solutions, but it is too early to specify or require one of these as a preferred solution:

- hardware A/V parsing and audio decode w/ "CD-like" analog interconnect to audio Codec
- hardware A/V parsing and audio decode w/ asynchronous I^2S digital interconnect to audio controller
- software A/V parsing and audio decode w/ software drift detection and rate correction
- software A/V parsing and audio decode w/ hardware drift detection and correction done by the Codec

4. Digital Audio Migration

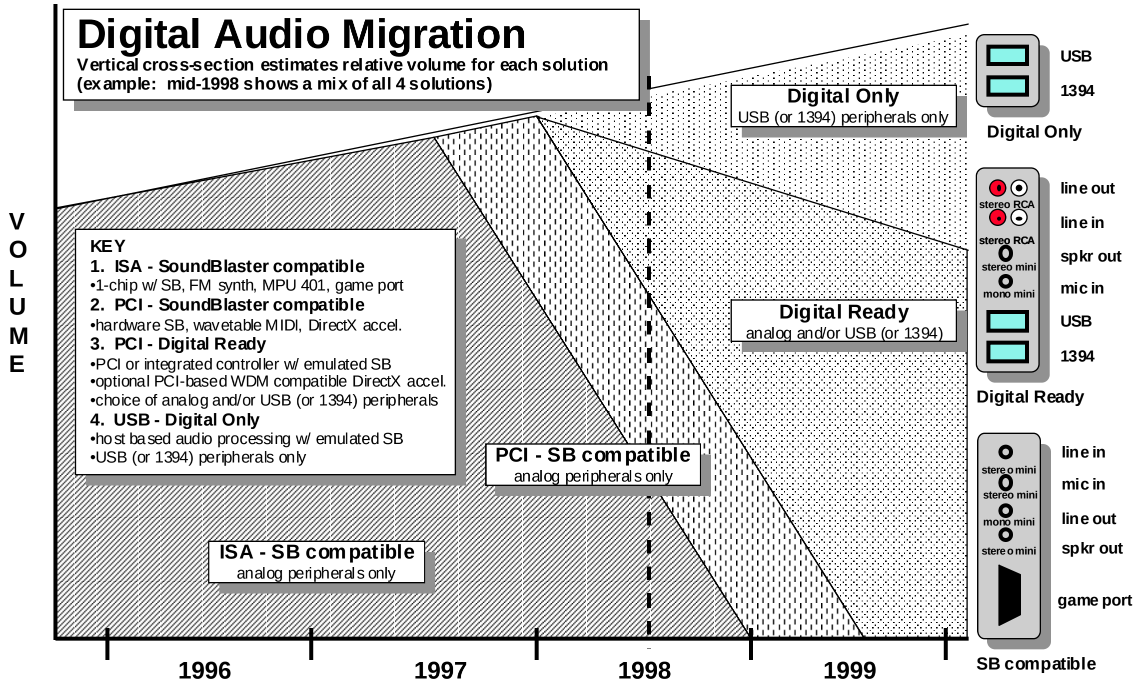

Figure 2. Digital Audio Migration

The Digital Audio Migration figure shows that by mid-1998 we expect four viable audio solutions in the PC marketplace. The figure offers a projection of the estimated market share for each solution over the next several years. The following is a description of each option:

1. **ISA - SoundBlaster compatible**. These are mature, low cost single-chip implementations which deliver real mode and Win9x DOS box support for SoundBlaster registers and mixing, OPL-compatible FM synthesis, MPU 401 MIDI UART, and game port. They are fully Plug and Play compatible. The typical SoundBlaster compatible riser includes 3 or 4 stereo mini jacks (line and/or spkr out, mic in, and line in) and a DB15 for the game port.
2. **PCI - SoundBlaster compatible.** The majority of PCI implementations are new two-chip split digital/analog designs based on the AC '97 architecture. These motherboard designs support real mode and Win9x DOS box compatibility using PC/PCI, DDMA, or other similar techniques, and are fully Plug and Play compatible. They also support high quality wavetable MIDI synthesis and optional DirectX audio acceleration features. They use the same SoundBlaster compatible riser.
3. **PCI - Digital Ready.** The next generation of PCI-based designs potentially deliver WDM-compatible audio acceleration that can be part of a kernel mode streaming filter graph which targets either the built-in analog port *or* a USB port for output. These designs do not incorporate SoundBlaster hardware devices, instead they rely on WDM audio's SoundBlaster emulation capabilities. The Digital Ready audio riser potentially eliminates the analog game port but provides line and/or spkr out, mic in, and line in. The user can configure any mix of analog and/or digital peripherals[5].
4. **USB (or IEEE 1394) - Digital Only.** These systems eliminate all built-in audio resources and utilize external USB (or IEEE 1394) speakers and mic for audio I/O.

[5] Most first generation USB speakers target output only, and do not address mic input support or DirectSound audio acceleration. For these reasons they actually address this Digital Ready market segment.

During this gradual analog to digital migration, Intel recommends that the built-in analog audio capability be viewed primarily as support for the existing 16-bit stereo analog standards, and that USB or IEEE 1394 be used to deliver new solutions for emerging high-end functionality which addresses authoring, audiophile rendering, and PC to CE connections for content which contains:

- greater than 16-bit data types
- more than 2-channels of decoded content
- higher than 48 kHz sample rate

Not all PC suppliers and customers will require or immediately make use of the PC's digital I/O capabilities. For 16-bit data types the quality of the built-in analog audio subsystem is likely to be comparable with audio rendered externally on USB. Stereo analog is a universal format supported by all existing PC and consumer audio equipment today, and the majority of PC to CE audio connections will still be analog in '98/99. Intel expects that for most systems:

- digital audio peripherals will complement analog peripherals
- support for existing Pro Logic CE will require an analog connection using stereo RCA jacks

Intel has worked to help establish USB as a mainstream platform capability. Establishing Digital Ready and Digital Only audio capabilities in 2H98 and beyond will help make the PC an attractive source of digital content. But for USB audio peripherals to become viable they will have to compete on features, quality, performance, and cost with built-in analog audio. It is Intel's position that market-driven technical and business requirements will dictate whether built-in or external, analog or digital audio peripherals be used in the various PC system implementations.

5. Intel Audio ‘98 Roadmap Summary

Audio has become a very important and highly visible part of today’s PC experience. With the arrival of very high quality built-in audio components and external digital connectivity, the quality of the PC audio experience will rapidly become a function of the PC customer’s budget for audio peripherals. The growing diversity of PC audio requirements, platform segments, and buses forces all industry players to acknowledge that there is more than one correct way to implement audio. What is needed is a scaleable (from low cost to high performance) architecture which supports audio on PCI, USB, and IEEE 1394, and comprehends built-in and/or external audio functionality.

Upcoming OS releases are expected to fully support external digital audio peripherals and emerging digital CE connections, increasing system flexibility and scalability on the high end. Until then a S/P-DIF output (built into the audio controller) offers the PC a high-end solution which can carry two-channel or AC-3 encoded audio to currently existing audiophile CE. By 1998, Intel expects digital extensions to the baseline system audio will emerge based on USB and IEEE 1394 specifications: USB for PC audio peripherals, and IEEE 1394 for connections to digital CE. Unlike S/P-DIF, these busses are capable of supporting supporting *bi-directional* exchange of multi-channel data *and* control between the PC and digital peripherals or CE. Baseline audio can support 100% digital expansion out USB or IEEE 1394 *if* all audio sources are available as digital streams *and* hardware audio acceleration is PCI-based and WDM-compatible (OS directs both source *and* destination).

AC ‘97 and USB (or IEEE 1394) should be viewed as overlapping yet **complementary** specifications that provide OEMs with more opportunities to address a wider range of platform implementations. Intel expects that the majority of PCs in 2H98 will support analog connectivity. But in the end, it is the PC OEM who is in the best position to determine whether a **SoundBlaster compatible**, **Digital Ready**, or **Digital Only** audio solution satisfies the customer’s needs.

5.1. Intel recommendations for 2H98

The volume PC delivers a high-quality baseline audio capability.
- CD quality output (~90 dB SNR), high quality mic and line in, full-duplex 16-bit stereo, 8 - 48 kHz (exception: mobile audio is driven by desktop equivalence in functionality, not necessarily quality)
- Analog stereo mini and/or RCA jacks for compatibility w/ existing peripherals and CE
- Speakerphone, headset, and POTS Video Conferencing support
- DirectX 3D games, DVD/CD-ROM, TV Tuner/VidCap, and multi-channel support
- Recommended: PCI-audio Controller + AC ‘97 Codec

Baseline PC audio is Digital Ready.
- Baseline audio supports 100% digital output via S/P-DIF, USB, and/or IEEE 1394
- All built-in audio sources re-directable as digital streams
- hardware audio acceleration PCI-based and Microsoft WDM-compatible

Baseline Digital Ready audio supports the following multi-channel output capabilities.
- Dolby Surround* encoded (Pro Logic) and virtual (HRTF 3D) multi-channel via stereo analog out
- True multi-channel (decoded Pro Logic, Dolby Digital AC-3, MPEG2, etc.) via USB or IEEE 1394

Recipe for advancing the audio platform and creating a scaleable architecture in 2H98.
- Target consumer quality audio, move audio hardware off ISA onto PCI
- Migrate the audio driver and PCI-based hardware acceleration to Microsoft’s new WDM model
- Promote DirectX games and only DOS games which run under SoundBlaster emulation
- Support audiophile quality and true multi-channel via S/P-DIF, USB and/or IEEE 1394
- Partition hardware and software for scalability with respect to increasing processor performance
- Incorporate power management capabilities into components

A. Appendix A: AC ‘97 Recommendations

A.1. AC ‘97 Digital Controller (DC ‘97) Recommendations

Function	Requirement	2H97[+]	2H98[+]
Controller System Bus I/F	• PCI 2.1 compliant bus mastered sample transport	R	R
	• PCI Bus Power Management Interface Spec 1.0		
	⇒ compliant support for states: ***D0, D3***	O	R
	⇒ compliant support for states: ***D1,D2***	O	O
	• stereo PCM input	R	R
	• stereo PCM output	R	R
	• stereo “final mix” input pin (D or A+D @ 48 kHz) • (supports Digital Ready output via USB or 1394)	O	R
	• mono AEC ref input available w/ mic in (supports mono echo cancellation for speakerphone)	O	R
	• mono PCM input from AC ‘97 Codec 3rd ADC (supports stereo echo cancellation for speakerphone and/or cont. avail. mic input for speech recog.)	O	O
Controller Codec I/F	• AC-link serial I/F as spec’d in AC ‘97 rev 1.03	R	R
	• dual voltage digital operation (5.0 or 3.3 V)	O	O
Controller Digital Input	• I^2S input with adaptive sample rate conversion (supports digital “push audio” sources such as DBS)	O	O
Controller Digital Output	• S/P-DIF digital consumer audio connection (supports audiophile CE and interactive PC theater)	O	O
Controller Sample Rate Conversion (SRC)	• minimum of 2 SRC streams dedicated to stereo PCM out: {8,11,16,22,32,44} to 48 kHz	R	R
	• minimum of 2 SRC streams dedicated to stereo PCM in: 48 kHz to {8,11,16,22,32,44}	R	R
	• full-duplex, independent input and output sample rate operation, either mono or stereo, at any rate {8,11,16,22,32,44,48}	R	R
	• additional rates for SoundBlaster compatiblty	R	O
	• additional SRC stream dedicated to 3rd ADC (supports stereo AEC ref and/or dedicated mic input)	O	O
	• adaptive SRC for I^2S input	O	O
Controller hardware SoundBlaster Compatibility	• SoundBlaster compatible I/O and mixer (220h-22Fh)	R	O
	• OPL-compatible FM synthesis (388h-38Bh)	R	O
	• MPU-401 compatible MIDI UART (330h-331h)	R	O
	• Game port (200h-207h)	R	O
	• Legacy Audio Control Register (LACR) as defined in *Implementing Legacy audio on PCI bus* rev 2.1 (supports uniform BIOS and compatibility header)	O	O
Controller Wavetable MIDI	• high quality MIDI synthesis w/ min 512K wavetable	R	R
	• DownLoadable Sample (DLS) MIDI support	O	R
Controller 3D Positional Audio	• n streams HRTF (or equiv) 3D positional audio (supports high performance 3D games)	O	O
Controller Digital Volume Controls	• a minimum of 2 digital inputs used to control the master output volume: **up, down, & mute** **volume up** momentary on (1st) **volume down** momentary on (2nd) **mute** momentary on (both)	O	O

Notes:

\+ R=Recommended Capability, O=Optional Capability (supports features described in parenthesis)

A.2. AC '97 Analog Codec Recommendations

Function	Requirement	2H97+	2H98+
Codec I/F	• AC-link serial I/F as spec'd in AC '97 rev 1.03 • dual voltage digital operation (5.0 or 3.3 V)	R O	R O
Codec Analog Supply	• 5.0 V analog operation • 3.3 V analog operation	R NR	R NR
Codec Sampling Characteristics	• 16-bit stereo DAC playback at 48kHz • 16-bit stereo ADC capture at 48kHz • full-duplex playback + capture at 48kHz • 18- or 20-bit stereo DAC playback at 48kHz (supports CE level certifications for high-end audio) • 16-bit mono 3rd ADC dedicated to mic (supports stereo AEC and/or cont. avail. mic input)	R R R O O	R R R O O
Codec Inputs - Mono	• **PHONE**: A mono line-level input which can be used for input connection from a voice modem subsystem • **MIC1, MIC2**: Selectable mono mic-level input w/ 20 dB boost and addt'l 20 dB of programmable gain • **PC_BEEP**: A mono path thru mixer w/ passive connection as described in AC97 technical FAQ	R R O	R R O
Codec Inputs - Stereo	• **LINE_IN**: A stereo line-level input with programmable left and right channel gain control which is dedicated to external connectivity • **CD**: A stereo line-level input with programmable left and right channel gain control which is dedicated for an internal CD-ROM drive connection • **VIDEO**: A stereo line-level input with programmable left and right channel gain control which is dedicated for an internal TV/Video capture subsystem connection • **AUX**: An additional stereo line-level input with programmable left and right channel gain control (supports addt'l int/ext analog audio connectivity)	R R R O	R R R O
Codec Outputs	• **LINE_OUT**: A stereo mix of all audio sources w/ line-level output and left and right channel programmable output gain control. • **MONO_OUT**: A mono line-level mix of all audio sources (excluding PHONE in) used for output connection to a voice modem subsystem • **HP_OUT**: optional headphone output (supports mobile platform requirements)	R R O	R R O
Codec Output Selection	• **PHONE, MIC**, **LINE_IN**, **CD, VIDEO, AUX**, and **PCM out** are ***mixable*** with each source having a persistent gain and mute setting	R	R
Codec Input Selection	• **MIC**, **PHONE**, **LINE_IN, CD, VIDEO**, **AUX**, or **mono** or **stereo mix out** sources are ***selectable via MUX*** at the input A/D, with a persistent master gain setting for each MUX option • capture of **MIC** + any 2-ch source using 3rd ADC	R O	R O
Codec Analog Enhancement	• analog 3D stereo enhancement • if Codec implements analog 3D, then the mixer implements bypass for PCM out • analog tone and/or loudness controls	O R O	O R O
Codec Power Mgmt.	• Supports low power modes through software control	R	R

Notes:

\+ R=Recommended Capability, O=Optional Capability (supports features described in parenthesis), NR=Not Recommended

A.3. System Audio Hardware Recommendations

Function	Requirement	2H97+	2H98+
System Audio Inputs	• **mic in**: High impedance electret and dynamic mono-microphone input support++	R	R
	• **line in**: stereo line-level input, 2Vrms max	R	R
	• **CD in**: internal stereo line-level input, 2Vrms max	R	R
	• **phone in**: internal voice modem connection	O	O
	• **video in**: internal stereo line-level, 2Vrms max (supports TV tuner or video capture subsystem)	O	O
	• **aux in**: internal stereo line-level input, 2Vrms max (supports additional internal analog interconnect)	O	O
	• **I²S Digital in**: internal digital input (supports digital “push audio (DBS) or other hw)	O	O
System Audio Outputs	• **line out**: Stereo min 1 Vrms line-level output	R	R
	• **spk out**: Stereo line-level output or amplified output that provides ≥ 1 Watt into a 4 ohm speaker (no internal amplification preferred for most cases)	O	O
	• **mono out**: Internal voice modem connection	O	O
	• **S/P-DIF digital out**: digital CE connection (supports audiophile consumer equipment)	O	O
	• **USB: Digital Ready** output capability	O	R
System Audio Back Panel Connectors	• **Back Panel (riser card or system board)** — **Type** / **Use**		
	line in — RCA/stereo-mini — ext. source in	R	R
	mic in — mono-mini — desktop mic	R	R
	line out — RCA/stereo-mini — line level out	R	R
	spk out — stereo-mini — speakers	O	O
	(RCA jacks recommended for line in and line out) (Spk out req’d if RCA jacks are used for line out)	O	R
	USB out — USB — digital output		
System Audio Front Panel Connectors	• **Front Panel (optional)** — **Type** / **Use**		
	headset in — mono-mini — headset mic	O	O
	headset out — stereo-mini — headset ear	O	O
	(If the Front Panel option is supported, the Back Panel **mic in** and **spkr out** output should be mechanically disabled when the corresponding front panel **headset in** or **headset out** connection is made.)		
System Audio Digital Volume Controls	• **Digital Volume Controls (optional)** — **Type** / **Use**		
	volume up — momentary on — (1st)	O	O
	volume down — momentary on — (2nd)	O	O
	mute — momentary on — (both)	O	O

Notes:

\+ R=Recommended Capability, O=Optional Capability (supports features described in parenthesis)

++ Nominal input voltage is 10 mV and 200 mVpp for dynamic and electret microphones respectively. Dynamic mics use mono (2 conductor) connector. Electret mics use stereo (3 conductor) connector.

A.4. System Audio Quality Recommendations

Function++	Requirement	2H97+	2H98+
Frequency Response	• -3 dB Frequency Response Limits (analog & digital) 8.0 kHz[3] 20 Hz - 3.2 Khz 11.025 kHz 20 Hz - 4.4 Khz 22.05 kHz 20 Hz - 8.8 Khz 44.1 kHz 20 Hz - 17.6 Khz 48.0 kHz 20 Hz - 19.2 Khz analog path 20 Hz - 20.0 Khz	R	R
Signal to Noise Ratio (SNR)	• SNR for 44.1 or 48 kHz Record (A-D-PC) >75dB • SNR for 44.1 or 48 kHz Playback (PC-D-A) >85dB • SNR for CD, VIDEO, or LINE_IN (A-A) >85dB	O O O	R R R
Total Harmonic Distortion (THD+N)	• THD+N for Record (A-D-PC) <0.1% • THD+N for Playback (PC-D-A) <0.02%	R R	R R
Full Scale Input Voltage	• FSIP (A-D-PC) <2.0Vrms	R	R
Full Scale Output Voltage	• FSOP (PC-D-A) >1.0Vrms	R	R
Crosstalk between Signal Channels	• Stereo separation >65dB	R	R
Noise Level During System Activity	• Noise floor degradation TBD	O	R
Sampling Frequency Accuracy	• Playback TBD • Record TBD	O	R
Mechanical Fan and Disk Noise	• SPL meter readings at 0.5m TBD	O	R

Notes:

\+ R=Recommended Capability, O=Optional Capability (supports features described in parenthesis)

++ Audio quality measurements as defined in "**Personal Computer Audio Quality Measurement Definitions**", by Dr. Steven Harris and Cliff Sanchez of Crystal Semiconductor, and available on the world wide web at **http://www.crystal.com/new/papers/meas.htm**

A.5. Windows Audio Drivers & API's Recommendations

Function	Requirement	2H97+	2H98+
Audio Drivers/APIs	• MMSYSTEM API • DirectX API • WDM-compatible	R R O	R R R
Legacy Compatibility	• DOS box (SoundBlaster) support under Windows (either in hardware or via software emulation)	R	R
Interrupts	• Interrupts never disabled through the processor interrupt flag (IF) for longer than 2.5 ms.	R	R
Power Management	• Support of low power state through software control using VPOWERD STANDBY events • PCI Power Management Interface Specification R1.0 compliant device driver (if PCI-based controller)	R O	R R
System Manageability	• Provide a MIF file for the audio subsystem that implements the DMTF specification *ComponentID* group. • Implement vendor private attributes as defined in the DMI Specification	O O	R R

Notes:

\+ R=Recommended Capability, O=Optional Capability (supports features described in parenthesis)

B. Appendix B: Audio Power Management

Audio has become an essential element of every PC shipped today regardless of whether it is used in the office for its communications capabilities, or in the home for its entertainment as well as communications capabilities. While audio is integral to each and every PC that is shipped, it does not always appear on the motherboard, but rather is added in many cases by means of an expansion slot prior to shipment of the system by the OEM. There is also a flourishing retail upgrade market for PC audio to be considered as well.

Increasing awareness of the benefits delivered by operating system directed power management, from both the perspective of energy conservation as well as improvement of the user’s experience, has fueled significant industry efforts targeting broad diffusion of intelligent, and interoperable power management features to all elements of the 1998 volume market segment PC.

There are two architecturally consistent specifications for power managing audio currently under development. These are the *Advanced Configuration & Power Interface* (ACPI), and *the PCI Bus Power Management Interface Specification* (PPMI). The choice of which specification to support is dependent upon the intended deployment of the audio subsystem. Any audio subsystem that is only targeting motherboard integrated implementations should ensure that their design can be implemented with an ACPI compliant motherboard/BIOS. If on the other hand a audio vendors wants to sell their audio solutions into the retail add-in market as well, the design must conform to the Revision 1.0 PCI Bus Power Management Interface Specification. The reader is encouraged to download one or both of these specs which are available at:

Advanced Configuration & Power Interface (ACPI)

http://www.teleport.com/~acpi

PCI Bus Power Management Interface Specification (PPMI)

http://www.pcisig.com

It is reasonable to assume that in most, if not all, cases audio vendors would not wish to limit their products’ marketability to only motherboard design wins. As such it is highly recommended that all new PCI audio designs implement the PCI Power Management interfaces. Once an audio vendor has committed their product designs to the PCI power management interfaces these same products may be implemented as either motherboard or add-in solutions. And, in the case of motherboard integrated solutions, these PPMI compliant products would not impose a software burden on their OEM customers. ACPI compliant motherboard devices must be comprehended by the motherboard BIOS. PPMI compliant designs, on the other hand, rely solely on the device driver that ships with the audio hardware, as well as the power management aware PCI bus driver that ships with an OSPM-enabled operating system such as Window 95 or Windows NT* 5.0.

The remainder of these power management sections deal specifically with PCI power management interface design considerations.

B.1. AC '97 Power Management Capabilities

The Audio Codec '97 specification defines 8 different power management states. These power management states, denoted PR0-PR7 power manage the following Codec subsections:

GPR Bits	Function
PR0	PCM in ADC's & Input Mux Powerdown
PR1	PCM out DACs Powerdown
PR2	Analog Mixer powerdown (Vref still on)
PR3	Analog Mixer powerdown (Vref off)
PR4	Digital Interface (AC-link) powerdown (external clk off)
PR5	Internal Clk disable
PR6	HP amp powerdown
PR7	Modem ADC/DAC off - if supported

While fine granular power management states have been defined for the Codec, there are still a few issues to be resolved in order to apply them interoperably within a system that implements an operating system directed power management architecture.

The first issue is that these power management state definitions only address power management functionality for the Codec features and do not apply in any way to the AC '97 digital controller. The second issue is that the power management features of the Codec are only visible to the AC'97 device driver, and as such are not compatible with the WDM driver model until they can be made visible to its power management aware PCI bus driver, which completes the link between the device driver and the power management hardware interface.

B.2. Recommended PCI Power Management Support for Audio

The PCI Bus Power Management Interface Specification requires that a compliant PCI function, at a minimum supports the ***D0***, ***D3****hot*, and ***D3****cold* states as defined below. The hardware infrastructure required to report, and manage the function's power management capabilities includes 2 DWORDs of PCI configuration space, as well as the linked list "Capabilities List" entry point hooks in the standard PCI function configuration space header. See the *PCI Bus Power Management Interface Specification* for detail.

Power Management Capabilities PMC		*Next Item Ptr*	*Capability ID*	Offest = 0
Data	*PMCSR_BSE Bridge Support Extensions*	*Power Management Control / Status Register PMCSR*		Offset = 4

Figure 3. PCI Power Management Interface Register Block

D0 (active) is the fully operational (and fully powered) mode of operation. All earlier PCI designs are always in what has been defined as ***D0*** (active) whenever they are enumerated/configured and activated.

D3*hot* is a software visible state effectively equivalent to a "soft off" state. The intent is to achieve the lowest possible power consumption (at the expense of resume latency). Only one of two things can happen to a PCI function once it has been programmed to ***D3****hot*:

1. Power is physically removed from the PCI component (***D3****cold* state entered)
2. Software transitions the PCI function back to ***D0*** (uninitialized)

In either case, in order to return the PCI function to its fully operational ***D0*** (active) state the function needs to be reset followed by either the restoration of any saved off context or reconfiguration of the function. For case 1 restoration of the PCI function is achieved by powering up the component (entire bus segment in most systems) followed by a bus reset (**RST#**). Following this, the function either has its context restored, or is reconfigured prior to activation. Any Revision 2.0 or 2.1 compliant PCI functions designed prior to the PCI power management specification (legacy PCI functions) would need to be completely reconfigured following the transition back to the ***D0*** uninitialized state.

In case 2 the power management register block, still being powered, is programmed back to ***D0*** which causes the function to transition back to the ***D0*** uninitialized state with the equivalent of an internal reset that is only seen by that individual PCI function. Again the function must either have its context restored, or be reconfigured prior to being reactivated.

B.3. Power Managed Audio for the Interactive PC Theater (IPCT)

When moving the PC into the family room, a change in the PC's character is needed that enables it to blend in with, and match the expectations users currently hold for the other consumer devices around it. Among these expectations:

- Always available
- Noiseless, and very low power when off

The IPCT (aka Family Room PC) should always be readily available when the user sits down to use it, much in the same way that televisions are expected to turn on almost immediately. Additionally, as the IPCT becomes the central processor for video/audio/data communications as well as entertainment, it should also be expected to always be connected to the phone line. Regardless of the operational state of the PC, it should always be capable of answering the phone, for example, to record an incoming call or to receive a fax[6].

Implementing the PCI power management interfaces for audio allows the operating system power management policy manager to be in control of turning audio on, and off. This architecture also enables a clean method for saving and restoring functional context which allows seamless resumption of suspended applications when the PC is ultimately brought out of a suspended state. And finally it specifies a wakeup protocol that is essential for AC '97 combo designs that integrate modem communications along with system audio.

[6] Assuming soft off vs. mechanical off.

B.4. Power Managing an AC '97 Combined Audio/Telephony Design

The following picture illustrates a typical AC '97 combined audio/telephony solution suitable for the Interactive PC Theater (Family Room PC).

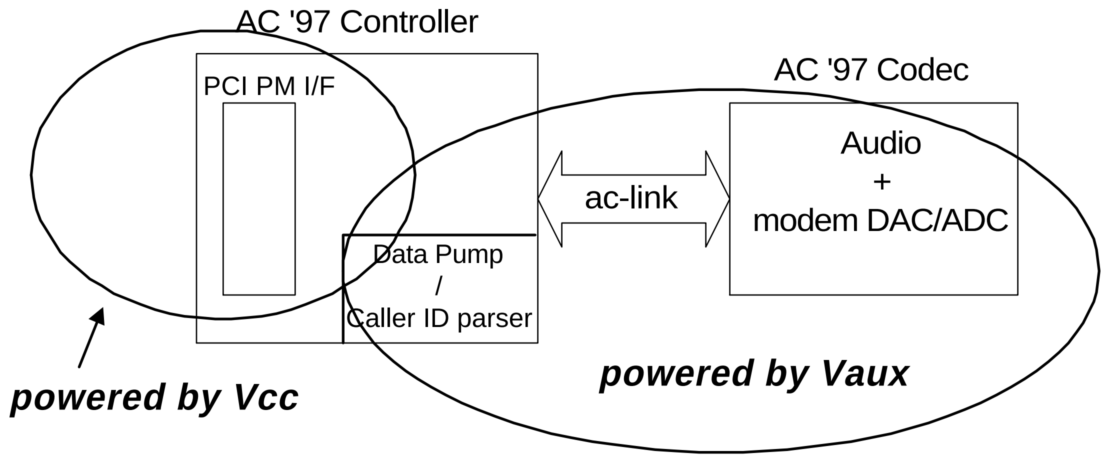

Figure 4. AC '97 Audio/Telephony power distribution

PCs shipped in the 1998 timeframe will incorporate a "dual mode" power supply that has on/off switchable $\mathbf{V_{CC}}$ as well as a persistent lower capacity auxiliary power source ($\mathbf{V_{AUX}}$). In Figure 4 a combo AC '97 design is shown with certain portions of the subsystem powered by the main $\mathbf{V_{CC}}$ power supply, and other portions powered by an auxiliary power source ($\mathbf{V_{AUX}}$).

The entire analog AC '97 Codec and AC-link are powered by $\mathbf{V_{AUX}}$. The portion of the digital controller that is also powered by $\mathbf{V_{AUX}}$ are the areas of the modem data pump that must be kept alive in order to sense a ring indication from the line. The ring indication would be detected and used to initiate a wakeup event (**PME#**) to the system. Additionally, if Caller-ID is supported by the modem, the data pump logic must also be capable of parsing out and storing the Caller ID data as well.[7]

In the lowest power "virtually connected" state, AC '97 Codec bits PR0-PR3, and PR6 would be set. This would internally power down all of the system audio subsections within the Codec while keeping the modem line Codec, and AC-link active. The digital controller would then be programmed to $\boldsymbol{D3_{hot}}$, and at some point the $\mathbf{V_{CC}}$ power source would be switched off transitioning the digital controller to $\boldsymbol{D3_{cold}}$, leaving only the previously identified "keep alive" logic active.

Note that in supporting power management events from $\boldsymbol{D3_{cold}}$, all context involved in determining the need for, and generation of, a power management event must survive the transition from $\boldsymbol{D3_{cold}}$ to ***D0*** (uninitialized). This includes the **PME_Status**, and **PME_Enable** bits of the *PMCSR* register, as well as any other PME context including perhaps a ring indication flag and Caller-ID data.

[7] In today's PC architecture Caller ID data is available in real-time and is either captured when it is transmitted or lost forever. To overcome resume latency Caller-ID issues, a new modem AT command for resending Caller-ID is now being proposed. The remaining element of the Caller-ID solution is building hardware that will save off the Caller-ID data and resend it to the host when asked for it.