

Using AC'97 Codecs in Non-PC Systems

National Semiconductor
Application Note 1528
Harry Holt
December 2006



Add Safety And Convenience To Your Non PC System Using Standard Hardware And Software

Introduction

At first glance, a welding machine, a fetal heart monitor, a tractor, a bulldozer, and a PC have little in common, but all of them have a machine-man interface to communicate information. If your system only has visual indicators, you may want to add aural indicators for user friendliness or extra safety. A loud recorded voice stating the specific danger is more useful than a simple raucous tone or buzzer. For a new user, the system can talk them through step by step in the correct operation. For data entry, keyboards are often too small, or present problems in dusty environments, so digitally recording the user's comments with a small weather proof microphone is quicker and allows hands free operation.

It would appear that the most straightforward way to add audio output to a microprocessor based system would be to simply add a Digital to Analog Converter (DAC), but this requires writing a custom driver for your application. In addition, pre-recorded sources, such as music, would need to be converted to the format that your system requires. Finally, because of the huge number of PCs sold every year, you can get two A/D converters and two D/A converters for less than the price of a single D/A! The secret is looking at the AC'97 standard. Using off-the-shelf AC'97 hardware and software and attention to detail greatly reduces the design time and headaches in implementing a production-worthy system.

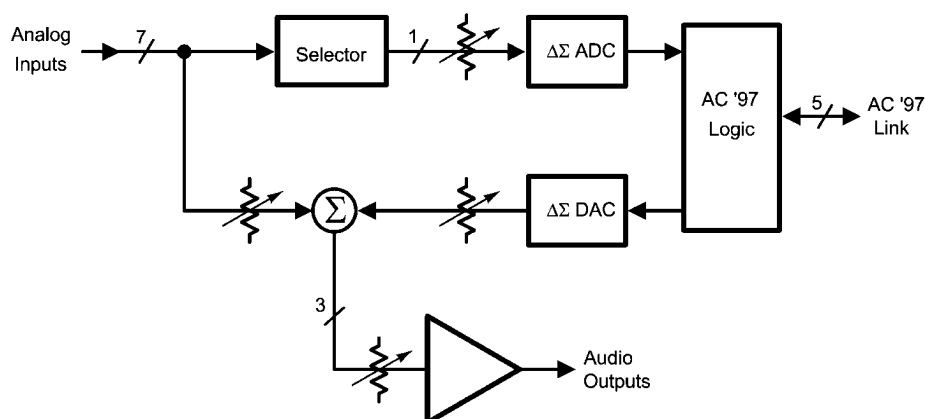
History

The AC'97 specification was developed by Intel(Note 1) in 1996 to provide an audio standard for the IBM compatible personal computer market. It was very successful, with over a half dozen vendors making AC'97 compatible coder/de-

coders (codecs). As vendors and customers started producing integrated circuits and systems, the specifications went through various revisions, the most popular being versions 1.03, 2.1, 2.2 and 2.3. Version 2.1 cleared up a number of ambiguities, and added some additional specifications. Version 2.2 added the optional Sony/Philips Digital Interface (S/PDIF) for home theater applications but version 2.3 required it. For non-PC applications, it is hard to justify the increased cost/die size, and in fact, there are more suppliers of revision 2.1(Note 2) than revisions 2.2(Note 3) or 2.3(Note 4). In addition, due to production history, it is easier to get revision 2.1 extended temperature parts. In 2004, Intel started work on a next generation audio specification, code named "Azalia", which later became the High Definition (HD) specification. This specification is targeted at applications such as DVD movies encoded with Dolby DTS and six channel surround sound. For one or two channels, an AC'97 part is quite adequate and less expensive. Grigory Liadov compared the two when the HD audio specification was finalized(Note 5). This showed that for industrial applications, the simpler AC'97 specification was quite sufficient.

What is an AC'97 Codec?

The AC'97 codec is a complete audio subsystem with multiple stereo input channels, multiple stereo output channels, a higher current headphone output channel, A/D converters (ADCs), D/A converters (DACs), and mixers, with gain controls for each path. The simplified block diagram (fig. 1) has multiple analog inputs going to two places, a selector for the input to the ADCs and attenuators, so digitally recording the user's comments with a small weather proof microphone is quicker and allows hands free operation. The AC'97 digital link gives data to a stereo DAC which also goes into the same mixer through an attenuator. This allows one to mix real-time analog signals from a microphone with prerecorded digital music. e.g. karaoke. The output of the mixer goes to three analog outputs, each with its own attenuator. The headphone output has more drive than the other two outputs, and is capable of delivering 50 mW. into 32 ohms.



20209301

FIGURE 1. Simplified Codec Block Diagram

Hardware

For best system performance, you should pay careful attention to several major areas: the AC'97 Link signals, digital outputs, digital inputs, analog inputs, oscillator pins, analog outputs, and power up.

AC'97 LINK SIGNALS

The AC'97 link is a full duplex serial link consisting of five signals. (fig. 2) Some manufacturers have various combinations of series resistors, pull-up resistors, or pull-down resistors on the various AC'97 Link signals. Be very careful with these resistors, as they will affect the rise time, fall time, and time delay. Some parts are very sensitive to this, so use the manufacturer's recommendations. Some users add addition-

al RC networks in series with the various Link signals, but this is not recommended because it adds a time delay which can cause the system to occasionally malfunction. The overriding factor is the rise and fall time on the Link signals: 2 ns min, 6 ns max., which is required by the Intel AC'97 specification. Because of the fast rise and fall times, there will be significant energy at harmonics of the 12.288 MHz bit clock. This makes it difficult to keep the ElectroMagnetic Interference (EMI) at a low level. Careful routing (by hand) of critical PC board traces and attention to the stackup layer spacing will do much to reduce the radiated harmonics. If you want to layout your board to use different parts, create a variant BOM and use DNS (Do Not Stuff) or zero ohm resistors to handle this. An additional consideration is the overall trace length of 15" as called out in the specification(Note 6) .

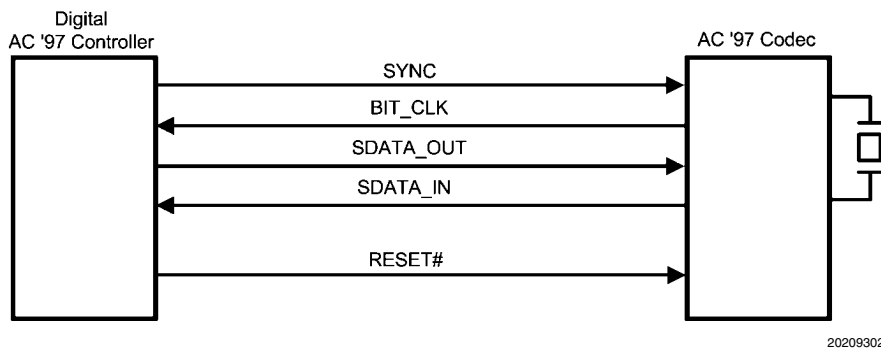


FIGURE 2. AC'97 Link

DIGITAL OUTPUTS

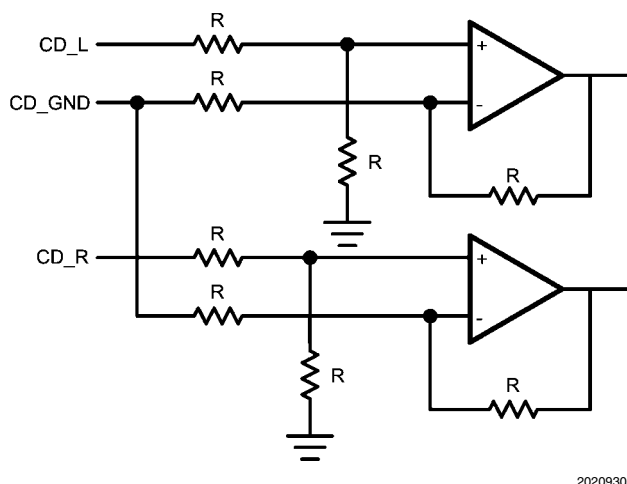
Pin 47 is the EAPD (External Amplifier Power Down) signal. The original intent was to turn on and off an external power audio amplifier, but it is just a general purpose digital output. The default power up value is guaranteed to be a logic low. Some audio amplifiers have a shutdown pin that is active low; others have a shutdown pin that is active high. If you have a choice of several audio amplifiers, you can avoid having to add an inverter by choosing the desired polarity. If you have plenty of general purpose I/O pins, you may choose not to use the EAPD pin.

DIGITAL INPUTS

Pins 45 and 46, the ID pins, are intended to allow the use of four codecs (eight channels) in large systems. Since the AC'97 specification was written in 1997, six channel codecs have become available, so the secondary modes are little used. These pins have internal pull-ups, so for primary mode using one codec, you can let them float. Other unused digital inputs, such as CIN, should be tied to digital ground directly.

ANALOG INPUTS

There are four stereo inputs and 4 mono inputs for a total of 12 analog inputs. With some minor internal signal path routing differences, most of them are similar with only different names and different registers to control them. PC_Beep, MIC1/MIC2, and CD_L,R, & gnd are slightly different from the other analog inputs. Pin 14 is "PC_Beep", the only analog input that is not muted by default on power up. If the microprocessor is unable to complete its startup routine and configure the AC'97 codec, a hardware error tone can still be generated and fed into the PC_Beep pin. Pins 21 and 22 are MIC1 and MIC2. Only one can be selected at a time, and once selected, an internal +20 dB amplifier may be switched in or out under software control. For low cost systems, and very low signal levels, this may be quite useful. On the other hand, you can use an external amplifier which may have a lower noise floor, in addition to adding some response shaping to compensate for microphone nonlinearities. The inputs CD_L, CD_R, and CD_gnd, comprise a stereo, pseudo-differential input as shown in the following figure from the AC'97 rev. 2.1 specification.



20209303

FIGURE 3. CD Input Stage

UNUSED ANALOG INPUTS

All of the unused analog inputs should be connected together and tied to analog ground through a capacitor. Do not tie them directly to ground. Technically speaking, if the particular input is muted, (default for all inputs except PC_Beep), you don't really need to AC ground the input, but one capacitor is inexpensive insurance. If you use only one or two inputs and one or two outputs, take a look at the other members of the AC'97 family such as the LM4546B or LM4549B, and layout your PC board to accept any of them, perhaps with a jumper or two. Because of different production volumes and differences in leadtimes, you may be able to get one of your alternates if lead times increase on your preferred part.

CRYSTAL OR NOT?

You do not have to use a 24.576 MHz crystal with the codec. If there is a convenient clock frequency that already exists in your system, you might be able to use it, but there are trade-offs. If you use a 24.576 MHz crystal, then you will have a frame rate of 48 kHz and be able to record on any PC and play back on your system. If you only need audio out, then you only need one capacitor to ground for all of the analog inputs. If possible, you can pick some high multiple of 24.576 MHz, say 245.76 MHz for your controller, and divide down to generate the 24.576 MHz. If you have to use a frequency that does not conveniently divide down to 24.576 MHz, the considerations are more subtle.

24.576 CRYSTAL

To obtain the maximum flexibility and avoid hassles, it's better to use a 24.576 MHz crystal. This allows recording on any PC to playback on your system. You can mix a prerecorded .wav file or music from a CD with a recorded message of your own, which would help in field service. The technician would not need to have to have a laptop computer; the system would be completely standalone. If the system records and plays back, the exact frequencies recorded will be reproduced. There is a disadvantage however; if a prerecorded wave file (.wav) is played, all of the frequencies will be shifted.

NOT 24.576 MHZ

If you use the same frequency to record and playback, there is no problem unless the frequency is very low (<5 MHz). There is an advantage if you use 24.576 MHz, either with a

crystal or external clock, because you can record audio on a PC and play it back on your system. If you use a lower frequency, then you will have to record on your system, or on a system with the same frequency, or use sample rate conversion. If you use one frequency, say 24.576 MHz on a PC to record, and a lower frequency is already available in the system, e.g. 20 MHz, the audio frequencies will be scaled down in direct ratio to the crystal frequency divided by 24.576 MHz. For example, 48 kHz is 24.576 MHz divided by 512. If the audio was sampled and recorded at 48 kHz on the PC, and the playback system uses a 20 MHz crystal, then the samples would be played back at a 39.0625 kHz rate. All of the frequencies would be 18.6% lower. One solution is to use Sample Rate Conversion (SRC). The AC'97 specification requires that six common sample rates be supported, however, the LM4550B family has a sixteen bit register that allow finer resolution. Audio recorded at 48 kHz could be played back at 39.062 kHz which may be acceptable.

ANALOG OUTPUTS

Pins 27 and 28 provide V_{REF} and V_{REF_OUT} . Different manufacturers have different implementations and internal uses. For example, one manufacturer has a simple resistive divider, so the internal stages are queued up at analog $V_{dd}/2$. This pin should be heavily bypassed, and the exact value is not too critical. National has a current source on this pin, which linearly charges the external capacitor, smoothly ramping the voltage. This ramp is used to slowly turn on the internal stages, eliminating turn-on "pops" or "clicks". In this case, the capacitor value should follow the manufacturer's recommendation. In the case of the resistive divider, the voltage level is roughly 2.5 Volts for analog $V_{dd} = 5$ V. If the V_{ref} is derived from a bandgap reference, then the voltage will be somewhat lower. Another philosophy is to set the V_{ref} for $V_{dd}(min)/2$, which would be approximately 2.1-2.4 Volts. In any case, V_{ref} is an internal reference, which should be bypassed, and V_{ref_out} is a buffered version that you can use for microphone bias, or to bias single supply op amps to operate in the middle of the supply range. V_{REF_OUT} can typically supply several milliamperes of current.

OPTIONAL PINS

The AC'97 specification defines eight pins (29-34, 43-44) to be used for optional features. These depend on the vendor,

and may not be used, may have different capacitor values pin to pin, or pin to ground. If you qualify multiple sources, a variant Bill Of Materials (BOM) must be created for each vendor's part. Do not use one manufacturer's "typical application" schematic with another manufacturer's part! Strange things can happen. For example, the LM4550B family uses a fixed depth 3D algorithm. This requires a 0.022 μF capacitor between pins 33 and 34. Other manufacturers use a different value between these pins, with an additional capacitor from pin 33 to ground. Some problems have been caused by using one vendor's part in another vendor's "typical application."

NC OR DON'T NC

Some manufacturers use "NC" to mean "we have something connected to this pin internally, so Nothing should be Connected externally"; most manufacturers now use NC to mean "we have No Connection internally to this pin, so you can connect it to anything you want". Check with each vendor to see what it really means if you are going to use it as a wire through. For the LM4550B family, the NC pins have no bond wires connected to them internally.

OTHER PINS

Pins 38 and 42 are an extra pair of analog Vdd/Vss. Hook them up, even though some codecs do not require them. If you use the headphone outputs, these pins will supply the majority of the output current, rather than pins 25 and 26. Using both sets of analog power pins will improve your distortion numbers slightly.

POWER UP SEQUENCING

An often overlooked detail is the interaction between the supplies and the various large capacitors in the system. The AC'97 specification states "there are no voltage sequencing requirements for AVdd and DVdd specifying which voltage source ramps up or down first." Although the codec itself can be powered up in either order, there are two things to consider: multiple digital supplies and audio clicks and pops.

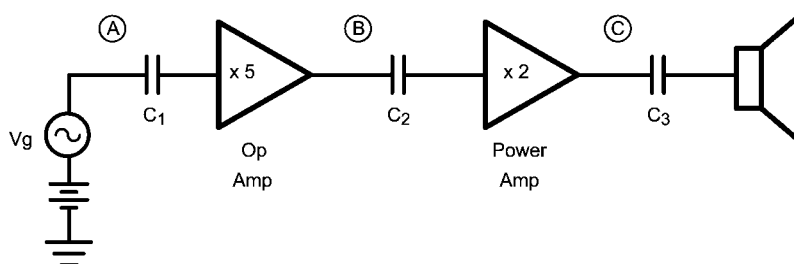
MULTIPLE DIGITAL SUPPLIES

Most integrated circuits have a specification that requires that requires the input voltage to be between $V_{dd} + 0.3 \text{ V}$ and

$V_{ss} - 0.3 \text{ V}$. (assuming the part runs on ground and V_{dd}) This is to avoid turning on the ESD protection network, which may be as simple as reverse-biased diodes to the rails. If you power the 3.3 V pin on the codec from a regulator that is powered from the +5 V analog supply for the codec, and the microprocessor is powered from a separate +3.3 V supply, then bringing up the microprocessor supply before the +5 V analog supply may blow up the digital input pins on the codec. This is because the microprocessor may be outputting a logic one greater than +3 V, and the codec V_{DD} pin is still at zero volts. A good rule of thumb is to minimize the number of different supply rails used, but unfortunately more and more systems today have three or more supplies. A PBX or Central Office may have -48 V , $\pm 15 \text{ V}$ and $+5 \text{ V}$, while a microprocessor/FPGA system may have $+1.8 \text{ V}$, $+3.3 \text{ V}$ and $+5 \text{ V}$. When designing with multiple supplies, either sequence the supplies, both powering up and powering down, or be absolutely sure that any sequence will not have an adverse effect. The wrong sequence may cause a temporary Electrical Overstress (EOS) that may result in failures months later.

CLICKS AND POPS

Clicks and pops may appear during power up or power down. These are caused by large DC voltage swings on the speaker, originating anywhere in the audio chain. The input coupling cap to the audio amplifier needs to be charged, and most audio amplifiers have a capacitor bypassing an internal node that also needs to be charged. The sequencing of the all the supply voltages and the charging of all the capacitors in the system need to be considered, otherwise, a loud pop or click will result. From a macro point of view, the problem is solved by turning the stages on in the direction of signal flow. (fig. 4) When the supplies are off, all of the capacitors are discharged. If the power amplifier is turned on first, then a small change at point A will be amplified when the op amp is turned on. On the other hand, if the op amp is turned on first, C1 is charged and point B is now stable. With controlled turn on of the power amplifier, C2 and C3 slowly charge, eliminating any pops or clicks.



20209304

FIGURE 4. Codec to Speaker Chain

MICROPROCESSOR PERIPHERAL PORT CONFIGURATION

The AC'97 specification states: "AC'97 has two test modes. One is for ATE in circuit test and the other is for vendor-specific tests. AC'97 enters the ATE in circuit test mode if SDATA_OUT is sampled high at the trailing edge of RESET#. AC'97 enters the vendor-specific test mode when coming out of RESET if SYNC is high. These cases (test modes. Ed.) will never occur during standard operating conditions.(Note 8)"

CONFIGURABLE PORTS

Microprocessors with configurable ports present a special problem during power up and configuration. Consider programming a general purpose I/O pin to function as the AC'97 signal, SYNC, during normal operation. During power up, the programmable I/O pins usually default to input mode, rather than output mode, in case there is an output pin driving the microprocessor pin during normal operation. Until the software can configure the pin as an output, it will be in a high impedance state, so the AC'97 codec may see this line as a

logic one. Some microprocessors state that they have a weak pull-up on I/O pins, so it would definitely be a logic one.

SELECTIVE PULL DOWNS

This problem can be solved with two high value, (typically 10k) pull down resistors. The microprocessor data sheet should provide the amount of current supplied by the internal pull-up. Put pads on the pc board, but don't install the resistors if you don't need them. Examples of microprocessors with programmable serial controllers that have programmable or fixed AC'97 ports are the Intel PXA255, the AMD/RMIAlchemy AU1550, and the Freescale SPC5200.

AUDIO AMPLIFIERS

The choice of integrated circuit audio amplifiers can be quite daunting, with literally, over 100 different parts available in the less than the three watt range. Fortunately, there are some basic architectures, with some audio amplifiers having a

method of controlling the turn on time. There is usually a capacitor, labeled "CB" which bypasses an internal node that biases most of the internal stages. The input coupling capacitor also needs to be charged, so there is interaction between the two. The ADI SSM2211 data sheet has an inequality for the two that must be satisfied (Note 9). The T.I. TPA301 data sheet discusses the CB bypass capacitor and has an equation to determine the value (Note 10), but the T.I. TPA0211 data sheet, states "The midrail bypass capacitor C(BYP), is the most critical capacitor... (Note 11)". Although it appears to be a similar design, it does not have an equation, just a suggested value. Always contact the manufacturer if the data sheet does not have the information you need; we appreciate the feedback. Several generations of National's "Boomer®" family are quite popular; with over two dozen parts in six packages. The architecture is the same for all parts (Note 12), so you can change parts at the last minute if need be.

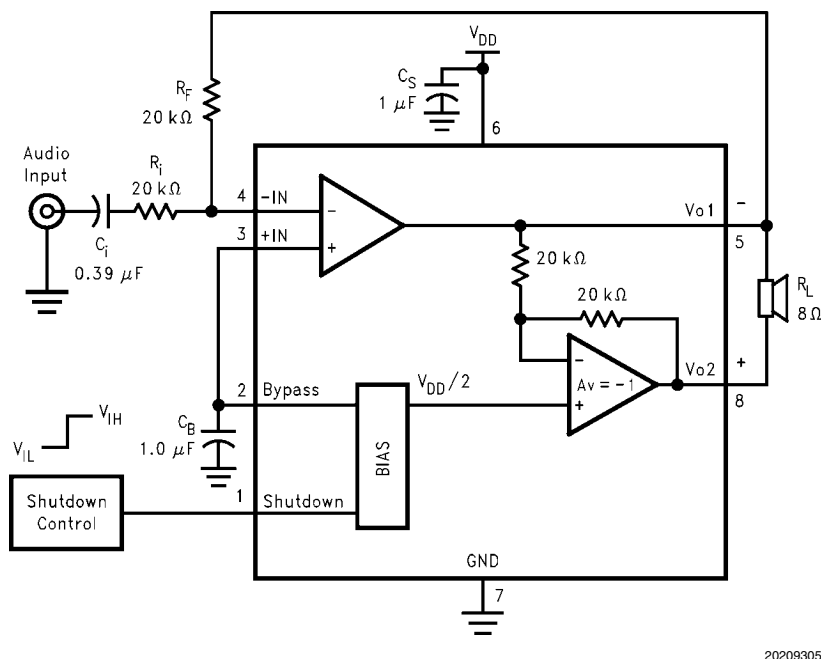


FIGURE 5. Typical National Semiconductor Boomer® block diagram

PC BOARD LAYOUT

If your system is in an industrial setting, you need at least a four layer board. With a minimum of one analog Vdd rail, one digital Vdd rail, analog ground, digital ground, and analog signals and digital signals, it is much easier to layout and route with six or eight layers and the incremental cost is not that much. With eight layers, the noise floor can be reduced to 100 dB down below full scale on all outputs. From one volt RMS, that is 10 μV. Using more layers than four not only reduces the industrial noise that gets into your signal path, but also reduces the EMI that you radiate into the environment. Additional details are in the references. If you use several op amps, consider two duals instead of a quad. Board layout is nicer, you have more choices, and you can get lower DC offsets with singles and duals vs. quads. (If needed). A nice selector application that you download, is available (Note 13). On the same page, there are some active filter design tools, once you know what your speaker does.

BYPASS CAPS

In a mixed signal environment, it is important to avoid generating noise, and if generated, to keep it from spreading throughout the system. A general model of a capacitor has an inductance and a resistance in series with the capacitance.

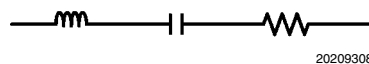


FIGURE 6. Simple Capacitor Model

CHIP CAPACITORS

Chip capacitors have very little inductance, but at high frequencies, it is still significant; a 1206 may have 1250 pH (Note 14). This may not be low enough to avoid self resonance in the range of interest. The newer reverse geometry capacitors (e.g. 0612 vs. 1206) have the connections on the longer side, and can reduce the self inductance by half (Note 15).



FIGURE 7. Classical and Reversed Capacitors

ESL AND ESR

Capacitor manufacturers have made improvements in dielectrics, so you can get more capacitance in a smaller package, but the ESR gets worse although the ESL gets better as the case size gets smaller. You will have to evaluate this trade-off. For bypassing at frequencies an order of magnitude higher, careful attention should be paid to the power and ground power planes and the spacing between them. (stack-up) Additional information on high speed board design considerations can be found in the references(Note 16).

SPEAKERS AND FREQUENCY RESPONSE

Some of the small (3", 1/2 watt) speakers have very NON-flat response curves. If you are going to manufacture your system for only a year or two, and can guarantee you can get the same type speaker, you can do some tricks with the audio chain. For example, if there is a peak at 3 kHz, (Figure 8) and you are handling voice, you could roll the audio chain off at 500-1kHz to compensate. Or if there is a notch at 1 kHz, you can add some peaking to compensate. If you will be in production for 5-10 years, then you would have to contact one or more speaker manufacturers to ensure a source of supply. An alternative would be to obtain several speakers, match different values of passive components to each speaker, and create a variant Bill Of Materials (BOM) for each speaker. Similar comments apply to microphone curves.

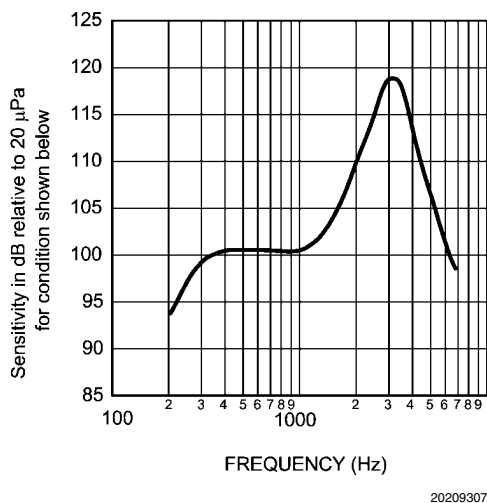


FIGURE 8. Speaker Frequency Response

COUPLING CAPACITORS

Large value input and output coupling caps are both physically large and expensive. If you are not going to record/play music, the frequency response doesn't need to go down to 5 Hz!! Because the "typical application" on a codec data sheet was targeted toward PC applications, the coupling capacitors are large enough to have negligible impedance at 20 Hz. If you are using a small speaker that only goes down to 100–

200 Hz, then you can save money with a smaller capacitor and restrict the response to avoid destroying your speaker. Besides affecting the response, large coupling capacitors will also affect the turn on time and may result in a turn-on pop. This is one of the most often overlooked factors. The AC'97 specification requires that the analog input impedance be greater than 10 kohms, so calculate the low frequency pole to be a realistic value for your system. Caution: Some manufacturers have a constant input impedance, and some have an input impedance that varies with the gain setting for that channel. Output impedance is not in the AC'97 specification, so depending on how the short circuit protection is implemented, this may be a few ohms or a few hundred ohms.

DITHER EMI

For some applications, the Electromagnetic Interference (EMI) specifications may be different than that required for a personal computer used at home. One method that has been successfully used by some customers to reduce the energy at a particular frequency is to vary the 24.576 MHz input frequency by 1-2%. This will spread out the energy of the harmonics, lowering the peak value. This maybe enough to reduce radiated EMI to a value that meets the specification. Caution! Codecs from some suppliers generate white noise when the input clock is dithered, so if you plan to use this, breadboard your application and talk to each individual supplier. Using this scheme, the microprocessor and AC'97 peripheral ports still run on a fixed frequency and the clock input to the codec is varied. This dither is not to be confused with the dither that is sometimes used with sigma-delta modulators in Analog to Digital Converters (ADCs). This is added to reduce idle tones.

EXTENDED TEMPERATURE

A system that will be outside during the winter can easily reach -35°C overnight if unpowered. Some manufacturers only offer AC'97 codecs in the commercial temperature range, so check before prototyping. Capacitors also change value over temperature, so look at the datasheet for the selected capacitor, and choose a value that will be the minimum desired value over the extended temperature range. X7R is usually a good choice.

Software

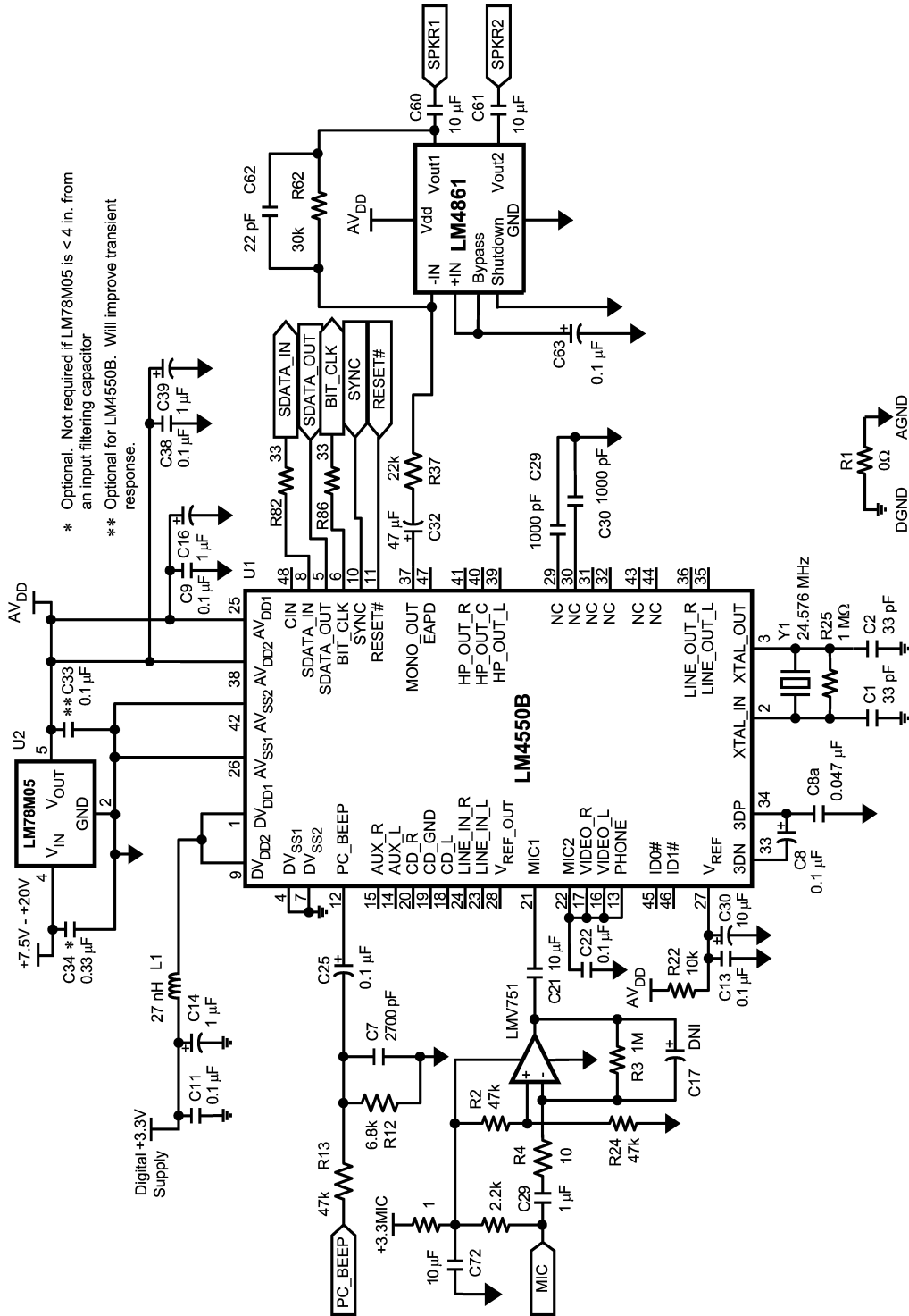
Some of the registers do not use all of the sixteen bits, so the unused bits are called reserve bits. When reading the register, the specification (rev. 2.0) requires that the codec return "0", but is rather vague as to what happens when you write a "1" in a reserve bit. To be on the safe side, set these bits equal to zero when assembling the frame to write out. Do not take an existing frame of data and simply set the active bits appropriately. "AND" the frame with the appropriate mask to force the reserve bits to zero. Revision 2.1 required that the driver test for presence or absence of support for: Mono_out, PC_Beep, Phone, Video, Aux, and MIC2 channels. The AC'97 Link runs at 48 kHz and most audio CDs are recorded at 44.1 kHz. Fortunately, the AC'97 specification covers Sample Rate Conversion (SRC) and requires that six of the more popular sample rates be supported. Some manufacturers use architectures that do not give exact sampling rates, e.g. 44,122.08 instead of 44,100. Although this is within the specification, it causes an annoying 'pop' every few seconds, so if you are going to use a rate other than 48 kHz, breadboard your design or talk to the manufacturer about SRC.

This page intentionally left blank.

Putting It All Together

As a fun exercise, the following figure has lots of errors that were accumulated over a three year period from many different customers. See how many you can find without turning the page. Very few of the errors prevent the circuit from work-

ing, but may impact the performance of the circuit depending on temperature, different production runs, etc. There are also areas of slight redesign that eliminate parts and reduce costs. Take a look at all of the data sheets; some of the errors are not LM4550B related.



202009309

FIGURE 9. DO NOT BUILD: MULTIPLE ERRORS!!

Things to look at (the answers)

- 1) The microphone is fed from the +3.3MIC supply. This is not really an error, but V_{REF_OUT} was designed for powering microphones, and is probably a cleaner source.
- 2) The LMV751 is powered from the +3.3MIC supply also. Although the output will swing more than 1Volt RMS, the input limit for the LM4550B, it would be better to power the op amp from the same +5 V_{DD} that powers the LM4550B for the following reasons: From the data sheet, at five volts, the voltage noise is less, the slew rate is higher, and the gain bandwidth is higher. True, it's not by much, but may make a difference in critical applications. The main reasons to run the op amp on the same supply as the LM4550B is to reduce the possibility of clicks or pops on turn on, and also to avoid the possibility of destroying a part if the +5 Volt analog supply doesn't come up and the op amp is trying to drive 3 volts into an input when the analog V_{DD} is zero.
- 3) Whenever you see a very small resistor, such as R4, 10 ohms, pay special attention. If the resistor was zero ohms, you would have a differentiator. Simulating the overall stage, there is a +20 dB. peak at 1 kHz. Without knowing the frequency response of the microphone, it's hard to say whether or not this is a good circuit. With a gain of 100,000, a slight increase in the microphone signal could easily overload the pin 21 input.
- 4) C21, the 10 μ F capacitor looks rather large in comparison to C29, the 1 μ F capacitor on the other side of the op amp. It would be worthwhile to calculate or simulate the frequency response of the overall circuit to see if C21 can be lowered. If the application is for voice only, the low frequency corner can be in the 100 Hz to 300 Hz range, rather than 20 Hz.
- 5) Note that pins 14, 15, 18–20, 23, 24, and 28 are floating. The data sheet states that unused audio inputs should be connected to analog ground through a 0.1 μ F capacitor. Connecting all of these pins together and to C22 will solve the problem.
- 6) Pin 27, V_{REF} has a 10k pull up resistor. This was required for the LM4550, but is not needed or recommended for the LM4550B. The turn on time and temperature coefficient of the internal reference are improved when it is removed. This is not an error, per se, but another way to squeeze cost out of a design.
- 7) Pin 27 also has C30, a 10 μ F capacitor. This value is shown on another manufacturer's data sheet. The recommended value for the LM4550B is 3.3 μ F. Again, not strictly an error, but does lead to a longer turn on time. If the turn on time for the LM4550B is longer than the turn on time for the audio amplifier used, you may get a click or pop on turn on.
- 8) Pins 33 and 34 are for the simulated 3D sound. The LM4550B uses a fixed depth 3D stereo enhancement, requiring a single 0.022 μ F capacitor. The values shown are for another manufacturer's implementation. When designing a production board to accept different manufacturer's parts, the variant Bill Of Materials (BOM) should be carefully reviewed to make sure that all of the variations are correctly matched. Having a colleague review everything will catch errors that are transparent to the creator.
- 9) For the LM4550B, pins 29 and 30 are labeled "NC". For the LM4550B, this means that there is No Connection internally. This is a fairly common usage, but some manufacturers use "NC" to mean "do Not Connect to this pin, we have something connected to it internally." If you need to use the pad area under the pin for a wire through, contact the manufacturer and determine what they mean by NC. C29 and C30 are required

for another manufacturer's part, so it does no harm to leave them on the board, but does increase the cost.

10) Without doing any calculations, the relative values of C21, C32, and C63 should be a yellow caution flag. C32 is too big; not only in terms of the low frequency corner, but also in terms of turn on time relative to C63. A good tip is to take a quick look at the entire signal path and look at the size of the coupling capacitors, e.g. C29, C21, C32, and C60/C61. Then look at the RC time constants. The input impedances for the LM4550B are 10k minimum, which the AC'97 specification requires, and typically 40k. Some codecs have an input impedance that varies with the attenuator setting, so check with both minimum and maximum.

11) The 33 ohm resistors, R82 and R86 will affect the rise and fall times. For EMI reduction, you want a very slow rise time, but the AC'97 specification has a maximum and a minimum. This is rather unusual for logic signals.

12) L1 was required with the LM4550, but is not required or recommended with the LM4550B. When a manufacturer revises a part or a data sheet, carefully review the new data sheet to see exactly what changed. Some data sheets have a revision table stating the differences, but sometimes not all of the differences are caught when the data sheet author is updating the revision table, so do your own page by page comparison. It is time consuming and boring, but saves having to rework thousands of boards.

I hope you found all of them. If you found one I didn't see, or just want to discuss the schematic, I can be reached at harry@ieee.org.

Conclusions

With the increasing pressure on time-to-market and total cost of ownership over the life of the product, sometimes the 'obvious' solution may not be the most cost effective. With the Intel AC'97 specification, multiple availability of audio codecs that meet this specification and off the shelf AC'97 drivers, audio input and output can quickly be added to a microprocessor based system. One of the advantages to using an AC'97 codec with standard driver software is the ability to create your own content on any PC. Downloaded songs, your own CDs, and the PC microphone can all be combined into a .wav file that the standard PC or Linux driver can handle.

Bibliography

Note 1: With inputs from Analog Devices, Creative Labs, National Semiconductor, and Yamaha Corporation

Note 2: Analog Devices, Ashahi Kasei, Crystal, National Semiconductor, T.I., Wolfson

Note 3: Realtek, Wolfson

Note 4: Analog Devices

Note 5: , Grigory ""Intel High Definition Audio tests by the example of the Realtek ALC880 codec" @ www.digit-life.com/articles2/intel-hdaudio/intel-hdaudio.html accessed 29 Aug 2006.

Note 6: Intel, Audio Codec '97 Revision 2.1, page 108, May 22, 1998

Note 7: Intel, Audio Codec '97 Revision 2.0, page 26

Note 8: Intel, Audio Codec '97 Revision. 2.1, page 49, May 22, 1998

Note 9: Analog Devices, SSM2211 data sheet, Rev. C

Note 10: Texas Instruments, TPA301 datasheet, Jan 1998, revised June 2004, page 18

Note 11: Texas Instruments, TPA0211 datasheet, Jan 2000, revised Nov 2002, page 12

Note 12: National Semiconductor, e.g. LM4818, LM4819, LM4871, LM4903 data sheets

Note 13: National Semiconductor, "Selguide Software - Selection guide software for Windows" www.national.com/appinfo/amps/

Note 14: Cain, Jeffrey, Ph.D., AVX Corporation "Parasitic Inductance of Multilayer Ceramic Capacitors". <http://www.avxcorp.com/docs/techinfo/parasitc.pdf> Accessed 2 Oct. 2006

Note 15: Yun Chase, AVX Corporation "Introduction to Choosing MLC Capacitors For Bypass/Decoupling Applications".

Note 16: Alexander, Mark "Power Distribution System (PDS) Design: Using Bypass/Decoupling Capacitors" February 28, 2005, available at <http://www.xilinx.com/bvdocs/appnotes/xapp623.pdf>

Note 17: http://www.knowlesacoustics.com/knowlesacoustics-apps/specialty_productdetail.do?product_id=39

Notes

THE CONTENTS OF THIS DOCUMENT ARE PROVIDED IN CONNECTION WITH NATIONAL SEMICONDUCTOR CORPORATION ("NATIONAL") PRODUCTS. NATIONAL MAKES NO REPRESENTATIONS OR WARRANTIES WITH RESPECT TO THE ACCURACY OR COMPLETENESS OF THE CONTENTS OF THIS PUBLICATION AND RESERVES THE RIGHT TO MAKE CHANGES TO SPECIFICATIONS AND PRODUCT DESCRIPTIONS AT ANY TIME WITHOUT NOTICE. NO LICENSE, WHETHER EXPRESS, IMPLIED, ARISING BY ESTOPPEL OR OTHERWISE, TO ANY INTELLECTUAL PROPERTY RIGHTS IS GRANTED BY THIS DOCUMENT.

TESTING AND OTHER QUALITY CONTROLS ARE USED TO THE EXTENT NATIONAL DEEMS NECESSARY TO SUPPORT NATIONAL'S PRODUCT WARRANTY. EXCEPT WHERE MANDATED BY GOVERNMENT REQUIREMENTS, TESTING OF ALL PARAMETERS OF EACH PRODUCT IS NOT NECESSARILY PERFORMED. NATIONAL ASSUMES NO LIABILITY FOR APPLICATIONS ASSISTANCE OR BUYER PRODUCT DESIGN. BUYERS ARE RESPONSIBLE FOR THEIR PRODUCTS AND APPLICATIONS USING NATIONAL COMPONENTS. PRIOR TO USING OR DISTRIBUTING ANY PRODUCTS THAT INCLUDE NATIONAL COMPONENTS, BUYERS SHOULD PROVIDE ADEQUATE DESIGN, TESTING AND OPERATING SAFEGUARDS.

EXCEPT AS PROVIDED IN NATIONAL'S TERMS AND CONDITIONS OF SALE FOR SUCH PRODUCTS, NATIONAL ASSUMES NO LIABILITY WHATSOEVER, AND NATIONAL DISCLAIMS ANY EXPRESS OR IMPLIED WARRANTY RELATING TO THE SALE AND/OR USE OF NATIONAL PRODUCTS INCLUDING LIABILITY OR WARRANTIES RELATING TO FITNESS FOR A PARTICULAR PURPOSE, MERCHANTABILITY, OR INFRINGEMENT OF ANY PATENT, COPYRIGHT OR OTHER INTELLECTUAL PROPERTY RIGHT.

LIFE SUPPORT POLICY

NATIONAL'S PRODUCTS ARE NOT AUTHORIZED FOR USE AS CRITICAL COMPONENTS IN LIFE SUPPORT DEVICES OR SYSTEMS WITHOUT THE EXPRESS PRIOR WRITTEN APPROVAL OF THE CHIEF EXECUTIVE OFFICER AND GENERAL COUNSEL OF NATIONAL SEMICONDUCTOR CORPORATION. As used herein:

Life support devices or systems are devices which (a) are intended for surgical implant into the body, or (b) support or sustain life and whose failure to perform when properly used in accordance with instructions for use provided in the labeling can be reasonably expected to result in a significant injury to the user. A critical component is any component in a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or system or to affect its safety or effectiveness.

National Semiconductor and the National Semiconductor logo are registered trademarks of National Semiconductor Corporation. All other brand or product names may be trademarks or registered trademarks of their respective holders.

Copyright© 2007 National Semiconductor Corporation

For the most current product information visit us at www.national.com



**National Semiconductor
Americas Customer
Support Center**
Email:
new.feedback@nsc.com
Tel: 1-800-272-9959

**National Semiconductor Europe
Customer Support Center**
Fax: +49 (0) 180-530-85-86
Email: europe.support@nsc.com
Deutsch Tel: +49 (0) 69 9508 6208
English Tel: +49 (0) 870 24 0 2171
Français Tel: +33 (0) 1 41 91 8790

**National Semiconductor Asia
Pacific Customer Support Center**
Email: ap.support@nsc.com

**National Semiconductor Japan
Customer Support Center**
Fax: 81-3-5639-7507
Email: jpn.feedback@nsc.com
Tel: 81-3-5639-7560