

VS1053B OGG VORBIS ENCODER

VSMPEG “VLSI Solution Audio Decoder”

Project Code:
Project Name: VSMPEG

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| 1.00 | 2007-12-03 | HH | Initial version. |

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1 Introduction

The VS1053b allows the user to encode files into the highly efficient Ogg Vorbis format. This makes it possible for the user to build a device that can record high-quality stereo sound while retaining moderate file sizes.

This document is an instruction manual on how to use the VS1053b Ogg Vorbis encoder application as well as an introduction to the Ogg Vorbis format itself. Example code in C is also provided.

Chapter 2 describes how to load and run different Ogg Vorbis profiles on a VS1053b. It also discusses recording levels and recording level meters.

Chapter 3 briefly introduces the Ogg Vorbis format. It also has some suggestions on how to encode data to Ogg Vorbis format as efficiently as possible on a PC. If you are unfamiliar with the Ogg Vorbis format, please read this chapter first.

Chapter 4 tells how to load a plugin code to a VS10XX chip.

Chapter 5 describes how a streaming VS1053b system can be built.

The document version history for the latest releases is provided in Chapter 6.

Finally, Chapter 7 contains VLSI Solution's contact information.

2 Using the Ogg Vorbis Encoder

The VS1053b Ogg Vorbis Encoder application is provided as a plugin in the same package as this document, downloadable at <http://www.vlsi.fi/en/support/software/vs10xxapplications.html>.

Before loading the application into your VS1053b, select one of the profiles shown below.

2.1 Limitations and Requirements

- Maximum SPI (SCI) clock speed is 3.5 Mbit/s. If a higher speed is used, there may be occasional data read errors.

2.2 Ogg Vorbis Encoder Profiles

There are 45 different Ogg Vorbis profiles available. They are divided into five groups, depending on their samplerate and number of channels.

2.2.1 Profile Groups

The five profile groups are presented below. As a comparison, bitrate figures for uncompressed 16-bit PCM (WAV) files with similar specifications are also shown.

| Ogg Vorbis Profiles | | | | | | | |
|-----------------------|------------------------|----------|----|--------------------------|-------------------------|-----------|-------------------------|
| Profile name | File name ¹ | SRate Hz | Ch | BRat ² kbit/s | WAV ³ kbit/s | Time h/GB | Vox+ Pause ⁴ |
| Voice | venc08k1qXX.plg | 8000 | 1 | 15 | 128 | 149 | Y |
| Wideband Voice | venc16k1qXX.plg | 16000 | 1 | 28 | 256 | 79 | Y |
| Wideband Stereo Voice | venc16k2qXX.plg | 16000 | 2 | 49 | 512 | 45 | N |
| HiFi Voice | venc44k1qXX.plg | 44100 | 1 | 87 | 706 | 26 | Y |
| Stereo Music | venc44k2qXX.plg | 44100 | 2 | 135 | 1411 | 16 | N |

¹ Replace XX with a quality value between 00 and 10. See Chapter 2.2.2 for details.

² Estimate for quality value 05. Actual bitrate depends on content being recorded.

³ Comparison bitrate for a 16-bit WAV file with the same specifications.

⁴ For details on Vox and Pause operation, see Chapter 2.5.

2.2.2 Profile Quality Settings

Each of the low-sample-rate profile groups has eleven quality profiles, numbered from 00 to 10. The high-sample-rate profile groups have six quality profiles from 00 to 05. This chapter presents the five profile groups and gives estimates of typical bitrates that can be obtained with the profile.

In general, quality setting 05 is designed to be a typical value that gives good quality for the application. Qualities 00 and 01 are for emergency use only when there just isn't storage space for better quality settings. High qualities, starting from 07 or 08, are intended for transparent sound quality, the intent being that compression cannot be heard anymore even under stringent circumstances.

The "Voice" Profiles

The "Voice" profiles are intended for speech applications.

These profiles support Vox and Pause.

| Voice | | | | | | | | | | | |
|-----------------------|----|----|----|----|----|-----------|----|----|----|----|----|
| Profile number | 00 | 01 | 02 | 03 | 04 | 05 | 06 | 07 | 08 | 09 | 10 |
| Typical kbit/s | 6 | 8 | 10 | 11 | 13 | 15 | 20 | 24 | 27 | 30 | 33 |

The "Wideband Voice" Profiles

"Wideband Voice" is intended to be used when high speech quality is required.

These profiles support Vox and Pause.

| Wideband Voice | | | | | | | | | | | |
|-----------------------|----|----|----|----|----|-----------|----|----|----|----|----|
| Profile number | 00 | 01 | 02 | 03 | 04 | 05 | 06 | 07 | 08 | 09 | 10 |
| Typical kbit/s | 6 | 10 | 14 | 18 | 23 | 28 | 37 | 45 | 52 | 58 | 63 |

The "Wideband Stereo Voice" Profiles

"Wideband Stereo Voice" is intended to be used when high speech quality with directional information is required.

These profiles don't support Vox and Pause.

| Wideband Stereo Voice | | | | | | | | | | | |
|-----------------------|----|----|----|----|----|-----------|----|----|-----|-----|-----|
| Profile number | 00 | 01 | 02 | 03 | 04 | 05 | 06 | 07 | 08 | 09 | 10 |
| Typical kbit/s | 9 | 17 | 25 | 44 | 41 | 49 | 66 | 84 | 101 | 119 | 136 |

The “HiFi Voice” Profiles

When extremely high quality speech is required, use the “HiFi Voice” profiles.

These profiles support Vox and Pause. However, Vox works best with the “Voice” and “Wideband Voice” profiles.

| HiFi Voice | | | | | | |
|-----------------------|----|----|----|----|----|-----------|
| Profile number | 00 | 01 | 02 | 03 | 04 | 05 |
| Typical kbit/s | 36 | 49 | 59 | 71 | 79 | 87 |

The “Music” Profiles

The “Music” profiles are intended for HiFi music, and are capable of offering very high-quality stereo sound.

These profiles don't support Vox and Pause.

| Music | | | | | | |
|-----------------------|----|----|----|----|-----|------------|
| Profile number | 00 | 01 | 02 | 03 | 04 | 05 |
| Typical kbit/s | 44 | 63 | 80 | 99 | 117 | 135 |

2.3 Running the VS1053b Ogg Vorbis Encoder

This chapter will describe how to load and run the Ogg Vorbis Encoder. A C language source file `vs1053oggrec.c` has been included in this package as an example.

2.3.1 VS1053b Ogg Vorbis Encoder Registers

| Register | Bits | Description |
|-------------|------|---|
| SCI_MODE | 14 | Select MIC/LINE1 |
| | 12 | Set to 1 when told in the instructions |
| | 1 | VU meter stereo mode activation |
| SCI_AICTRL0 | 15:0 | Maximum signal level, set to 0x8000 (mono) or 0x8080 (stereo) |
| SCI_AICTRL1 | 15:0 | Recording gain (1024 = 1×) or 0 for automatic gain control |
| SCI_AICTRL2 | 15:0 | Maximum autogain amplification (1024 = 1×, 65535 = 64×) |
| SCI_AICTRL3 | 0 | W: Finish recording, set to 0 |
| | 1 | R: Recording finished, set to 0 |
| | 2 | R: There is at least one byte to read, set to 0 |
| | 3 | W: Input channel select (only mono profiles), 0 = left, 1 = right |
| | 7:4 | W: Max samples in frame = $n \times 4096$, 0 = no limit |
| | 15:8 | R: The next data byte if available, set to 0 |

Before activating Ogg Vorbis recording, the user **must** initialize registers SCI_AICTRL0 - SCI_AICTRL3. SCI_AICTRL1 and SCI_AICTRL2 can be altered during recording.

SCI_AICTRL0 records the maximum absolute value of the signal. The maximum value of this linear register is 0x7FFF in mono mode, or 0x7F7F in stereo mode. For more information on how to use this register, see Chapter 2.4.1. SCI_AICTRL0 is updated once for every Vorbis block, i.e. 10...170 times per second with the current profiles.

SCI_AICTRL1 controls linear recording gain. 1024 is equal to digital gain 1 (recommended for best quality), 2048 is equal to digital gain 2, and so on. If the user wants to use automatic gain control (AGC), SCI_AICTRL1 should be set to 0. Speech applications are often better off using some AGC, as this helps to get relatively uniform speech loudness in recordings.

SCI_AICTRL2 controls the maximum AGC gain if SCI_AICTRL1 is set to 0. This limits amplification of noise when there is no signal. For more information on recording levels, see Chapter 2.4.

SCI_AICTRL3 offers run-time controls, channel selection for mono input, the maximum number of samples that are allowed in one Ogg frame with 4096 sample granularity, and the next unread byte, if any. Normally 0 (no limit) is a good value for granularity, but streaming applications often have maximum delay considerations, thus making limiting necessary. Note that limiting frame size isn't entirely accurate, so always select a maximum frame size slightly lower than your absolute upper delay limit.

Example: your samplerate is 44100 Hz and you want frame output at least every 500 ms. Then you'll need samples at 22100 sample intervals. Round this downwards to the closest 4096 multiple, and you'll get 16384 samples, so you'll write 0x40 to SCI_AICTRL3. The bitrate penalty of this example is ≈ 0.5 kbit/s.

For this to work your reads must be byte aligned as explained in Chapter 2.3.3.

For Vox operation controls, see Chapter 2.5.

2.3.2 Loading and Starting the Code

To load and start the VS1053b Ogg Vorbis Encoder, do the following steps:

1. Set the VS1053b clock to the highest value just below 55.3 MHz. Example: if the external clock is 12.288 MHz, this can be done by setting the clock to 4.5X, or 55.296 MHz by writing 0xC000 to register SCI_CLOCKF (3). If you use another input clock, adjust SCI_CLOCKF accordingly.
Examples: Value for 12 MHz is 0xC3e8, 12.288 MHz is 0xC000, 13 MHz is 0xA4E2.
2. Set SCI_BASS (2) to 0.
3. Reset VS1053b by setting bit SM_RESET (2) to 1 in register SCI_MODE (0). At the same time, clear bit SM_ADPCM (12) to 0. Remember that resetting takes time, so don't do any further register writes before the DREQ pin has risen!
4. Disable all interrupts except the SCI interrupt by writing 0x2 to VS1053's internal register VS1053_INT_ENABLE. This is done by first writing 0xC01A to SCI_WRAMADDR (7), then 0x2 to SCI_WRAM (6).
5. Load the plugin profile you intend to run (Chapter 4). Note that you will have to redo this each time you want to activate recording.
6. Set bit SM_ADPCM (12) in register SCI_MODE (0) to 1. At the same time, you can also select LINE input instead of MIC input by setting bit SM_LINE1 (14) to 1. If you want to use the VU meter in stereo mode, set also bit SM_LAYER12 (1) to 1. Do *not* set SM_RESET (2) at the same time!
7. Set recording level control registers SCI_AICTRL1 (13) and SCI_AICTRL2 (14). Typical good values for conservative AGC are 0 and 4096, respectively. For a HiFi application, recommended values are 1024 and 0, respectively.
8. If you want to use a VU meter, write 0x8000 to SCI_AICTRL0 (12) if using a mono profile or 0x8080 is using a stereo profile.
9. Set a proper value (often 0) to SCI_AICTRL3 (15).
10. If you use a profile that support Vox, set Vox registers. For details, see Chapter 2.5.
11. Activate the encoder by writing 0x34 to register SCI_AIADDR (10).
12. Wait until DREQ pin is high before reading any data.

2.3.3 Reading Ogg Vorbis Data

After Ogg Vorbis recording has been activated, registers SCI_HDAT0 and SCI_HDAT1 have new functions.

The Ogg Vorbis bitstream buffer size is 4096 16-bit words, or 8 KiB. The fill status of the buffer can be read from SCI_HDAT1. If SCI_HDAT1 is greater than 0, you can read that many 16-bit words from SCI_HDAT0.

If data is not read fast enough from SCI_HDAT0, the buffer overflows and returns to empty state. A data overflow will result in an incorrect file that may be undecodable. However, because of the large size of the bitstream buffer and the relatively slow bitrates of Ogg Vorbis, this situation should be easy to avoid.

Ogg frames are byte aligned. Because of the 16-bit SCI interface this may be a problem for streaming applications where it is important to forward any Ogg frame as soon as possible: the latest frame may pend upon its last byte. If transferring data with a low delay is important, you can read whether there is one extra data byte by reading SCI_AICTRL3 *twice in a row*. The result of the latter read will contain the correct data: if bit 2 is 1, then bits 15:8 contain the odd byte. After reading the odd byte successfully, discard bits 15:8 of the next read from SCI_HDAT0 because they contain the same data. (NOTE: if you don't stream or don't need the shortest possible delay, you can ignore this paragraph!)

If you are having trouble with receiving data, notice that all Ogg Vorbis files always begin with the following 4 bytes: 0x4f 0x67 0x67 0x53 (the string "OggS"). If you get 0x67 0x4f 0x53 0x67 ("gOSg") instead, you are storing the least and most significant byte in the 16-bit data words incorrectly. If you get 0x00 0x00 0x67 0x53, you have read data from SCI_HDAT0 too soon after starting the application.

2.3.4 Reading Additional Data while Recording Ogg Vorbis

You can get extra side information while recording Ogg Vorbis data to see whether VS1053b is still working. The following VS1053b X memory addresses may be read for extra data:

| X Memory Address | Description |
|------------------|--------------------------------------|
| 0x8 | 16 LSb's of recording time (seconds) |
| 0x9 | 16 MSb's of recording time (seconds) |
| 0xC | 16 LSb's of average bitrate (bits/s) |
| 0xD | 16 MSb's of average bitrate (bits/s) |
| 0x1800 | 16 LSb's of sample counter |
| 0x1801 | 16 MSb's of sample counter |

Example: To read the average bitrate, do as follows. First write 0xC to SCI_WRAMADDR (7). Then read from SCI_WRAM (6). This is 16 least significant bits of the bitrate. Then read the 16 more significant bits by reading SCI_WRAM again.

You can read the recording time as a sanity check that VS1053b is working: if the register contents don't change every second, you'll have to take protective measures.

2.3.5 Finishing Ogg Vorbis Recording

To create fully compliant Ogg Vorbis files, Ogg Vorbis bitstreams need to be shut down properly. The following algorithm can be used to implement this:

1. Set bit 0 of SCI_AICTRL3 (15) to 1.
2. Continue reading data through SCI_HDAT0 and SCI_HDAT1 as usual, but check SCI_AICTRL3's bit 1 from time to time. When this bit turns to 1, the Ogg Vorbis encoder has finished writing to the buffer.
3. Write the remaining words from the bitstream buffer as normal using SCI_HDAT0 and SCI_HDAT1.
4. Read SCI_AICTRL3 *twice* (changed from version 1.4!) and check whether bit 2 is 1 in the latter read. If it is, then don't write to the file the last byte (bits 7:0) of the last word that have come through SCI_HDAT0.
5. Reset VS1053b to normal state using software reset. Remember to clear register SCI_MODE (0) bit SM_ADPCM (12) if you don't wish to start ADPCM recording. Remember to also set bit SM_LAYER12 (1) to an appropriate value.
6. If you want to restart recording, you have to completely reload and restart the recording application.

2.4 Recording Levels and Automatic Gain Control (AGC)

The VS1053b Ogg Vorbis Encoder offers signal level monitoring through SCI_AICTRL0. It is recommended that devices that offer recording would show a signal level in a decibel scale. For the decibel scale, see Chapter 2.4.4. This can be done by showing and clearing SCI_AICTRL0 contents at regular intervals.

A good VU meter should be implemented in such a way that it visually advises the user to avoid using the last 6 dB of the available dynamic range.

2.4.1 Reading the Recording Level

The recording level meter has two settings: mono and stereo. You can use mono mode with both mono and stereo streams, but you should use the stereo mode only with stereo profiles. The new meter is compatible with versions pre 1.60 if SCI_MODE bit SM_LAYER12 is cleared first.

Recording Level Meter: Mono Mode

Activate mono mode by clearing SCI_MODE (0) register bit SM_LAYER12 (1) to 0.

To read the level, repeat the following loop:

- Write 0x8000 to SCI_AICTRL0.
- Wait for at least 1/50 s. Note: Constant reading of side information causes load on the VS1053 and may cause unexpected crackles in sound.
- Check whether SCI_AICTRL0 & 0x8000 is 0. If not, wait a little more and read again.
- Use the value as explained in this Chapter. Repeat the loop.

Recording Level Meter: Stereo Mode

Activate stereo mode by setting SCI_MODE (0) register bit SM_LAYER12 (1) to 1.

To read the left and right channel levels, repeat the following loop:

- Write 0x8080 to SCI_AICTRL0.
- Wait for at least 1/50 s. Note: Constant reading of side information causes load on the VS1053 and may cause unexpected crackles in sound.
- Check whether SCI_AICTRL0 & 0x8080 is 0. If not, wait a little more and read again.
- Left channel value is SCI_AICTRL0 & 0x7F00.
- Right channel value is (SCI_AICTRL0 & 0x7F) × 256.
- Use the values as explained in this Chapter. Repeat the loop.

2.4.2 Setting AGC

When the highest dynamic range and sound fidelity is required, AGC should be turned off and recording gain should be set to 1 (SCI_AICTRL1 = 1024). A good example of this would be music recording. This is particularly recommended for the “HiFi Voice” and “Music” profiles, although there might be cases where recording level control would be needed even with these cases.

However, in some cases it is required that the audio dynamic range is compressed. An example of such a case is when a device should retain a uniform recording level of a discussion of several people or of one person moving closer and further from the recording device. In such a case, it is a good idea to use AGC.

The AGC unit adjusts signal power in such a way that the maximum sample value from a sine wave would become as close to 16300 as possible. If the signal is too strong, recording level is decreased, and vice versa. The maximum recording level can be set with register SCI_AICTRL2.

When AGC is used, conservative maximum gain values often give the best sounding results. Example: 12 dB (SCI_AICTRL1 = 0, SCI_AICTRL2 = 4096). In some cases more extreme values may help to make quiet speech more intelligible, but such values may also add excessive background noise and make sound quality less pleasing.

2.4.3 Building a Useful VU Meter

In an encoder application, if the recording level is too low, extraneous background noise may be introduced to the sound. Conversely, if the recording level is so high that the highest values cannot be represented numerically, signal clipping occurs, and this may cause severe distortion to sound.

In a recording device, it is useful to have a VU meter that shows the signal level so that both too low signal levels and clipping is avoided. This is very important so that the user has a chance to either adjust the recording or input signal level.

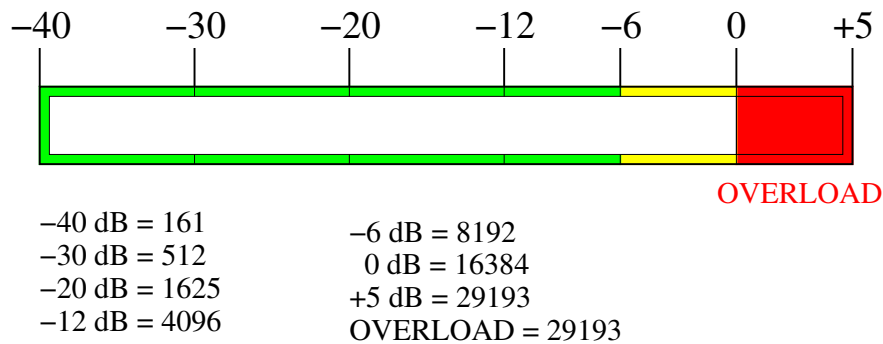


Figure 1: Example colour VU meter.

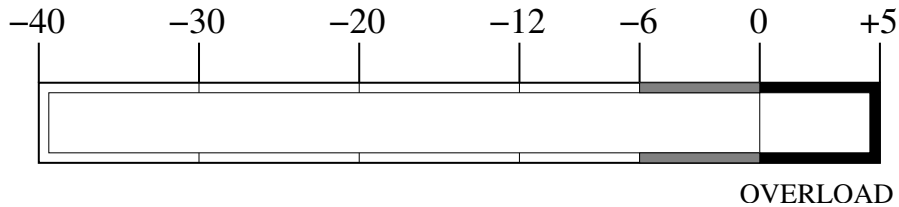


Figure 2: Example monochrome VU meter.

Figures 1 and 2 show example VU meters. The 0 dB reference point has been set to signal level 16384, which is one half of the maximum amplitude, leaving a 6 dB headroom for the device.

The lowest signal level shown is a choice that can vary a lot depending on the application. While -40 dB is a high-fidelity favourite, a VU meter will work just as well with a lower limit of -20 dB. If display space is scarce, low limit could even be set to -12 dB.

Between -6 and +6 dB the VU meter precision should preferably be 1 dB, and at most 2 dB. Below -12 dB step size can be several decibels.

The important thing in a VU meter is to visually show the user that it is not recommended to regularly use the highest 6 dB of the recording scale, and that an overload situation ($\geq +5$ dB, or over linear value 29193) is an error condition. To help this the OVERLOAD symbol should be kept lit or blinking for at least 2 seconds each time an overload situation occurs. Many of these cues are often ignored in digital VU meters, and partly as a result of this even professional recordings are all too often made at recording levels that destroy signal integrity.



Figure 3: Real record display with monochrome VU meter.

Figure 3 shows a real implementation of a recording display that uses a Monochrome VU Meter. Information shown on the top line includes recording time, free disc space, overload warning and a bitrate counter. All this data except from the free disc space number have been obtained from the VS1053b Ogg Vorbis Encoder.

Recording gain and AGC can be set at the center of the screen if a profile is used that support these functions. However, they are greyed out in this picture because they are not available in the Stereo Music profile that has been used.

The VU Meter is at the bottom. The solid line is the current recording level as read from SCI_AICTRL0 and converted to Decibel scale as shown in Chapter 2.4.4. The greyed line is the top level of the last 3 seconds. If the greyed line $\geq +5$ dB, the orange OVERLOAD message blinks twice a second for three seconds.

2.4.4 Converting from Linear to Decibel Scale

To convert from linear to dB scale, use the formula

$$dB = 20 \times \log_{10}\left(\frac{m}{32768}\right) + 96$$

where dB is the result and m is a value returned by the Recording Level Meter.

To implement a good approximation of this formula from linear to dB scale on architectures where multiplications and logarithms are expensive operations, the following code can be used:

```
const unsigned short linToDBTab[5] = {36781, 41285, 46341, 52016, 58386};

/*
  Converts a linear 16-bit value between 0..65535 to decibels.
  Reference level: 32768 = 96dB (largest VS1053b number is 32767 = 95dB).
  Bugs:
  - For the input of 0, 0 dB is returned, because minus infinity cannot
    be represented with integers.
  - Assumes a ratio of 2 is 6 dB, when it actually is approx. 6.02 dB.
*/
unsigned short LinToDB(unsigned short n) {
    int res = 96, i;

    if (!n)                /* No signal should return minus infinity */
        return 0;

    while (n < 32768U) { /* Amplify weak signals */
        res -= 6;
        n <<= 1;
    }

    for (i=0; i<5; i++) /* Find exact scale */
        if (n >= linToDBTab[i])
            res++;

    return res;
}
```


2.4.5 vs1053oggrec.c

The file `vs1053oggrec.c`, quoted below, has also been included in the VS1053b Ogg Vorbis Encoder package.

```
/*
```

```
Example code how to implement VS1053 Ogg Vorbis recording using  
the VS1053 Ogg Vorbis Recording plugin. The code is generic enough  
so that it should pretty much compile and run on any microcontroller.
```

```
The code makes the following assumptions:
```

- `<stdio.h>` functions `fopen()`, `fclose()`, `fgetc()` and `fputc()` are available
- The following VS1053 interfacing functions must exist:
 - `void Write1053Sci(int regNo, u_int16 value)`: writes value to SCI register
 - `u_int16 Read1053Sci(int regNo)`: reads value from SCI register
 - `WaitFor1053Dreq(int timeOut)`: Waits for 1 microsecond, then until DREQ goes up or timeOut is reached (timeOut=1 is 10 ms).
- `EndRecording()` function must exist, which returns non-zero when the user has requested that recording should be finished.

```
NOTE!
```

```
This code serves as an example of how to create generic C microcontroller  
code for VS1053 recording.
```

```
Author: Henrik Herranen / VLSI Solution 2011.
```

```
Copyright: Use freely for any project with any VLSI Solution's IC.
```

```
Warranty: Absolutely none whatsoever.
```

```
*/
```

```
#include <stdio.h>  
#include <stdlib.h>  
#include <string.h>
```

```
/* Change these if they don't match you architecture. */
```

```
typedef unsigned short u_int16;  
typedef short          s_int16;  
typedef unsigned long  u_int32;  
typedef long           s_int32;
```

```
#define SCIR_MODE          0  
#define SCIR_STATUS       1  
#define SCIR_BASS         2  
#define SCIR_CLOCKF       3  
#define SCIR_DECODE_TIME  4  
#define SCIR_AUDATA       5  
#define SCIR_WRAM         6  
#define SCIR_WRAMADDR     7  
#define SCIR_HDAT0        8  
#define SCIR_HDAT1        9  
#define SCIR_AIADDR      10  
#define SCIR_VOL          11  
#define SCIR_AICTRL0     12
```

```
#define SCIR_AICTRL1    13
#define SCIR_AICTRL2    14
#define SCIR_AICTRL3    15

/* returns minimum of two given numbers */
#define min(a,b) (((a)<(b))?a):(b))

/* Loads an image file into VS1053 from a file. */
auto u_int16 SpiLoadImageInto1053(FILE *fp);

/* Main recording program */
void main(void) {
    FILE *outFP, *inFP;
    u_int16 pluginStartAddr;
    u_int16 state = 0;
    u_int16 i;
    u_int16 wordsToRead;
    u_int16 wordsWaiting;

    /* Perform Microcontroller specific initializations here. */

    /* Following VS1053 operations are according to the
       VS1053b Ogg Vorbis Encoder application manual. For
       details read Chapter Loading and Starting the Code. */

    /* Set VS1053 clock to 4.5x = 55.3 MHz */
    Write1053Sci(SCIR_CLOCKF, 0xC000);
    WaitFor1053Dreq(TIMER_TICKS/10);

    /* Clear SCI_BASS */
    Write1053Sci(SCIR_BASS, 0);

    /* Reset VS1053 */
    Write1053Sci(SCIR_MODE, SMF_SDINew | SMF_RESET);
    WaitFor1053Dreq(TIMER_TICKS/10);    /* Wait until DREQ is high or 100 ms */

    // Disable all interrupts except SCI
    Write1053Sci(SCIR_WRAMADDR, VS1053_INT_ENABLE);
    Write1053Sci(SCIR_WRAM, 0x2);

    /* Load the recorder application to VS1053
       This source code uses .img image files for loading.
       If you use .plg files, use the source as described
       in the VS1053b Ogg Vorbis Encoder application manual. */
    inFP = fopen("venc44k2q05.img", "rb");
    if (!inFP)
        goto end;
    pluginStartAddr = SpiLoadImageInto1053(inFP);
    fclose(inFP);
}
```

```
/* If loading failed, give up. */
if (pluginStartAddr == 0xFFFF)
    goto end;

/* Now open output file. It's better to do this before activating
   recording so that even if opening the output file is slow,
   you will not lose audio data. */
outFP = fopen("record.ogg", "wb");
if (!outFP)
    goto end;

/* Set VS1053 mode bits as instructed in the VS1053b Ogg Vorbis Encoder
   manual. Note: for microphone input, leave SMF_LINE1 unset! */
Write1053Sci(SCIR_MODE, SMF_LINE1 | SMF_ADPCM | SMF_SDINew);

/* Rec level: 1024 = 1. If 0, use AGC */
Write1053Sci(SCIR_AICtrl1, 1024);
/* Maximum AGC level: 1024 = 1. Only used if SCI_AICtrl1 is set to 0. */
Write1053Sci(SCIR_AICtrl2, 0);
/* Miscellaneous bits that also must be set before recording. */
Write1053Sci(SCIR_AICtrl3, 0);

/* Activate recording from the address we got. (In the case of the Ogg
   Vorbis Encoder application, pluginStartAddr = 0x34.) */
Write1053Sci(SCIR_AIADDR, pluginStartAddr);
WaitFor1053Dreq(TIMER_TICKS/10);

/*
   By now we have:
   - Initialized the VS1053
   - Loaded the VS1053 recording plugin
   - Opened the output file
   - Activated the VS1053 recording plugin

   So, now it's time to record. Below is the recording loop.

   The variable "state" controls the progression of recording as follows:
   state = 0: Normal recording.
   state = 1: User has requested end of recording, microcontroller has
       also requested this from the VS1053 recording plugin.
   state = 2: The VS1053 plugin has stopped recording, but the
       microcontroller is still collecting data from the VS1053 buffers.
   state = 3: Recording finished.
*/

/* Main loop */
while (state < 3) {

    /* Check when to end recording. The function EndRecording() is
       microcontroller specific and should be implementing separately
       for each application. */
```

```

if (EndRecording() && !state) {
    state = 1;
    Write1053Sci(SCIR_AICTRL3, 1); // Send VS1053 request to stop recording
}

/* See how many 16-bit words there are waiting in the VS1053 buffer */
wordsWaiting = Read1053Sci(SCIR_HDAT1);

/* If user has requested stopping recording, and VS1053 has
stopped recording, proceed to the next state. */
if (state == 1 && Read1053Sci(SCIR_AICTRL3) & (1<<1)) {
    state = 2;
    /* It is important to reread the HDAT1 register once after
VS1053 has stopped. Otherwise there is the chance that
a few more words have just arrived although we just
read this register. So, do NOT optimize the following
line away! */
    wordsWaiting = Read1053Sci(SCIR_HDAT1);
}

/* Read and transfer whole 512-byte (256-word) disc blocks at
the time. The only exception is when recording ends: then
allow for a non-full block. */
while (wordsWaiting >= ((state < 2) ? 256 : 1)) {
    wordsToRead = min(wordsWaiting, 256);
    wordsWaiting -= wordsToRead;

    /* If this is the very last block, read one 16-bit word less,
because it will be handled later separately. */
    if (state == 2 && !wordsWaiting)
        wordsToRead--;

    /* Transfer one full data block, or if this is the very last
block, all data that's left except for the last word. */
    {
        u_int16 t;
        u_int16 i;
        for (i=0; i<wordsToRead; i++) {
            t = Read1053Sci(SCIR_HDAT0);
            fputc(t >> 8 , outFP);
            fputc(t & 0xFF, outFP);
        }
    }

    /* If this is the last data block... */
    if (wordsToRead < 256) {
        u_int16 lastWord;
        state = 3;

        /* ... read the very last word of the file */
        lastWord = Read1053Sci(SCIR_HDAT0);

        /* Always write first half of the last word. */
        fputc(lastWord >> 8 , outFP);
    }
}

```

```
        /* Read twice SCIR_AICTRL3, then check bit 2 of latter read. */
        Read1053Sci(SCIR_AICTRL3);
        if (!(Read1053Sci(SCIR_AICTRL3) & (1<<2))) {
            /* Write last half of the last word only if bit 2 is clear. */
            fputc(lastWord & 0xFF, outFP);
        }
    } /* if (wordsToRead < 256) */
} /* while (wordsWaiting >= ((state < 2) ? 256 : 1)) */

} /* while (state < 3), end of main loop */

/* That's it! We've perfectly recorded an Ogg Vorbis file, so now
   we only need to close the file and be happy about it. */
fclose(outFP);

end:
/* Finally, reset VS1053 so that we will hear no more monitor audio */
Write1053Sci(SCIR_MODE, SMF_SDINEW | SMF_RESET);

/* End up in infinite loop */
while (1)
    ;
}
```

2.5 Vox and Pause Operation

Vox / Pause allows the user to temporarily pause recording either based on audio content or direct user control. (For Ogg Vorbis Encoder Profiles that support Vox / Pause operation, see Chapter 2.2.1.)

Vox control allows the unit to record only when someone is actually speaking. An audio buffer makes it so that recording resumes slightly “before” the moment when speech is detected, so in typical cases no syllables are lost at the beginning of a sentence.

Pause override allows the user to set and clear pause mode at will. This allows the user to create a system where pause mode may be activated with a pause switch, like in a traditional tape recorder.

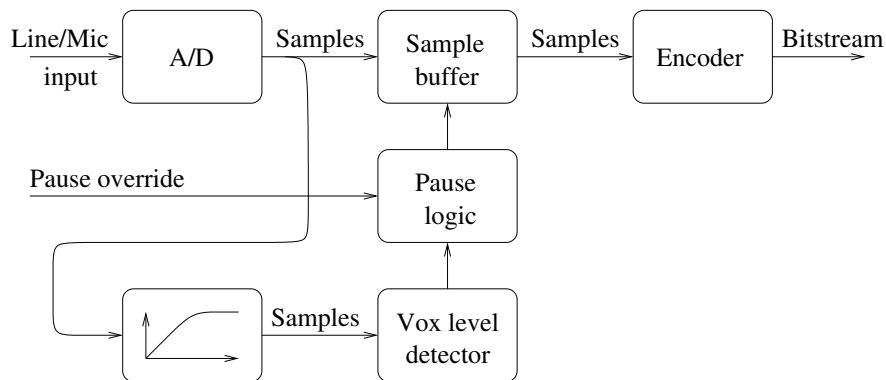


Figure 4: Vox / Pause logic.

Figure 4 presents the pause logic. Input samples are fed to the Vox detector through a high-pass filter. If pause hasn’t been overridden by the user, the Vox detector level is used to control pause mode.

Note: It is not recommended to use Vox with a streaming system. When pause is activated either by the user or by Vox, the sample counter (Chapter 5.1) stops and no Ogg frames, not even empty ones, are output by the Encoder.

2.5.1 Vox and Pause Registers

| X Mem Addr | Name | Default | Description |
|------------|------------|---------|--|
| 0x1808 | OffLimit | 0x18 | Signal limit for Vox pause |
| 0x1809 | OnLimit | 0x20 | Signal limit for Vox record |
| 0x180A | OffTimeLSW | 0x7700 | 16 LSB's of pause delay time in 1/48000 s |
| 0x180B | OffTimeMSW | 0x1 | 16 MSb's of pause delay time in 1/48000 s |
| 0x180F | PauseCtl | 0x2 | Vox control / Pause override 0 = Automatic Vox operation 1 = forbidden 2 = Pause override: Normal recording 3 = Pause override: Pause on |

If the signal after the high-pass filter is below OffLimit for more than OffTime 48 kHz samples, and if PauseCtl = 0, or if PauseCtl = 3, then pause mode is activated. Default value of OffTime = 0x17700 = 96000 equals two seconds. Note that OffTime is always calculated in the 48 kHz domain regardless of the samplerate of the Ogg Vorbis Encoder Profile.

If even a single sample goes above OnLimit, and if PauseCtl = 0, or if PauseCtl = 2, then pause mode is deactivated and normal recording continues.

OffLimit and OnLimit are linear values. Thus, doubling the value lifts the limit by 6 dB. Having two separate values for the limits allow for hysteresis between stopping and restarting recording. OnLimit must always be greater than or equal to OffLimit.

Example: To set OffTime, do as follows. First write 0x180A to SCI_WRAMADDR (7). Then write 16 least significant bits of OffTime (e.g. 0x7700) to SCI_WRAM (6). Then write the 16 most significant bits by writing (e.g. 0x1) to SCI_WRAM (6) again.

Vox and Pause registers may be written to while the Ogg Vorbis Encoder is active.

2.5.2 Vox Output to GPIO4

It is optionally possible for the user to optionally see the current status of Vox in GPIO4. To activate this option, do the following steps before activating the Ogg Vorbis Encoder:

- Write 0xC017 to SCI_WRAMADDR (7).
- Read value x from SCI_WRAM (6).
- Set $x = x|16$;
- Write 0xC017 to SCI_WRAMADDR (7).
- Write new value x to SCI_WRAM (6).

After this operation, whenever GPIO4 is low, normal recording is done. When GPIO4 is high, then pause mode (either by Vox or user control) is active. So, whenever GPIO4 goes high, the main controller may read all data that is left in the buffer, and set itself to sleep for as long until GPIO4 goes low again.

2.6 Samplerate Considerations

The Ogg Vorbis encoder cannot always work at exactly the right samplerate. To be exact, the samplerate is accurate only when the input clock is 12.288 MHz and the nominal samplerate of a profile is either 8000 Hz or 16000 Hz. In all other cases the samplerate can be calculated as follows. First let:

- f_i = input clock divided by 4000 (same value that you write to SC_FREQ (bits 10:0) of register SCI_CLOCKF, or 3072 if you have written 0 to these bits to indicate 12.288 MHz clock).
- f_n = nominal samplerate of the profile (8000, 16000 or 44100).
- $r = 3$ if $f_n = 8000$, otherwise $r = 2$.
- Now let $u = f_n \times r$.
- Let $d = \lfloor \frac{f_i \times 2000 + \frac{u}{2}}{u} \rfloor$
- Now our real samplerate $f_s = \frac{2000 \times f_i}{d \times r}$

Example: We are running at an input clock of 12.288 MHz and we are running the Stereo Music profile that has a nominal samplerate of 44100 Hz.

First $f_i = \frac{12288000}{4000} = 3072$.

Because $f_n = 44100$, then $r = 2$.

Thus $u = 44100 \times 2 = 88200$.

This leads to $d = \lfloor \frac{3072 \times 2000 + \frac{88200}{2}}{88200} \rfloor = 70$

And, finally, our real samplerate $f_s = \frac{2000 \times 3072}{70 \times 2} \approx 43885.7$ (Hz)

As can be seen, in this example the nominal and real samplerate have a difference of 0.5%. While this is normally not significant, it is good to know and important in the case of streaming.

2.7 Post-Processing the Recording with VorbisGain

It is recommended to post-process your own recording later on a PC machine using VorbisGain to get equal loudness with other recordings. For details, see Chapter 3.3.

3 The Ogg Vorbis Format

This chapter gives a brief introduction to the Ogg Vorbis format and presents recommendations for basic parameters when transcoding MP3 files or compressing CD content into Ogg Vorbis files on a PC. The intent is to give VLSI Solution's customers information on how to create high-quality Ogg Vorbis content.

Before using the information in this document, you should get the free Ogg Vorbis encoder "oggenc", minimum version 1.0.2 (2005), or a version with aoTuV tunings. While the instructions will work with older versions, sound quality will not be as good. Download oggenc at <http://www.vorbis.com/>.

It is also strongly encouraged to get VorbisGain, a program that tags files with loudness information (Chapter 3.3). For this example, vorbisgain v0.36 has been used. Download VorbisGain at <http://www.sjeng.org/vorbisgain.html>.

3.1 Introduction to Ogg Vorbis

Ogg Vorbis is a license-free audio codec that allows for high-quality sound around a large gamut of bit-rates, ranging from roughly 10 to 500 kbit/s.

With a given bit-rate, Vorbis is capable of surpassing the quality of MP2, MP3, WMA and AAC LC, particularly in low-bit-rate applications.

An Ogg Vorbis file is a Vorbis compressed file that has been encapsulated inside an Ogg stream. The default file extension for Ogg Vorbis files is ".ogg".

An Ogg Vorbis file consists of two major parts: header and actual data. Every Ogg Vorbis file begins with a header which contains compression tables that the decoder needs to correctly decode first. After the header has been fully received, Vorbis audio may be decoded. The size of the header information is around 4 KiB for most encoders. (However, for VLSI Solution's VS1053b encoder, header size is only roughly 1.5 KiB.)

After the header has been decoded, full random access is available in an Ogg Vorbis file. As opposed to many other formats, an Ogg Vorbis file contains its own time code, so absolute position in a file can be displayed after random access operations (fast forward / rewind).

Ogg Vorbis is not particularly well suited for encoding very short, low bit-rate samples. E.g. a 16 kbit/s audio sample that lasts for one second would take 2 KiB for the actual audio data, so the default 4 KiB header triples the file size. However, for normal applications where audio lasts for more than 10 seconds, this header overhead is negligible.

3.1.1 Variable Bit-Rate

For a long time almost all MP3 files had a constant bit-rate, typically 128 kbit/s. While constant bit-rate (CBR) makes it easy to calculate a relation between file size/position

and song length, and while it makes it easier to stream files, CBR is not optimal for quality. When there is a difficult passage in music, there may not be enough bits available to encode audio flawlessly. Conversely, in passages that are easier to encode there may be bits left unused because the encoder didn't need all the bits available in the bitstream.

Where CBR tries to keep the bit-rate constant regardless of content, Variable Bit-Rate (VBR) tries to keep quality constant. This will have the effect of changing the bit-rate of the file depending on how difficult a particular portion of music is to encode. Because sound quality is always kept constant, VBR has a bit advantage to CBR. Thus, VBR allows either for smaller files with the same perceived sound quality or equally sized files with better perceived sound quality.

Ogg Vorbis is by nature a variable bit-rate format and works best when this feature is not limited. Depending on the material the bit-rate can have significant fluctuations: e.g. songs that have been compressed with a quality setting with a nominal bit-rate of 96 kbit/s can easily have average bit-rates between 80 to 105 kbit/s, or even more with extreme material.

3.1.2 Transcoding

Transcoding is the process of converting from one lossy format to another, like from MP3 to Ogg Vorbis.

It is important to understand that although Ogg Vorbis is a better format than MP3, transcoding never enhances sound quality. What has been lost in the initial MP3 compression stage, will stay lost when converting to Ogg Vorbis, and there will always be some additional quality loss. While the extra quality loss can be small enough that it may be impossible to tell, the end result still is never better than the original file was.

If possible, it is recommended that users should avoid transcoding to avoid generation loss. If transcoding is done (e.g. to get smaller files for a portable device), it is a good idea to keep the original files.

For best results, compress Ogg Vorbis files from uncompressed sources, like CDs.

3.2 Compressing into Ogg Vorbis with a PC

The whole process of getting Ogg Vorbis files looks roughly like this:

- Preparation: Decode an MP3 / WMA / AAC etc file or preferably rip a CD to WAV format and make sure that you have “oggenc” (Chapter 3.2.1).
- Compression to Ogg Vorbis (Chapters 3.2.2 and 3.2.3).
- Optional post-processing with VorbisGain (Chapter 3.3).

3.2.1 Preparation

If you intend to transcode (=recompress) MP3 files, you first have to convert them to 16-bit RIFF WAV format (usually known for a “.wav” file name extension). However, before you do that, please have a look at Chapter 3.1.2 for details on transcoding.

If you encode CDs, you have to make sure they are read initially into WAV format. It is recommended to use CD sources for compression if possible.

When you have audio in WAV format, you can use *oggenc* to compress files, either in stereo or mono.

Before continuing to the next stage, make sure you have the free Ogg Vorbis encoder “oggenc”, minimum version 1.0.2 (2005).

3.2.2 Compressing CD-Quality Music

If we assume the input file is called file.wav and the output is to be called file.ogg, the following parameters may be used.

It is assumed that the input audio is sampled at the CD 44.1 kHz sample rate. While these commands will also work for other samplerates, quality and file sizes may differ.

For each quality setting, the table shows the command needed to convert the file, a typical bit-rate for that quality, how many hours of music could be stored to a 1 gibibyte memory card, and a short description of the mode. For comparison purposes, also an uncompressed CD bitstream is shown in the table.

| CD music compression | | | |
|-----------------------|-------------|--------------|--|
| Command | Typ. kbit/s | Hours/ 1 GiB | Description |
| oggenc -q -1 file.wav | 45 | 53 | Smallest files size, better than 96 kbit/s MP3 |
| oggenc -q 0 file.wav | 64 | 37 | Ok quality, equals 112 kbit/s MP3 |
| oggenc -q 2 file.wav | 96 | 25 | Better than most 128 kbit/s MP3 files |
| oggenc -q 4 file.wav | 128 | 19 | Often CD transparent |
| oggenc -q 6 file.wav | 192 | 12 | CD quality almost always |
| CD | 1411 | 1.7 | Uncompressed CD |

Graphical front-ends usually contain one or several CBR bit-rate slider(s) and a quality slider that usually goes from -1 to 10. CBR sliders should be deactivated, and the quality slider should be set to the “-q” value presented in the table.

3.2.3 Compressing Speech

Speech requires different coding parameters than music. First, speech can usually be coded in mono, so all the following examples convert audio to mono. Also, to get smaller files, speech bandwidth can usually be suppressed without adversely affecting intelligibility.

The following table shows the command needed to convert a speech file called file.wav, a typical bit-rate for that quality, how many hours of music could be stored to a 1 gibibyte memory card, and a short description of the mode.

| Speech compression | | | |
|--|-------------|--------------|-----------------------------------|
| Command | Typ. kbit/s | Hours/ 1 GiB | Description |
| oggenc -downmix -resample 4000 -q -1 file.wav | 6 | 400 | Very low bandwidth |
| oggenc -downmix -resample 6000 -q -1 file.wav | 8 | 300 | Near mobile phone quality |
| oggenc -downmix -resample 8000 -q -1 file.wav | 9 | 265 | Slightly better than mobile phone |
| oggenc -downmix -resample 8000 -q 0 file.wav | 13 | 184 | Clean 3 kHz bandwidth sound |
| oggenc -downmix -resample 11025 -q -1 file.wav | 14 | 170 | Toy application quality |
| oggenc -downmix -resample 11025 -q 0 file.wav | 17 | 140 | Cleaner toy application |
| oggenc -downmix -resample 11025 -q 1 file.wav | 20 | 119 | Clean sound, 5 kHz bandwidth |
| oggenc -downmix -resample 16000 -q 1 file.wav | 24 | 99 | Wideband (7 kHz) sound |
| oggenc -downmix -resample 22050 -q 1 file.wav | 30 | 80 | 10 kHz bandwidth |
| oggenc -downmix -resample 44100 -q 0 file.wav | 36 | 66 | Full bandwidth (15+ kHz) |
| oggenc -downmix -resample 44100 -q 1 file.wav | 42 | 57 | Cleaner sound |
| oggenc -downmix -resample 44100 -q 2 file.wav | 48 | 50 | Close to transparent |
| oggenc -downmix -resample 44100 -q 5 file.wav | 80 | 30 | CD quality (but mono) |

The “-downmix” option converts sound to mono and the “-q” control works as in Chapter 3.2.2. Unfortunately, many graphical front-ends are missing the “-resample” option, which is a very powerful parameter for speech compression. If your program misses this slider, you either have to fill the missing values in a command option window or compress your files from oggenc’s command line mode.

3.3 Post-Processing with VorbisGain

Although the original CD standard defines a reference loudness that should be used for CD recording, current CDs no longer follow that standard. Because of this unequal loudness of CDs, songs compressed from CDs may have wildly differing subjective loudness, a phenomenon that is known to most users of portable digital audio players.

VorbisGain is a program that uses a psycho-acoustical model to determine an actual, perceived loudness of an audio track or album, and tags this information to the headers of an Ogg Vorbis file. This makes it possible for a VorbisGain aware decoder to adjust its output volume accordingly, and thus equalize loudness differences of songs without a need to recompress them.

Using VorbisGain on all Vorbis songs will enhance the user's listening experience because there is no need to turn volume up and down between songs. Many Ogg Vorbis playback programs and plug-ins for PC's as well as all VLSI Solution's Ogg Vorbis decoder chips are compatible with VorbisGain.

4 How to Load a Plugin

4.1 How to Load a .PLG File

A plugin file (.plg) contains a data file that contains one unsigned 16-bit vector called plugin. The file is in an interleaved and RLE compressed format. An example of a plugin vector is:

```
const unsigned short plugin[10] = { /* Compressed plugin */
    0x0007, 0x0001, 0x8260,
    0x0006, 0x0002, 0x1234, 0x5678,
    0x0006, 0x8004, 0xabcd,
};
```

The vector is decoded as follows:

1. Read register address number `addr` and repeat number `n`.
2. If `n & 0x8000U`, write the next word `n` times to register `addr`.
3. Else write next `n` words to register `addr`.
4. Continue until table has been exhausted.

The example vector first tells to write 0x8260 to register 7. Then write 2 words, 0x1234 and 0x5678, to register 6. Finally, write 0xabcd 4 times to register 6.

Assuming the vector is in vector `plugin[]`, a full decoder in C language is provided below:

```
void WriteVS10xxRegister(unsigned short addr, unsigned short value);

void LoadUserCode(void) {
    int i = 0;

    while (i < sizeof(plugin)/sizeof(plugin[0])) {
        unsigned short addr, n, val;
        addr = plugin[i++];
        n = plugin[i++];
        if (n & 0x8000U) { /* RLE run, replicate n samples */
            n &= 0x7FFF;
            val = plugin[i++];
            while (n-- > 0) {
                WriteVS10xxRegister(addr, val);
            }
        } else { /* Copy run, copy n samples */
            while (n-- > 0) {
                val = plugin[i++];
                WriteVS10xxRegister(addr, val);
            }
        }
        i++;
    }
}
```

4.2 How to Load an .IMG File

The VS1053 image format is a bootable / loadable binary format with a three-byte header, followed by one or more boot records. The default image file suffix is “.IMG”.

The 3-byte header is shown below:

| VS1053 Boot Header, begins the file | | |
|-------------------------------------|-------|--------------------------|
| Name | Bytes | Description |
| HEADER | 3 | “P&H” (0x50, 0x26, 0x48) |

A boot record is shown below:

| VS1053 Boot Record, from 1 to n, last is always TYPE = Execute | | |
|--|-------|---|
| Name | Bytes | Description |
| TYPE | 1 | 0 = Instruction memory 1 = X data memory 2 = Y data memory 3 = Execute |
| L1 L0 | 2 | LEN = 256×L1 + L0 |
| A1 A0 | 2 | ADDR = 256×A1 + A0 |
| D1 D0 | LEN | DATA = 256×D1 + D0, repeat LEN/2 times |

The last boot record is always with TYPE = Execute. When an execute record is found, ADDR is the start address of the application.

The VS1053 boot sequence will skip any unknown records.

4.2.1 Example Microcontroller .IMG File Decoder

```

/* This support function that writes one word through SCI is needed. */
void WriteVS10xxRegister(unsigned short addr, unsigned short value);

#define TYPE_I 0
#define TYPE_X 1
#define TYPE_Y 2
#define TYPE_E 3

/* Returns either 0xFFFF for error or image file start address.
   For compactness does NOT check if fgetc() fails! */
auto u_int16 SpiLoadImageInto1053(FILE *fp) {
    s_int16 type;
    if (fgetc(fp) != 'P' || fgetc(fp) != '&' || fgetc(fp) != 'H')
        return 0xFFFF;

    while ((type = fgetc(fp)) >= 0 && type < 4) {
        static const u_int16 offsets[3] = {0x8000U, 0x0U, 0x4000U};
        u_int16 len, addr;

        /* Get length and address of the record */
        len = fgetc(fp) << 8; len |= fgetc(fp);
        addr = fgetc(fp) << 8; addr |= fgetc(fp);

        /* If execute record: return with start address */
        if (type == TYPE_E)
            return addr;

        /* Map address to WRAMADDR register space */
        if (type != TYPE_Y || addr < 0xE000)
            addr += offsets[type];

        /* Set write address */
        Write1053Sci(SCIR_WRAMADDR, addr + offsets[type]);

        /* Convert len from bytes to words, then write data */
        len >>= 1;
        while (len-- > 0) {
            u_int16 data = (u_int16)fgetc(fp) << 8;
            data |= fgetc(fp);
            Write1053Sci(SCIR_WRAM, data);
        };
    } /* while (type >= 0 && type < 4) */

    return 0xFFFF; /* Pass-through indicates error condition */
}

```

5 Building a Streaming System

This chapter presents how to build a streaming system over the Internet, RF link or other media.

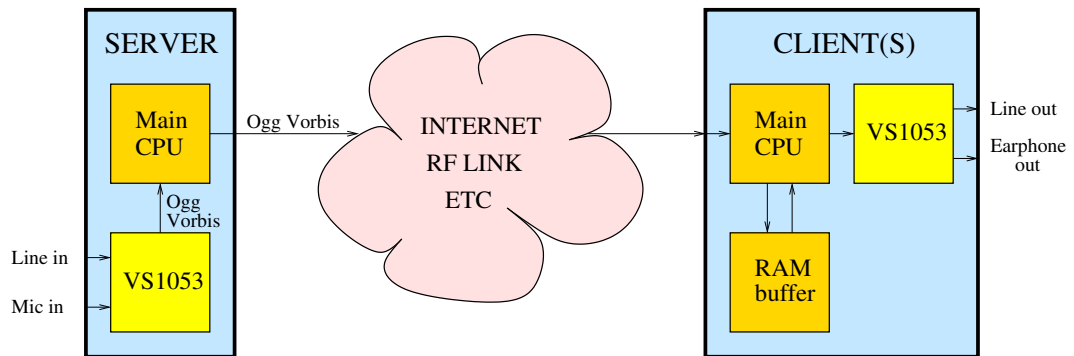


Figure 5: Streaming system using VS1053b.

Figure 5 presents an example system that uses a VS1053b for both encoding and decoding Ogg Vorbis audio.

First the audio data is fed to the VS1053b from a microphone or line input. It is encoded into Ogg Vorbis, which is sent by the Server's Main CPU over the transfer medium. To make sure Ogg Vorbis packets don't become too long, the Main CPU has set bits 7:4 in SCI_AICTRL3 to a sensible value prior to beginning encoding (Chapter 2.3.1).

The Main CPU on the Client end receives data and stores it into a RAM ring buffer (from e.g. 8 to 512 KiB depending on the application). It also transmits data to the VS1053b from the other end of the ring buffer. If the ring buffer becomes too full, the Main CPU must carefully increase VS1053b's playback samplerate as explained in Chapter 5.3, *Playback Speed Adjustment*. Similarly, if the buffer is too empty, playback samplerate is slightly decreased. If the changes are done slowly enough and with small enough steps, the listener can't notice them.

Note that VS1053b may encode at a slightly different speed from what is the nominal samplerate as explained in Chapter 2.6. Also, clock skew and other factors may affect the real speeds of the Server and Client(s). Thus, playback speed adjustment is a must in any streaming system. You may use a sample counter, presented in Chapter 5.1, to help control the end-to-end delay.

Note that Ogg Vorbis files are not designed to be resilient to bit errors. If you have a transmission channel that may lead to bit error (e.g. RF link), you should check for them in your transmission path and remove the packets that are broken. This will lead to unsynchronized audio until your playback speed adjustment corrects for that.

For further information, see Chapter 5.4, *Streaming Example*.

5.1 Sample Counter

An 32-bit sample counter, added for v1.3, is designed to help streaming Ogg Vorbis files. It tells the absolute sample number that is currently recorded through the ADC when an Ogg Vorbis file is being recorded. The sample counter is located at the beginning of the X memory user area, at address 0x1800, and it can be read through SCI.

The VS1053b Patches package has a similar counter. This makes it possible to maintain synchronization between the encoder and the decoder within an accuracy of a few samples if the data link has a constant delay and the sample counter data is transmitted from the sender to the receiver (e.g. RF link).

Note: The sample counter is not valid for the first few milliseconds of encoding.

As the sample counter is 32 bits and the SCI interface is 16 bits, the most significant bits of the counter may change while it is being read. To prevent incorrect values, read the sample counter using the following, self-correcting code:

```
unsigned short ReadVS10xxRegister(unsigned short addr);
void WriteVS10xxRegister(unsigned short addr, unsigned short value);

unsigned long Read32BitsFromSCI(unsigned short memAddr) {
    unsigned short msbV1, lsb, msbV2;

    WriteVS10xxRegister(port, SCI_WRAMADDR, addr+1);
    msbV1 = (u_int16)ReadVS10xxRegister(port, SCI_WRAM);
    WriteVS10xxRegister(port, SCI_WRAMADDR, addr);
    lsb = (u_int32)ReadVS10xxRegister(port, SCI_WRAM);
    msbV2 = (u_int16)ReadVS10xxRegister(port, SCI_WRAM);
    if (lsb < 0x8000U) {
        msbV1 = msbV2;
    }
    return ((u_int32)msbV1 << 16) | lsb;
}
```

The code is used like this:

```
unsigned long sampleCount = Read32BitsFromSCI(0x1800);
```

The VS1053b Patches package, which contains the other half of the Ogg Vorbis sample counter as well as some Ogg Vorbis decoding quality patches, is available at

<http://www.vlsi.fi/en/support/software/vs10xxpatches.html>

5.2 End-to-End Delay of a Streaming System

For a rough end-to-end delay estimate of a streaming Ogg Vorbis system, the following formula can be used:

$$d = \frac{4096 \times n_f \times b + 4000}{f_s}$$

where

- d is the result in seconds.
- n_f is bits 7:4 of SCI_AICTRL3, see Chapter 2.3.1. For this formula to work, you must set the bits to a non-zero value.
- $b = 1$ if you do byte-aligned read operations as instructed in Chapter 2.3.3. Otherwise $b = 2$.
- f_s is the samplerate.

Example: A 16 kHz voice profile is used. SCI_AICTRL3(7:4) is set to 1 for minimum delay. However, byte-aligned reads are not done. The system delay is:

$$d = \frac{4096 \times 1 \times 2 + 4000}{16000} = 0.76 \text{ s}$$

Naturally, you still have to add your transmission link delay to this value.

5.3 Playback Speed Adjustment

VS1053b's playback samplerate may be adjusted with the recommended *VS1053b Patches w/ FLAC Decoder* package, downloadable from <http://www.vlsi.fi/en/support/software/vs10xxpatches.html>.

The patch lets the user to adjust samplerate with approximately 2 PPM increments. For details, read the documentation for the VS1053b Patches package, particularly Chapter *Sample Rate Finetuning*.

Example:

you are encoding Ogg Vorbis data using XTALI=12.288 MHz at a nominal sample rate of 44100 Hz. However, you have learned from Chapter 2.6, *Samplerate Considerations*, the actual samplerate to be approximately 43885.7 Hz. How much do you need to adjust the samplerate?

$$\left(\frac{43885.7 \text{ Hz}}{44100 \text{ Hz}} - 1 \right) \times 512000 = -2488$$

Thus, write -2488 to the VS1053b Patches package Sample Rate Finetuning adjustment register.

Note: Adjusting the sample rate is a relatively expensive operation and it should not be done more often than once every 10 ms, preferably even less often than that.

5.4 Streaming Example

Let's take a streaming system that uses two VS1053b's, both running at 12.288 MHz crystals, and using best possible quality: the 44.1 kHz stereo Music Profile, Quality 5.

This is what you need to do on the encoder side:

- Load and start the VS1053b Ogg Vorbis Encoder.
- If you want to maintain synchronization for an indefinite time, send also the sample counter in your message packets. For how to read the sample counter, see Chapter 5.1, *Sample Counter*.

This is what you need to do on the decoder side:

- Load and run the VS1053b Patches package (with or without FLAC decoding) to the decoding VS1053b.
- As seen in Chapter 2.6, *Samplerate Considerations*, the encoding VS1053b records at 43885.7 Hz although it reports using 44100 Hz. So, set the playback rate as told in Chapter 5.3, *Playback Speed Adjustment*.
- If you want to maintain sync indefinitely, compare the recording sample counter value to the sample counter of the decoder. For how to read the sample counter at the decoder and, refer to the documentation of the VS1053b Patches package, Chapter *Sample Counter*.
- Decide what your target difference between the sample counters are. If, for instance, you are using Internet as your transfer medium, and you have lots of buffering in your microcontroller, the time may be e.g. 10 seconds (441000 samples). On an RF link, the time difference may be e.g. 0.5 seconds (22050 samples).
- By making very small positive and negative adjustments to the playback sample-rate, keep the recording and playback sample counter difference as constant as possible.

If you take all these steps, you will have a streaming system that both keeps synchronized for extended periods of time, and will self-adjust back to sync even after such issues as packet loss.

6 Latest Version Changes

This chapter describes the most important changes to the Vorbis VS1053b Ogg Vorbis Encoder and this document.

Version 1.70c, 2012-11-16

This is a documentation change only. Software is unchanged since v1.70.

- Added a Chapter 5.4, *Streaming Example*.
- Corrected values in Chapter 5.3, *Playback Speed Adjustment*, to correspond with values required by the VS1053b Patches package.

Version 1.70b, 2011-06-29

This is a documentation change only. Software is unchanged since v1.70.

- Changed recommendations for how to load and start the code in Chapter 2.3.2.
- Provided example for how to run the encoder in file `vs1053oggrec.c`. The file has also been quoted in Chapter 2.4.5.
- Added files in the binary `.img` image file format in the `profiles` directory. Documentation for the format also added to Chapter 4.2.

Version 1.70, 2010-09-09

This update adds functionality and enhances documentation.

- Added Vox operation for mono profiles. Other profiles are unchanged except for the bitstream version number. See Chapter 2.5 for details.
- Presented a rough estimate of end-to-end audio delay in Chapter 5.2.

7 Contact Information

VLSI Solution Oy
Entrance G, 2nd floor
Hermiankatu 8
FI-33720 Tampere
FINLAND

Fax: +358-3-3140-8288
Phone: +358-3-3140-8200
Email: sales@vlsi.fi
URL: <http://www.vlsi.fi/>

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

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