VS1053b+VS1000 Hi-Fi Recorder

VSMPG "VLSI Solution Audio Decoder"

Project Code:
Project Name: VSMPG

Revision History			
Rev.	**Date**	**Author**	**Description**
0.91	2010-04-08	HH	Documentation update.
0.90	2010-04-07	HH	Enhanced recording quality.
0.80	2010-02-18	HH	First hardware release.
0.51	2009-12-09	HH	Updated Figure 1.1.
0.50	2009-12-09	HH	First publication with binaries.
0.10	2009-07-08	HH	Initial pre-release.

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1 Introduction

The VS1053b+VS1000 Hi-Fi Recorder (from hereon "Recorder") is a demonstration of how to create a high-performance player / recording application using the VS1000 chip as the controller and the VS1053b chip as the audio decoder / encoder. It can play back .OGG, MP3, .AAC, .M4A, .WMA, .FLAC, .WAV, .IMA and .MID formats (Chapter 2.1) and record in .WAV and .OGG formats (Chapter 2.2). The player contains all the basic functions needed to create a useful, high-fidelity playback / recording device.

This document is organized as follows.

Chapter 2 presents the features of the Recorder.

User instructions are provided in Chapter 3.

Chapter 4 shows the recording and playback performance of the Recorder.

Chapter 6 discusses how to modify the player for your own needs.

A detailed version history is provided in Chapter 7, followed by contact information in Chapter 8.

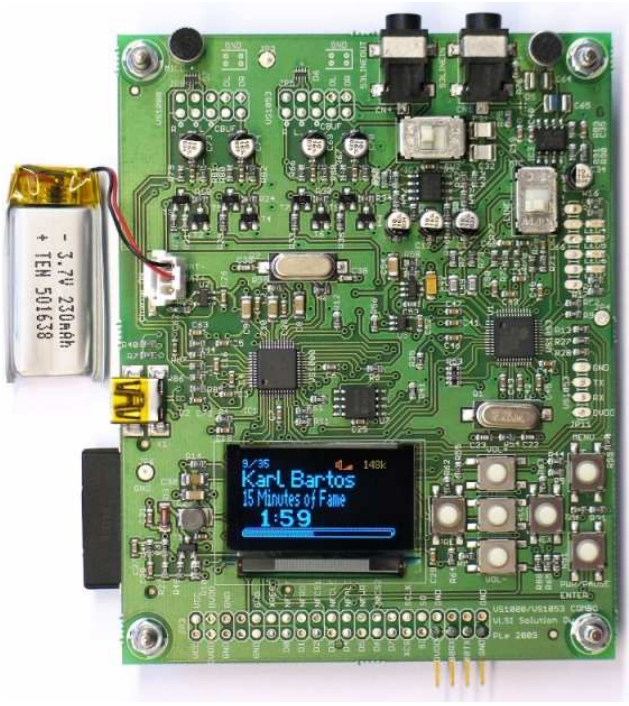

Figure 1.1: VS1053b+VS1000 Hi-Fi Recorder board.

2 Features

The Recorder has the following features:

- Capable of playing all the audio formats that VS1053b is capable of, from extremely low-bitrate lossy compression formats to straight PCM and the lossless FLAC format. Bitrates upto 1536 kbit/s are supported. For details, see Chapters 2.1 and 4.1.
- Can record with several different quality settings, ranging from approximately 45 to 1536 kbit/s. For details, see Chapters 2.2 and 4.2.
- Can play back audio from MMC/SD/SDHC cards, and SD Micro cards with an adapter.
- Supports a 3.7 V Lithium Ion battery which is automatically charged whenever a USB power source is available. In playback it typically draws a current of 40-50 mA. When recording, power consumption is typically 90 mA. Both figures are for the whole system, incuding SD card.
- Contains 7 buttons and a 132x64 pixel OLED display for the user interface. OLED can be replaced with a compatible LCD.
- Advanced bass and treble controls with user-definable cut-off levels.
- Uses ReplayGain technology to equalize volume levels between songs when playing back Ogg Vorbis files.
- Full Speed USB interface (12 Mbit/s) to load files from/into a PC. Alternatively a card reader (not included) can be used for faster file operations.
- Optionally offers EarSpeaker auralization which simulates a room for a more natural earphone experience.

2.1 Supported Playback Formats

The Recorder is capable of playing files in the following formats:

- .OGG: Ogg Vorbis upto 2 channels, 48 kHz
- .MP3: MPEG 1 & 2 layer III, all standard samplerates and bitrates.
- .AAC, M4A: MPEG4/2 AAC-LC(+PNS), HE-AAC v2 (Level3)(SBR+PNS)
- .WMA: Windows Media Audio 4.0/4.1/7/8/9, all profiles, non-DRM
- .FLAC: Free Lossless Audio Codec upto 16 bits 48 kHz
- .WAV, .IMA: 8-bit and 16-bit PCM, 4-bit IMA ADPCM
- .MID: General Midi 1 / SP-MIDI format 0

2.2 Supported Recording Formats

The Recorder is capable of recording in the following formats:

- 48 kHz 16-bit stereo PCM using WAV format, 1536 kbit/s.
  - Full CD-quality audio.
- 44.1 kHz Ogg Vorbis stereo, nominally 135 kbit/s.
  - Intended for Hi-Fi applications where file size matters.
  - Uses Ogg Vorbis encoder v1.60, Music profile 5.
- 16 kHz Ogg Vorbis stereo, nominally 66 kbit/s.
  - Intended for high-quality stereo speech applications.
  - Uses Ogg Vorbis encoder v1.60, Wideband Stereo Voice profile 6.
- 16 kHz Ogg Vorbis mono, nominally 45 kbit/s.
  - Intended for high-quality speech applications.
  - Uses Ogg Vorbis encoder v1.60, Wideband Mono Voice profile 7.

3 Usage

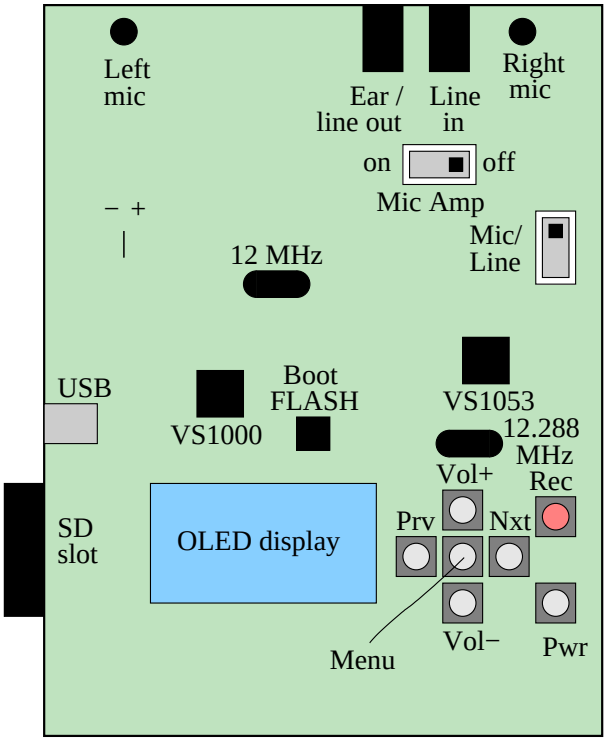

Figure 3.1: VS1053b+VS1000 Hi-Fi Recorder's user interface and some components.

The Recorder's user interface consists of an OLED display and keys as shown in Figure 3.1.

3.1 Keys

Use the "Pwr" key to turn the unit on (also called "Pause" and "Enter"). If you have inserted a memory card and you have not connected your device to USB, you will get the main display which is shown in Figure 3.2 on page 9.

In this mode pushing "Pwr" will switch between pause and normal playback, and pushing it for 2 seconds will turn the unit off.

Use the "Menu" key to enter the Main Menu (Chapter 3.3).

Use "Vol+" and "Vol-" (also called "Up" and "Down") to turn volume up and down.

Note: to save I/O pins the Menu button has been implemented on the PCB as a combination of Vol+ and Vol-. Pushing both at the same time may bring the Main Menu up.

Use “Prv” and “Nxt” (also called “Left” and “Right”) to jump to either the previous or next song, respectively. If you are in random mode, you will get a new random song from both of these buttons. By keeping “Prv” or “Nxt” pushed, song is rewinded or fast forwarded, respectively.

Pushing “Rec” for a second starts recording with currently selected recording quality (Chapter 3.4: Settings).

Choose the “Mic / Line” switch to select between microphone and line inputs. If using the microphone input, select analog amplification with the “Mic Amp” switch.

3.2 Main Playback Display

Figure 3.2: Main playback display.

In the top left corner the number of the file being played as well as the total number of playable files in the memory card are shown. Battery charge status is shown with green. The red loudspeaker symbol will show the current volume level and the orange number is the average bitrate of the file so far in kilobits per second.

If the file is an .MP3 file with a ID3V1 header or an Ogg Vorbis file with title information, the artist and song title is displayed on lines 2 and 3. Otherwise the file name is displayed.

The fourth line shows the playback time of the current song. If the user has fast forwarded or rewinded during the playback of a song, this value will be updated only if the file format is such that it provides an absolute song position. Otherwise 99:99 is shown. 99:99 is also shown if the current position is at 100 minutes or more.

The bar at the bottom shows the relative location in the file to be played.

If the battery level is too low (approx. 3.4 volts), the system will perform an automatic shutdown.

3.3 Main Menu

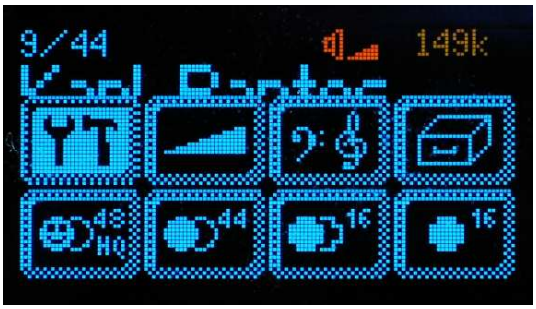

Figure 3.3: Main Menu display.

By pushing the "Menu" key you can enter the Main Menu which is shown in Figure 3.3. "Up", "Down", "Left" and "Right" keys are used as a four-way controller to navigate inside the menu. The operation is selected by pushing the "Enter" key. You can exit the menu by pushing "Menu" again.

The menu options from left to right, top to bottom are: Settings, Volume, Tone Control, File Browser, High Fidelity PCM Recording, Music Ogg Vorbis Recording, Stereo Wideband Speech Vorbis Recording and Wideband Speech Vorbis Recording.

3.4 Settings

Figure 3.4: Settings display.

You can change personal preferences in the Settings menu (Figure 3.4). The menu is navigated by pushing "Up", "Down", "Left" and "Right". To exit the menu, push "Menu" or "Enter".

Currently there are five customizable settings:

- Random play controls whether songs are played in sequential or random order.
- EarSpeaker controls the amount of EarSpeaker Spatial Processing used, from "off" to "high". EarSpeaker uses a room and head-related transfer function model to create a simulated loudspeakers in a simulated listening room. It externalizes the

audio so that it doesn't sound like it's coming from inside the listener's head, thus creating a realistic listening experience for people using headphones. When used with loudspeakers, EarSpeaker should be turned off.

- Playback speed controls, as the name implies, playback speed. The default is 1X speed, but it can also be set to 2X, 4X and 8X. Note, though, that all codec and bitspeed combinations cannot necessarily run at the higher speeds.
- ReplayGain is a technology that equalizes perceived loudness differences between songs using a psychoacoustic model.
  - Left: No ReplayGain.
  - Center: ReplayGain for Ogg Vorbis files. Assume no ReplayGain for other formats, so they are played at -6 dB relative to Ogg Vorbis files. This is usually the best selection if the user hasn't specifically run ReplayGain to e.g. MP3 files (Mp3Gain).
  - Right: ReplayGain for Ogg Vorbis files. Assume other files have been prepared with ReplayGain, so play them at default volume.
- Recording Quality: select between four recording quality settings when the Rec button is pushed. Options are in the same order as in the Main Menu (Chapter 3.3).

3.5 Volume

Figure 3.5: Volume display.

The Volume control is shown in (Figure 3.5). You can control the volume by pushing "Left", "Right", "Vol+" or "Vol-". Exit the control by pushing "Menu" or "Enter"

3.6 Tone Control

Figure 3.6: Tone Control display.

The Recorder has a precisely adjustable bass and treble controller (Figure 3.6). Use “Up” and “Down” to select the value to control, “Left” and “Right” to change a value.

The Tone Controller allows you to adjust both the amount of bass boost or treble attenuation/boost and their cut-off frequencies. This allows you to better adjust your controls to match your earphones or sound system.
Example: high-end earphones are often well off with a bass control cut-off of 40-60 Hz, while less expensive models work better if the limit is between 70-100 Hz.

Exit the controller by pushing “Menu” or “Enter”.

3.7 File Browser

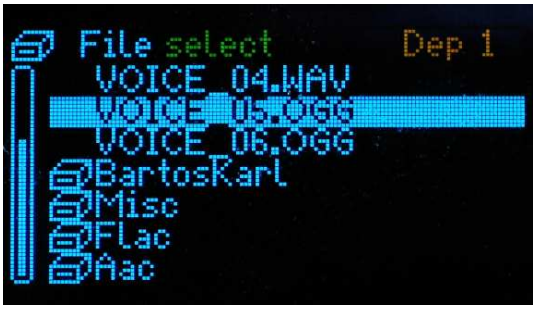

Figure 3.7: File Browser display.

Use the File Browser menu to browse the folders and files on the memory card and select the next file to play. Figure 3.7 shows an example of the menu with three files and four directories visible.

Use the “Up” and “Down” keys to scroll through the files. Push “Right” or “Enter” to enter a directory / folder (indicated by a drawer symbol on the left) or to select a song to be played. Push “Left” to return to an upper directory level.

To exit the File Browser menu without selecting a song, push “Menu”.

3.8 Recording

Audio recording with very high quality is the main functionality the VS1053b+VS1000 Hi-Fi Recorder is designed to do. Thus the Recorder offers four different Main Menu selections for audio recording. These four recording options offer different quality and bitrate levels, from pure CD quality PCM recording to low-bitrate voice recording. The unit can record from either its line input or stereo microphones that are integrated on the PCB. Use the Mic/Line switch on the board to select the input source.

Figure 3.8: Recording with AGC capable profile display.

The basic recording display is shown in Figure 3.8. The top line shows the current recording time, amount of space left for the recording and the average bitrate of the file in kbit/s. Note that the recorder software can only record to non-fragmented blocks of memory with a maximum file size of 512 MiB. Because of this the "space left" number may be smaller than the actual free space of the card. Whenever the maximum file size limit is reached, and unless the card is full, the recorder will automatically create a new file whenever the limit is reached.

The maximum allowed AGC amplification level is shown on the next line (set to 12 dB). This value can be controlled with the "Up" and "Down" keys. If you turn AGC off by pushing the "Left" key, the value shown is a constant digital amplification value.

By pushing "Next", you may finish the currently recorded file and start another one. This will take a few seconds and the edit point is not seamless.

You can finalize the recorded file and exit recording by pushing "Menu" or "Enter". To cancel recording without saving a file, keep "Left" pushed for two seconds.

Figure 3.9: Recording display with overload symbol shown.

If the input signal is too strong, an Overload symbol blinks for 3 seconds, as shown in Figure 3.9. If this happens anywhere else than at the very beginning of the recording, lower the signal level to the microphones or line input (or if you have a profile capable of AGC and AGC is off, first turn recording amplification down to 0 dB). Otherwise sound may have distortion.

Figure 3.10: Recording with non-AGC capable profile display.

The High Fidelity PCM and Music Ogg Vorbis profiles don't have an Automatic Gain Control (AGC). In these profiles the AGC controls are ghosted as shown in Figure 3.10.

3.8.1 High Fidelity PCM Recording

High Fidelity PCM Recording is done in stereo at 48 kHz and 16 bits. This offers the best quality that the card is capable of with the price of using memory card space at 1536 kbit/s (11.0 MiB/s).

To maintain the highest possible quality, AGC is not active with this profile.

3.8.2 Music Ogg Vorbis Recording

Ogg Vorbis offers a memory efficient way to record very high quality music at 44.1 kHz stereo. While maintaining a very high compression ratio of over 10:1 as opposed to the High Fidelity PCM Recording profile (nominal bitrate is 135 kbit/s), the sound quality of these profiles are in most cases indistinguishable for human listeners. This format is

recommended when very high quality is needed but when the size of the memory card is not large enough for uncompressed PCM sound.

To maintain the highest possible quality, AGC is not active with this profile.

3.8.3 Stereo Wideband Speech Vorbis Recording

The Stereo Wideband Speech Vorbis profile is, as the name implies, designed to effectively pick up human voice with very good quality. The bitrate is only 66 kbit/s on average and an adjustable Automatic Gain Control (AGC) equalizes sound levels.

3.8.4 Wideband Speech Vorbis Recording

The Wideband Speech Vorbis profile is intended to be used in situations where even the Stereo Wideband Speech Vorbis profile creates too large bitstreams, or when a mono microphone is connected to the system. It records the left input with a bitrate of approximately 46 kbit/s. As the Stereo Wideband Speech Vorbis profile, this profile also benefits of an adjustable AGC.

4 Performance

All figures depicted in this chapter are from actual measurements using a real Recorder. A Rohde & Schwarz UPV Audio Analyzer / Signal Generator was used for the tests. The board was connected to the analyzer with a mini-plug to RCA cable.

16-bit .WAV test files for playback are available on request from support@vlsi.fi.

Unless otherwise noted, all measurements in this section have been performed with 48 kHz 16-bit stereo PCM WAV files (High Fidelity PCM Recording) at 1001.23 Hz with a 200 kΩ pick-up, volume at full (-0 dB). ReplayGain was turned off, volume set to maximum, and tone controls were not active.

4.1 Playback Performance

The playback characteristics have been measured using a typical Hi-Fi Recorder. Below is a summary, followed by more detailed measurement results.

Parameter	Typ	Unit
Full Scale Output Voltage (200 kΩ)	1.89	Vpp
Full Scale Output Voltage (200 kΩ)	670	mVrms
Background noise on empty channel (200 kΩ)	12.8	μVrms
Dynamic Range (DAC unmuted, A-weighted)	94	dB
S/N Ratio (full scale signal)	88	dB
Interchannel Isolation (Cross Talk)	53	dB
Frequency Response (20-20000 Hz)	±0.15	dB

4.1.1 Playback Interchannel Isolation

Parameter	Left	Right	Unit	Isolation
Full Left Signal	670	1.44	mVrms	53.4 dB
Full Left Signal	1.44	670	mVrms	53.4 dB

4.1.2 Playback Noise and THD Ratios

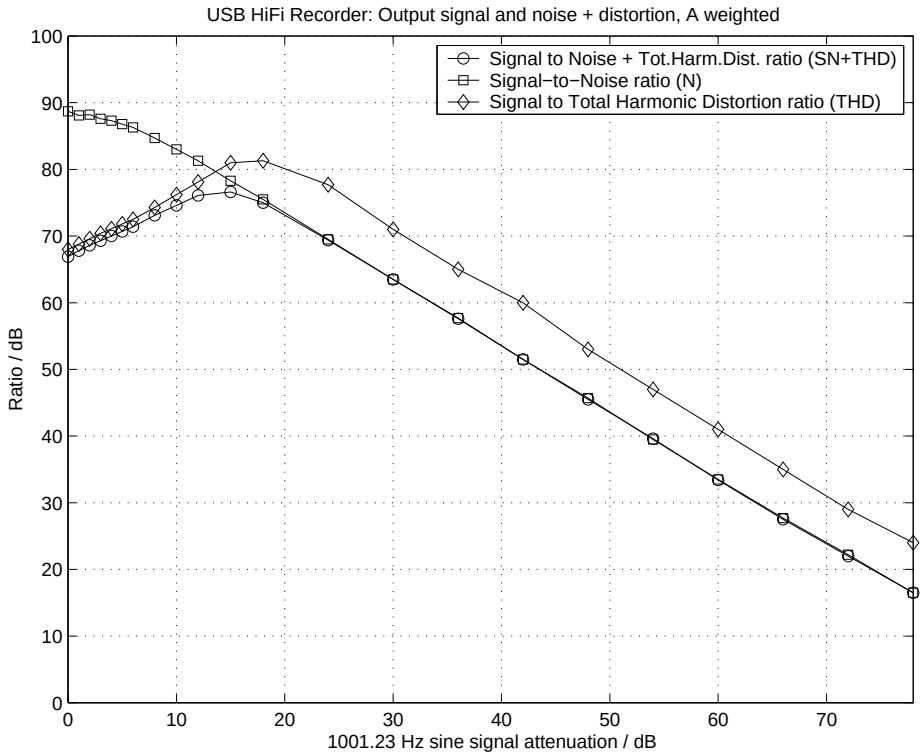

Figure 4.1: Playback noise + THD ratios.

Figure 4.1 presents the Noise and THD ratios for 1001.23 Hz 16-bit PCM files that have a signal level between 0 and -78 dB. Weighting curve A has been used for the measurements.

4.1.3 Playback Frequency Response

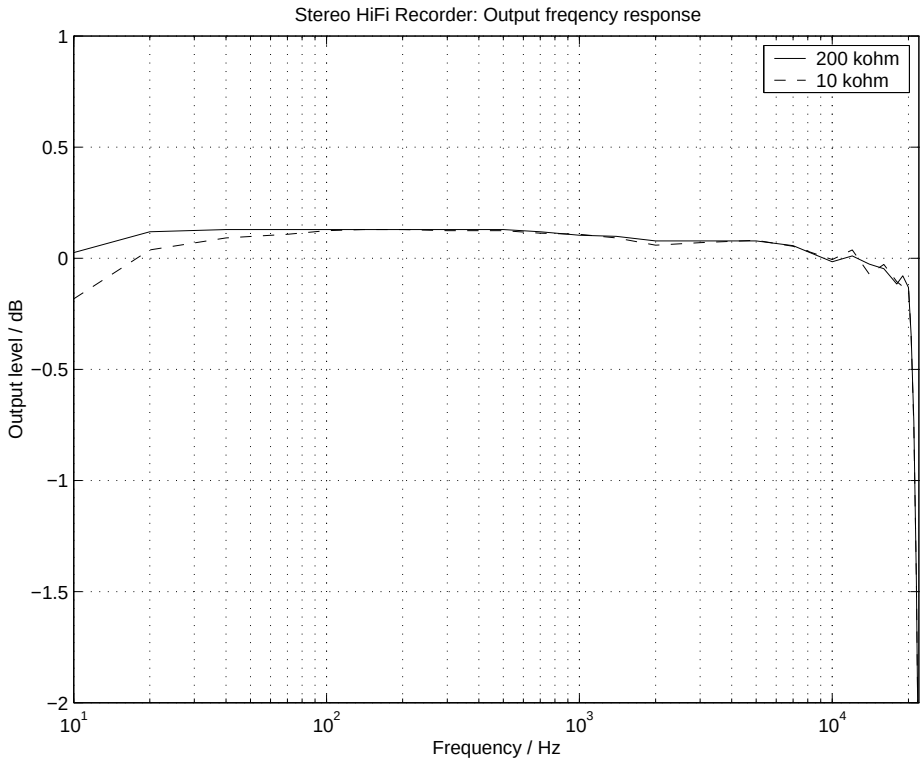

Figure 4.2: Playback frequency response.

Figure 4.2 presents the frequency response of playback at 48 kHz. The response is within ±0.15 dB for the whole human hearing frequency area.

4.2 Recording Performance

Unless otherwise noted, all measurements in this section have been performed with the 48 kHz 16-bit stereo PCM WAV profile with a test frequency of 1001.23 Hz, line input with a 10 Ω drive from the signal generator. Resulting 16-bit stereo output files have then been analyzed with MatLab.

Parameter	Typ	Unit
Maximum Amplitude	3100	mVpp AC
Total Harmonic Distortion	0.013	%
S/N Ratio	86	dB
Dynamic Range	95	dB
Interchannel Isolation (Cross Talk)	95	dB
Impedance	80	kΩ
Frequency Response (20-20000 Hz)	±0.8	dB
Frequency Response (70-20000 Hz)	±0.1	dB

4.2.1 Recording Noise and THD Ratios

Figure 4.3 shows the Noise and THD ratios of recording a 1001.23 Hz sine signal at different signal levels. 0 dB level is 1.1 V(rms), or 3.1 Vpp. The A weighting curve has been used.

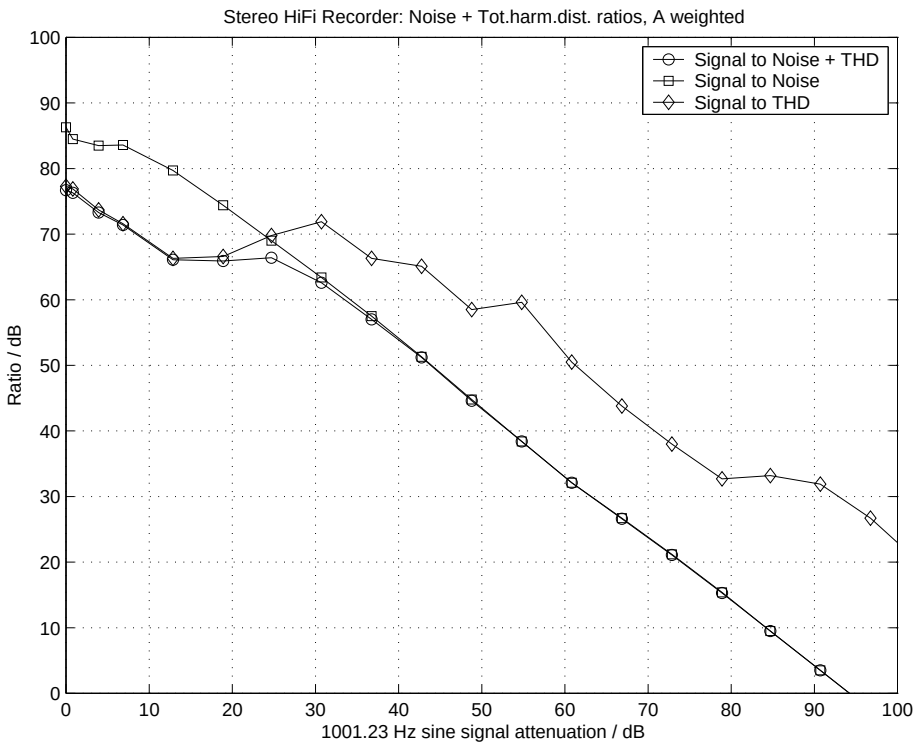

Figure 4.3: Recording noise + THD ratios.

4.2.2 Recording Frequency Response

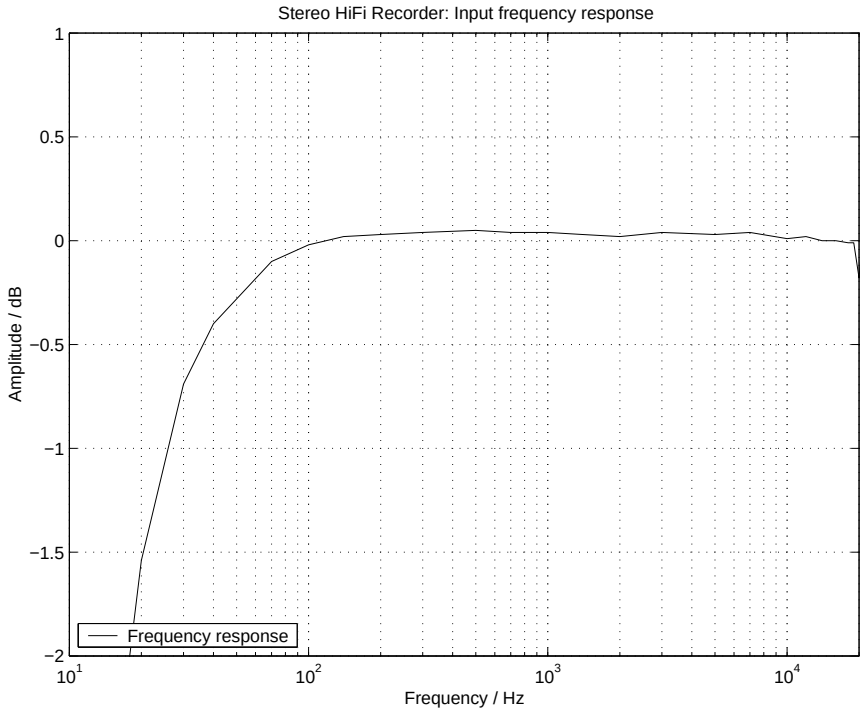

Figure 4.4: Recording frequency response.

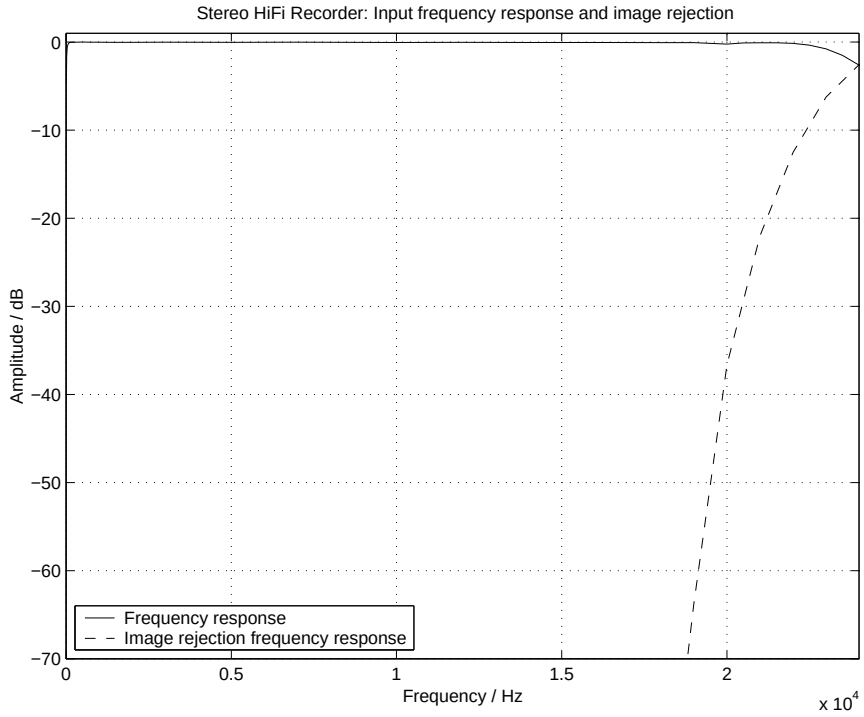

Figure 4.5: Recording image rejection frequency response.

Figure 4.4 presents recording frequency response and Figure 4.5 image rejection.

4.2.3 Recording Monitor Frequency Response

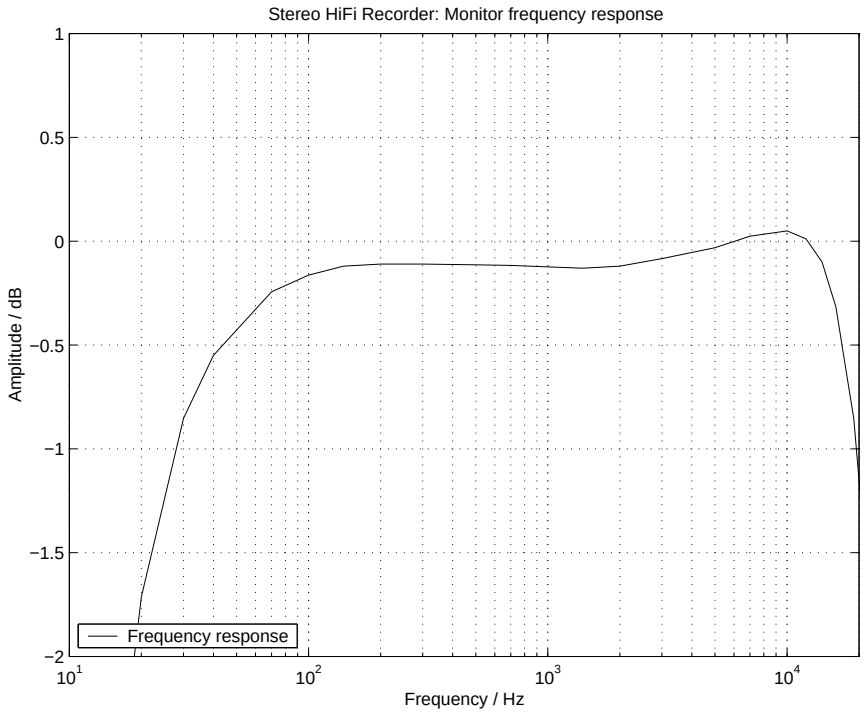

Figure 4.6: Recording monitor frequency response.

Figure 4.6 presents the recording monitor frequency response. Unlike other results under Chapter 4.2, these have been measured from line output with a 200 kΩ impedance.

Note that the recroding monitor does *not* represent recording quality that goes to the output file, which is presented in Chapters 4.2.1 and 4.2.2.

5 Loading New Software

To update to a new software version, you need a PC/Windows computer with an RS232 port, an RS232 cable and an RS232 adapter. If you don't have an RS232 adapter, you can order one from VLSI Solution's Web Store or build it yourself: the adapter consists of one single MAX3232 compatible RS232 signal converter.

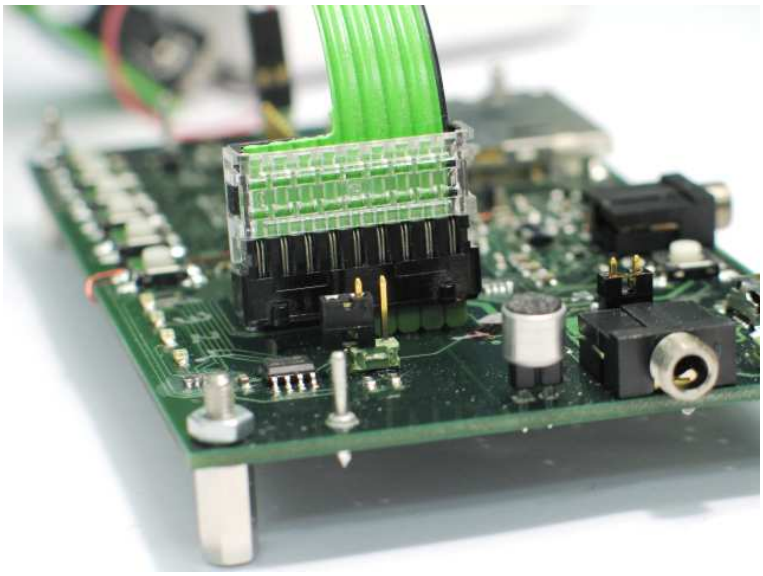

Figure 5.1: How to connect an RS232 adapter to VLSI's board

If loading a program to VLSI Solution's example boards, connect the adapter cable to the main board as shown in Figure 5.1. The black thread should go to pin 1. If you use a custom board, you will have to use your own adapter.

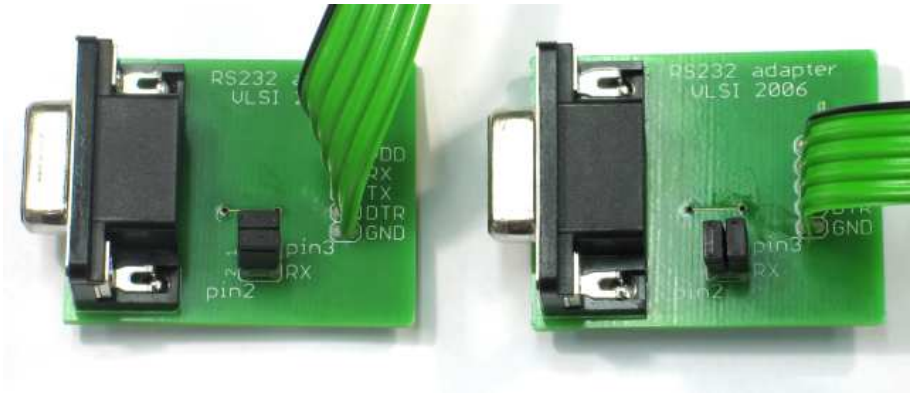

Figure 5.2: Two possible RS232 jumper configurations in some adapters

This package includes command files named `prom1.bat` through `prom4.bat`. They are intended to be used from serial ports COM1 through COM4, respectively.

To load the new code to the board, perform the following steps:

1. Open the .zip package that contains the files. As you are reading this document, you have probably already done that.
2. Open a command prompt, and use the CD command to go to the `Firmware/` directory where the files are.
3. Connect a serial cable between the PC and the VLSI board.
4. Turn the VLSI unit on. It doesn't matter what mode it is in.
5. Check which COM port it is on.
6. If COM1, run prom1.bat by typing `prom1` and pressing the Enter key. For COM2, run prom2.bat etc.
7. You should see roughy the following text appearing on the screen:

```
VSEMU 2.1 Nov 28 2007 11:50:01(c)1995-2007 VLSI Solution Oy
Clock 11999 kHz
Using serial port 1, COM speed 115200
Waiting for a connection to the board...
Caused interrupt
Chip version "1000"
Stack pointer 0x19e0, bpTable 0x7d4d
User program entry address 0x4083
eeprom.bin: includes optional header, 16 sections, 539 symbols
Section 1: code        page:0 start:80 size:3 relocs:1 fixed
[... many similar lines deleted ...]
Section 16: VS_stdiolib$0  page:0 start:689 size:134 relocs:37
0000
Erase
0000
 status

0000
0010
[many similar lines deleted]
Finished!!
```

   Never interrupt programming!
8. Sometimes you may only see

```
VSEMU 2.1 Nov 28 2007 11:50:01(c)1995-2007 VLSI Solution Oy
Clock 11999 kHz
Using serial port 1, COM speed 115200
Waiting for a connection to the board...
```

   In such a case you have either used a wrong COM port in your script or you must change the jumper configuration as shown in Figure 5.2.

6 Modifying Code

This chapter will be updated when the full VS1000 source code is formatted in such a way that it may be compiled and modified with VLSI Solution's Windows compilation tools. The expected time table for this is Q2/2010.

7 Latest Version Changes

This chapter describes the most important changes to the VS1053b+VS1000 Hi-Fi Recorder and this document.

Version 0.91, 2010-04-08

Minor updates to this documentation.

Version 0.90, 2010-04-07

- Both .WAV PCM and Ogg Vorbis recording quality enhanced. See Chapter 4.2 for new measurements.
- To do list from release 0.80 remains.

Version 0.80, 2010-02-18

- Updated playback and recording performance measurements in Chapter 4 to correspond with the cards that are put on sale.
- Hardware and software changes made for better compatibility with different SD / SDHC brands. The biggest hardware change was to add a separate regulator to power newer memory cards that require high currents.
- New Recording button added.
- Added battery level indicator and emergency power-off.

To do list:

- Source code is still not available.
- Pause function has been implemented in a way that may cause instability.
- Save user parameters like volume and EarSpeaker settings when powering off so that they will automatically be restored on power-on.
- A better, automatic and real-time ReplayGain-like algorithm is in the works.When ready, it will make all files play at roughly equal volume even if not preprocessed beforehand by the user with ReplayGain.
- Battery level not checked while recording.
- Files are played in file system order. Same goes for the file browser. This should be changed to alphabetical order.
- Music Ogg Vorbis Recording quality still could be better.

Version 0.51, 2009-12-11

- Updated Figure 1.1 on page 5 to reflect the current board.

Version 0.50, 2009-12-09

First binary release version that looks pretty much as the final version.

To do list:

- Source code is still not available.
- Pause function has been implemented in a way that may cause instability.
- Shutdown isn't always perfect yet.
- Save user parameters like volume and EarSpeaker settings when powering off so that they will automatically be restored on power-on.
- An automatic, real-time ReplayGain-like algorithm is in the works. When ready, it will make all files play at roughly equal volume. When ready, this will greatly enhance the user experience.

Version 0.10, 2009-07-08

Initial pre-release version. Contains lots of measurement data that will be superseded when final boards become available.

To do list:

- Source code for VS1000 control software made available in a format that can directly be fed to VLSI Solution's Windows compilation tools.
- Update the Recorder to include a direct "Record" button (by mechanism of pushing Vol+ and Vol- simultaneously).
- Save user parameters like volume and EarSpeaker settings when powering off so that they will automatically be restored on power-on.
- Add optional, automatic Replay Gain -like functionality to VS1053 so that all songs would play back at roughly equal volume.

8 Contact Information

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For technical questions or suggestions regarding this application, please contact support@vlsi.fi.