

VS1005 VSOS AUDIO SUBSYSTEM

VS1005g

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Revision History			
Rev.	Date	Author	Description
3.67	2026-04-23	HH	Release for VSOS 3.67.
3.66a	2023-02-28	HH	Added Chapters 7.5, 8.7, 11.3, 7.1.1.
3.66	2023-02-14	HH	Updated version number for VSOS 3.66.
3.65b	2022-03-24	HH	Added FTIREV and FTIREV23, Chapter 8.4.
3.65a	2022-03-23	HH	Added AUOI2SMV, Chapter 7.6.2.
3.65	2021-12-23	HH	Updated for VSOS 3.65.
3.60	2020-10-13	HH	Updated for VSOS 3.60.
3.58	2019-08-24	HH	Added e.g. decapc.dl3 to Chapter 13.
3.57	2019-04-10	HH	Minor corrections.
3.55b	2018-06-22	HH	Added Noise Killer audio driver.
3.55a	2018-04-24	HH	New features to Reverb Generator audio driver.
3.55	2018-04-05	HH	Added Reverb Generator audio driver.
3.52	2018-01-22	HH	Updated for VSOS 3.52.
3.42	2017-05-18	HH	More S/PDIF drivers, FLAC Encoder, Pitch Shifter.
3.40	2016-11-03	HH	Updated for VSOS 3.40.
3.30a	2016-07-14	HH	Bug patch release for VSOS 3.30.
3.30	2016-06-22	HH	Updated for VSOS 3.30.
1.03	2016-02-15	HH	New AUXPLAY, fract. rates, updated AuOutput.
1.02	2016-01-27	HH	Added AuOutput app and Slave Sync drivers.
1.01	2015-09-14	HH	Corrections, e.g. Figure 10.
1.00	2015-09-04	HH	Initial release.

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1 Introduction

The VS1005 VSOS offers many, versatile audio drivers.

This document explains how to use the numerous drivers to your best advantage.

After the disclaimer and definitions in Chapters 2 and 3, an overview of the Audio subsystem is given in Chapter 4, *Overview*, followed by requirements in Chapter 5, *Requirements*.

The VSOS audio subsystem is presented in Chapter 6, *The VS1005 VSOS Audio Subsystem*.

The currently existing audio drivers are presented in Chapter 7, *Audio Drivers*, followed by a presentation of the currently existing filters in Chapter 8, *Audio Driver Filters*, and control programs in Chapter 9, *Audio Control Programs*,

Some examples on how to start audio drivers from config.txt or the VSOS Shell are shown in Chapter 10, *Configuration Examples*.

Chapter 12 shows how to control some aspects on audio using UiMessages, even if the program that is currently running doesn't have any audio controls.

Audio Decoders are presented in Chapter 13, and Audio Encoders in Chapter 14.

The document ends with Chapter 15, *Latest Document Version Changes*, and Chapter 16, *Contact Information*.

2 Disclaimer

VLSI Solution makes everything it can to make this documentation as accurate as possible. However, no warranties or guarantees are given for the correctness of this documentation.

3 Definitions

DSP Digital Signal Processor.

I-mem Instruction Memory.

LSW Least Significant (16-bit) Word.

MSW Most Significant (16-bit) Word.

RISC Reduced Instruction Set Computer.

VS_DSP⁴ VLSI Solution's DSP core.

VSIDE VLSI Solution's Integrated Development Environment.

VSOS VLSI Solution's Operating System.

X-mem X Data Memory.

Y-mem Y Data Memory.

4 Overview

The VSOS Audio Subsystem provides numerous drivers to handle the many audio Input/Output options of VS1005. The audio drivers can be controlled either with `ioctl()` calls from the C language, or from VSOS Shell control program.

While instructions for how to use each audio driver are provided in the README.TXT or documentation .PDF files of the drivers, this document will provide an overview of the capabilities of the drivers. However, for details, refer to documentation of the audio drivers themselves.

5 Requirements

To test the audio drivers in this document, you need to have the following building blocks:

- VS1005g Developer Board. The VS1005g BreakOut Board should also work, but these instructions have been tested with the DevBoard.
- Latest version of VSOS installed (at least v3.66, released 2023-02-14).
- USB cable between DevBoard and PC for uploading new software.
- If you want to use the VSOS Shell environment, you will also need:
 - UART or USB->UART cable connected between DevBoard and PC for using the UART interface. Data speed is 115200 bps, format is 8N1.
 - Your favorite UART Terminal Emulation program installed on the PC. Read the “VS1005 VSOS Shell” for further details.

When all of this is in order, you are ready to test the VSOS Audio Subsystem.

6 The VS1005 VSOS Audio Subsystem

As a default, VSOS offers a simple audio output driver that lets the user output 16-bit mono or stereo audio to the VS1005 analog output pins LEFT and RIGHT, and control the sample rate.

VSOS Audio makes it very easy to produce sound with its standard-C-like standard audio interface (Chapter 6.1, *Standard Audio*). Instead of being forced to use audio-specific I/O routines, audio looks just like files.

More complex audio operations and redirections can be done using the audio drivers, described Chapter 7, *Audio Drivers*.

6.1 Standard Audio

VSOS offers the user a standard audio source and destination, although the audio source is only activated if an appropriate audio input driver is loaded (Chapter 7). Called *stdaudioin* and *stdaudioout*, standard audio file handles are to sound much like *stdin* and *stdout* are to standard input and output in standard C. It is not allowed for the user to close standard audio input or output files, but the user may modify their parameters.

By default, *stdaudioout* is connected to analog output pins LEFT and RIGHT, although this can be changed with appropriate audio drivers.

Both standard audio input and output open in stereo, 16-bit, 48 kHz mode. These parameters can be changed by the user, with driver and hardware dependent limitations.

The user may use all standard read and write operations to read from and write to standard audio. It is, however, required that *fread()* / *fwrite()* functions are used instead of character-based operations like *fgetc()* and *fprintf()*. It is also recommended to handle larger chunks of samples, like 32, at a time.

Stereo samples are stored in an interleaved fashion. In 32-bit mode, the least significant word is stored first. This is the same as the native VSDSP 32-bit word order.

Audio sample buffer 16-bit word order				
Audio format	Word 0	Word 1	Word 2	Word 3
16-bit stereo	Left 0	Right 0	Left 1	Right 1
32-bit stereo	Left 0 LSW	Left 0 MSW	Right 0 LSW	Right 0 MSW

6.2 VSOS Audio Output Example Program

The following audio program example creates a low-intensity sine wave to the left channel, then outputs the samples.

```
#include <vo_stdio.h>
#include <stdlib.h>
#include <math.h>
#include <saturate.h>
#include <aploader.h>

#define SIN_TAB_SIZE 96
#define SIN_AMPLITUDE 1000 /* Max 32767 */

static const s_int16 __y sinTab[SIN_TAB_SIZE];

int main(void) {
    // Remember to never allocate buffers from stack space. So, if you
    // allocate the space inside your function, never forget "static"!
    static s_int16 myBuf[2*SIN_TAB_SIZE];
    int i;

    /* Build sine table */
    for (i=0; i<SIN_TAB_SIZE; i++) {
        sinTab[i] = (s_int16)(sin(i*2.0*M_PI/SIN_TAB_SIZE)*SIN_AMPLITUDE);
    }

    while (1) {
        // Clear buffer
        memset(myBuf, 0, sizeof(myBuf));

        // Create sine wave to the left channel.
        for (i=0; i<SIN_TAB_SIZE; i++) {
            myBuf[i*2] = sinTab[i];
        }

        // Write result
        fwrite(myBuf, sizeof(s_int16), 2*SIN_TAB_SIZE, stdaudioout);
    }

    // Not really needed because there was a while(1) before
    return EXIT_SUCCESS;
}
```

6.3 VSOS Audio Input/Output Example Program

The following audio program reads audio from the default input, and sends it to the default output, until the user pushes Ctrl-C in the VSOS Shell Environment.

```
#include <vo_stdio.h>
#include <apploader.h> // Contains LoadLibrary() and DropLibrary()
#include <consolestate.h>

#define BUFSIZE 128

ioresult main(char *parameters) {
    static s_int16 myBuf[BUFSIZE];

    if (!stdaudioin || !stdaudioout) {
        printf("E: NO AUDIO IN OR OUT!\n");
        return S_ERROR;
    }

    while (!(appFlags & APP_FLAG_QUIT)) { /* Until Ctrl-C is pushed */
        fread(myBuf, sizeof(s_int16), BUFSIZE, stdaudioin);
        fwrite(myBuf, sizeof(s_int16), BUFSIZE, stdaudioout);
    }

    return S_OK;
}
```

7 Audio Drivers

VS1005g has multiple hardware audio paths, and software Audio Drivers that are meant to interface between the user and hardware. The Audio Drivers offer a consistent interface to the user so that most of the time the User Application doesn't need to know which audio driver it is interfacing with.

This Chapter will explain which driver you will need to attach each audio driver to your software.

7.1 General

With few exceptions, VS1005 VSOS audio drivers offer a 2-channel (stereo) input, and/or a 2-channel (stereo) output. An exception to this rule is the 3-channel input driver presented in Chapter 7.5, *Analog Input 3-Channel ADC Audio Driver*.

Most if not all audio drivers may be set either to 16-bit or 32-bit mode. The default is 16 bits. If the driver cannot receive or send its word length status, it is operating in 16-bit mode.

Many audio drivers allow for their sample rate to be set. If applicable for the audio driver, 48 kHz is typical default sample rate. If the driver cannot set or return its sample rate, it is typically operating at 48 kHz. There are exceptions to this, like the I2S slave drivers (Chapters 7.6, *I2S Audio Drivers*) that simply follow external clocking.

Audio drivers are named using the following format:

AUdyyyyyz.DL3

where

Symbol	Description
d	Driver direction: I = input, O = output, X = Input+Output
yyyyy	Driver name, max. 5 characters
z	Optional M or S if e.g. I2S driver is Master or Slave

There may be more than one audio driver in use at the time. Most audio drivers may be started as *system* drivers in which case they connect to file handles stdaudioin and/or stdaudioout for easy access from the User Application. If not started as system drivers, they must be accessed through explicit file handles.

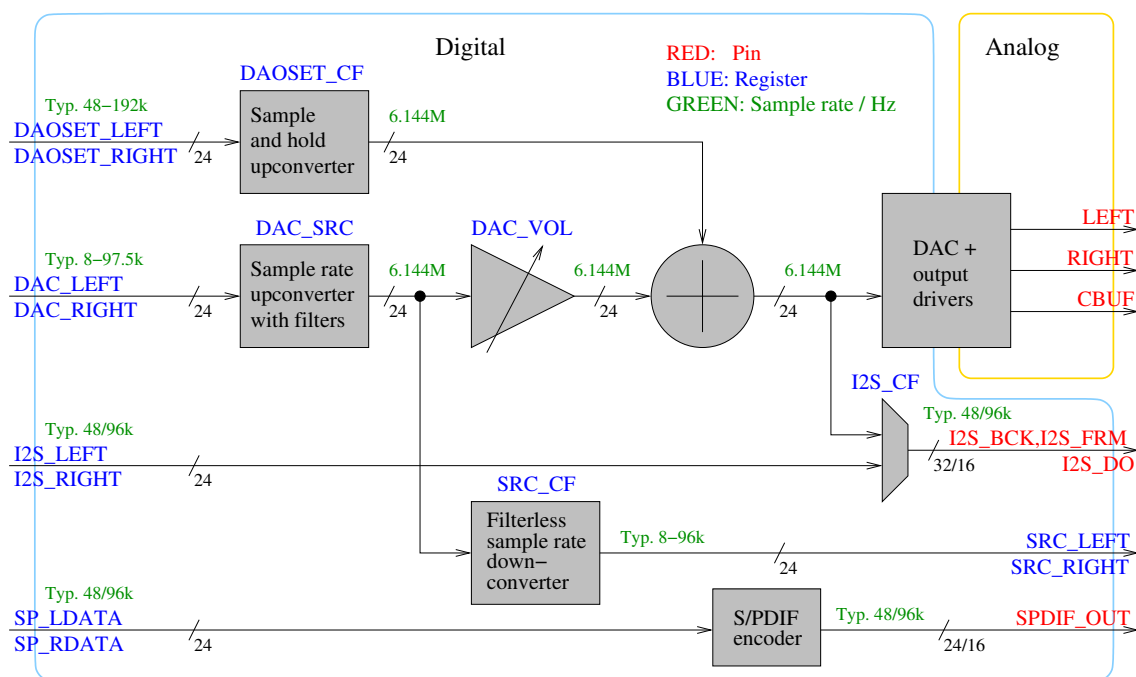


Figure 1: VS1005g playback (DA) audio paths

Figure 1 shows the VS1005 hardware output audio paths. Most of these have a driver controlling them.

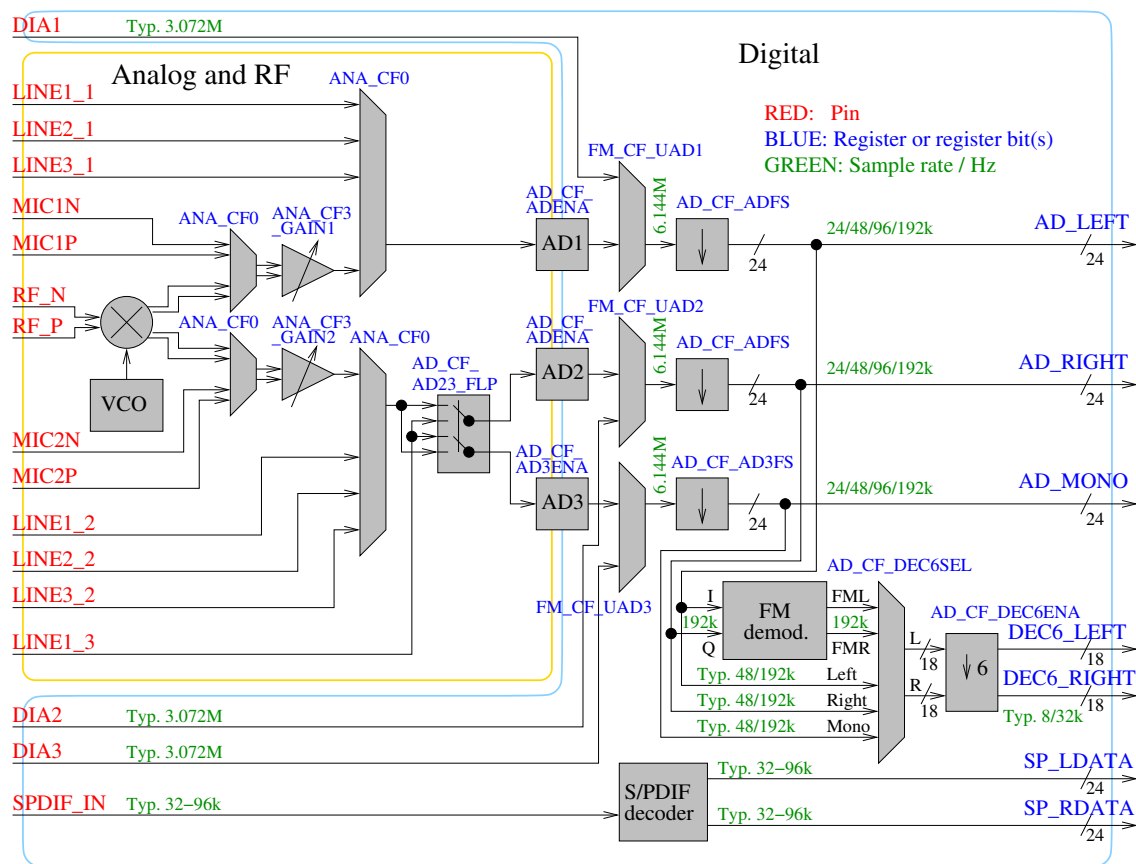


Figure 2: VS1005g recording (AD, FM, etc) signal paths

Figure 2 shows the VS1005 hardware input audio paths. Most of these have a driver controlling them.

7.1.1 Examples of Loading and Unloading Audio Drivers

To load and activate the Analog Output DAC Audio Driver AUODAC.DL3 (Chapter 7.2), you may add the following line to S:CONFIG.TXT:

```
AUODAC s
```

Alternatively you may enter the following command on the VSOS Shell command line:

```
S:>driver +auodac s
```

Both of these methods will load and activate the audio driver. The parameter “s” stands for *system*, and it will make the audio driver automatically connect to stdaudioout. If this was an input driver, it would have connected to stdaudioin.

To verify that the driver has actually loaded and is running, you may run the following command on the VSOS Shell command line:

```
S:>auoutput
stdaudioout:      0x2056, auodac::audioFile=0x0c43(3139)
->Identify():      0x3c4f, auodac::Identify returns "AUODAC"
->op:              0x205f, auodac::audioFileOps=0x0000(0)
->Ioctl():          0x3b06, auodac::AudioIoctl
->Write():          0x3c05, auodac::AudioWrite
Sample rate:      48000
Bits per sample:  16
Channels:         unknown (assuming 2)
Buffer size:      512 16-bit words (256 16-bit stereo samples)
Buffer fill:      4 16-bit words (2 16-bit stereo samples)
Sample counter:   2102830
Underflows:       2100532
Volume:           +0.0 dB of maximum level
```

If you need to load another output audio driver, you can do it and check its status separately. Note that we already have a system driver for stdaudioout, so this driver will be started without the “s” system option. Below is a VSOS Shell command line example:

```
S:>driver +auooset
S:>auoutput -dauooset
audioFP:          0x241c, auooset::audioFile=0x0c43(3139)
->Identify():      0x436a, auooset::Identify returns "AUOOSSET"
->op:              0x2423, auooset::audioFileOps=0x0000(0)
->Ioctl():          0x423c, auooset::AudioIoctl
->Write():          0x4311, auooset::AudioWrite
Sample rate:      48000
Bits per sample:  16
Channels:         unknown (assuming 2)
Buffer size:      512 16-bit words (256 16-bit stereo samples)
Buffer fill:      4 16-bit words (2 16-bit stereo samples)
Sample counter:   351032
Underflows:       350780
Volume:           +0.0 dB of maximum level
```

To remove the previous driver, you may enter the following command:

```
S:>driver -auooset
S:>auoutput -dauooset
E: Library auooset was not already in memory
```

More examples on how to load and unload audio driver are provided in Chapter 10, *Configuration Examples*.

7.2 Analog Output DAC Audio Driver

7.2.1 Driver AUODAC.DL3

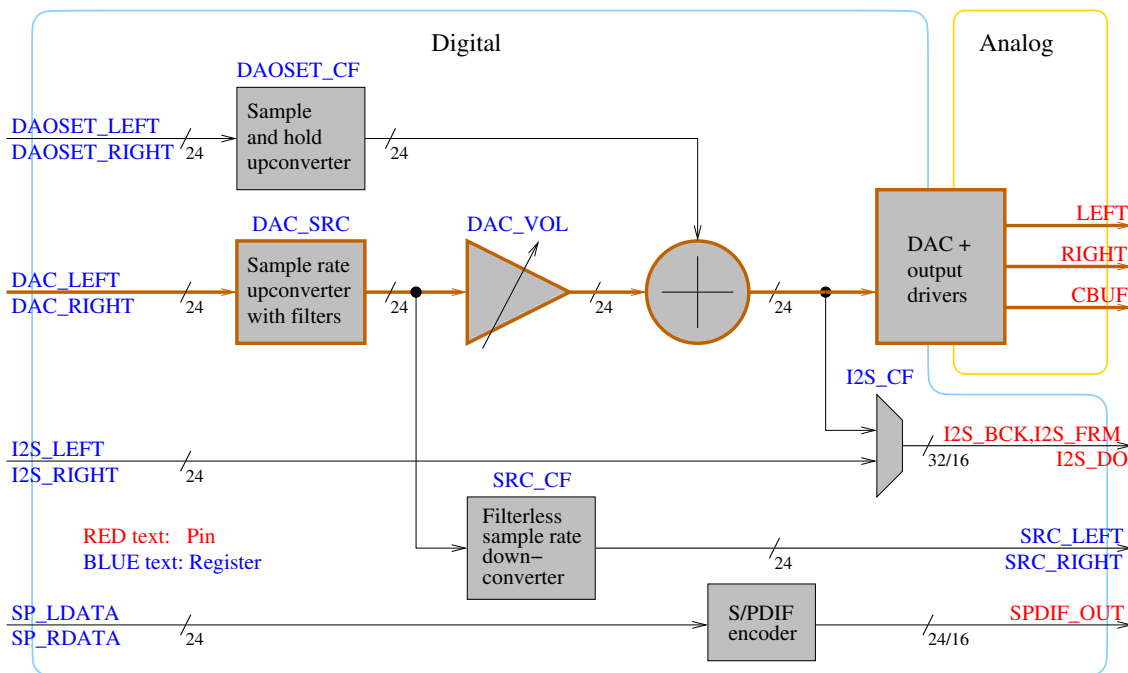


Figure 3: AUODAC.DL3 signal paths shown in **bold brown**

Figure 3 shows the VS1005 high-quality, fully filtered analog output main audio path.

AUODAC.DL3 is the basic DAC output driver. It takes over the VSOS default driver and offers a lot of functionality over it, like 16-bit and 32-bit data transfers. It takes over *stdaudioout*, so all software that writes to standard output will send audio to this driver.

The driver offers setting the sample rate with an approximately 0.09 Hz accuracy between 100 and 97500 Hz on VS1005g. On VS1005h, sample rate accuracy is generally better. Audio is upconverted to an extremely high rate of 6.144 MHz by a high-quality hardware sample rate upconverter.

Playback volume can be set with 0.5 dB accuracy between full level volume (-0 dB) and -127 dB.

Note: On VS1005g, and using the standard 12.288 MHz crystal, some standard sample rates can be played back accurately (or as accurately as the system clock crystal runs), while some others have slight rounding errors. E.g. 96000, 48000, and 24000 Hz can be played back exactly. However, 44100 Hz is played back at ≈ 44100.0366 Hz, and 8000 Hz is played back at ≈ 7999.9695 Hz. While these errors are of the same order of magnitude as crystal speed errors and usually insignificant, intime they can break internal sync between the ADC and DAC converters. When run on VS1005h, the driver uses a “fractional sample rate” hardware feature that allows it to play such standard sample rates as 8000, 16000, 32000, 11025, 22050, and 44100 accurately.

7.3 Analog Output Side Path Audio Driver

7.3.1 Driver AUOOSSET.DL3

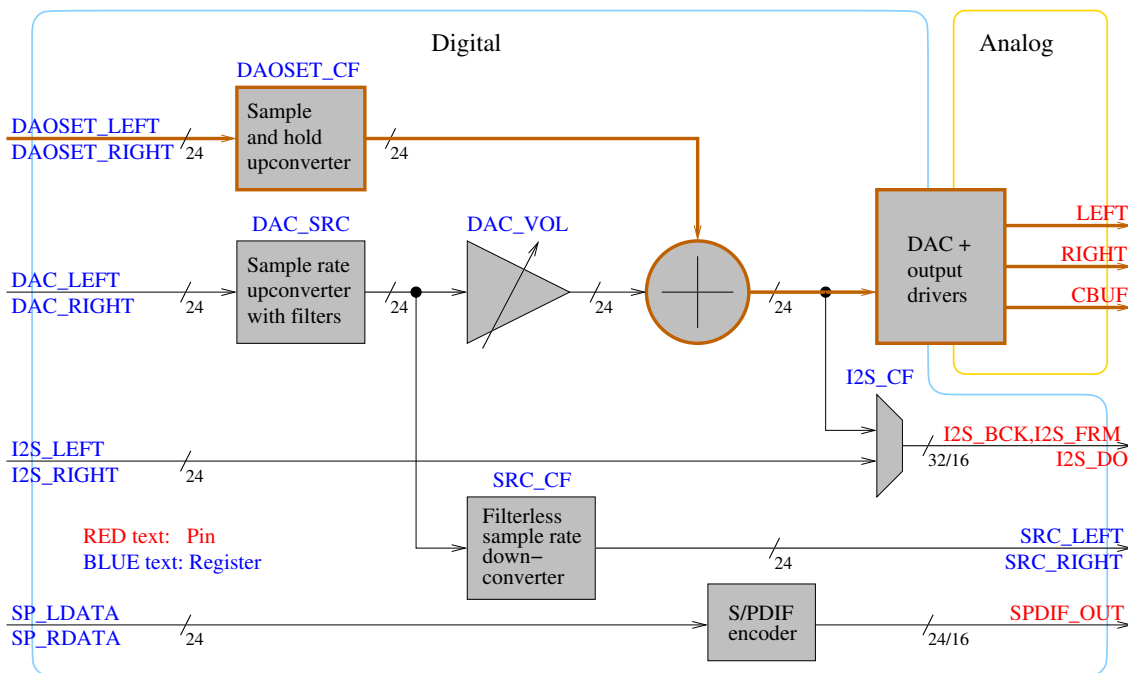


Figure 4: AUOOSSET.DL3 signal paths shown in **bold brown**

Figure 4 shows the VS1005 analog output audio side path. This audio path is not filtered; it is only put through a Sample and hold upconverter. As such, audible aliasing distortion may be heard if low sample rates are used. This audio path is best suitable for different kinds of alarm and effects sounds that may easily be independently overlayed on top of the audio of the main audio path (see Chapter 7.2.1).

The sample rate of the side audio path is independent from the main audio path. While it may be set to up to 192 kHz, all sample rates cannot be set accurately. While certain sample rates like 24, 48, and 96 kHz can be played accurately, some others, like 44.1 kHz, may have an up to 150 Hz error. While not a problem for effects sounds, this may be create issue with accurate timing when playing longer audio passages.

While there is no hardware volume control for the side audio path, the driver offers an equivalent software volume control.

7.4 Analog Input ADC Audio Driver

7.4.1 Driver AUIADC.DL3

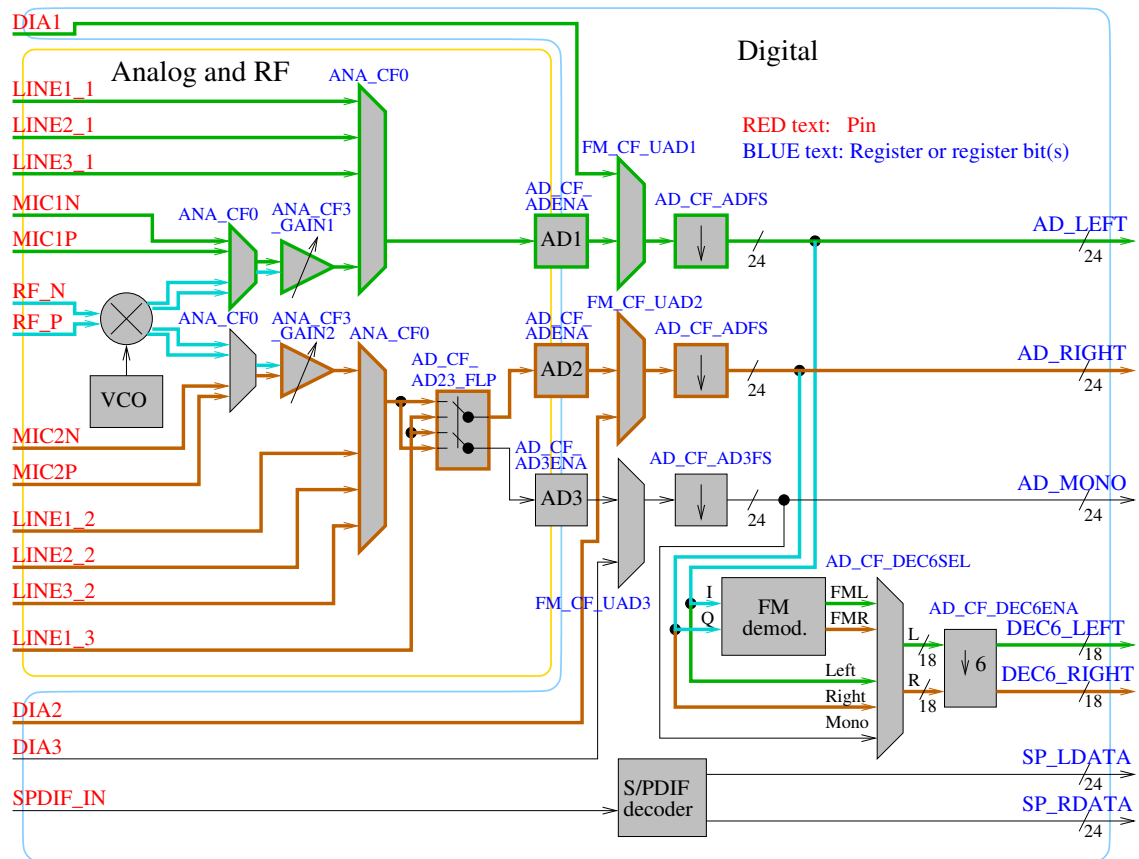


Figure 5: AUIADC.DL3 selectable input signal paths shown in **bold green** for the left channel, and **bold brown** for the right channel. Alternative RF audio path shown in **bold cyan**

The AUIADC.DL3 driver lets the user select a stereo input from a multitude of analog and some digital sources. The sources used may be chosen at startup time, or changed dynamically while the driver is running. Any **green** source in Figure 5 may be combined with any **brown** source to form a stereo signal. However, if the **cyan-coloured** RF input is selected, it takes over the whole stereo audio path.

Supported sample rates are 192, 96, 48, and 24 kHz. However, it is also possible to use a high-quality down-by-6 decimator to create such sample rates as 32, 16, and 8 kHz. When the decimator is selected, the driver automatically reads its samples from the DEC6_LEFT/DEC6_RIGHT registers instead of the default AD_LEFT/AD_RIGHT.

Note that even if RF is selected for FM radio input, all of the FM hardware is not started by the driver. So you will still need a dedicated FM Receiver program to e.g. tune the FM radio. The only supported sample rate for the FM receiver is 32 kHz (using 192 kHz main sample rate and putting the signal through the I/Q - FM demodulation - down-by-6

decimator hardware).

Optionally, digital microphone inputs DIA1 and DIA2 may be used instead of the analog inputs. The 1-bit signals in the megahertz domain from the microphones are fed to the high-quality digital low-pass filtering path of VS1005.

On the VS1005 DevBoard, line inputs are connected LINE1_1 and LINE1_3. On the VS1005 BreakOut Board, LINE1_1 and LINE1_2 are used.

Input selection can be controlled using the the AUINPUT program (Chapter 9.1).

AUIADC.DL3 Command Line Parameters

If “s” is provided as the first command line parameter, then the driver will become a *system* driver, i.e. it will connect to the standard file handle *stdaudioin* so that all software may automatically connect to it.

A sample rate in Hz may also be provided as a command line parameter. Alternatives are 24000, 48000, 96000, and 192000. If a separate “dec6” parameter is provided on the command line to activate the hardware decimate-by-6 filter, 4000, 8000, 16000, or 32000 may be selected.

To select the inputs, either one stereo element, or one left and one right element from the following list may be selected:

Stereo Elements (stereo output)	
fm	
Left Elements (left output)	Right Elements (right output)
line1_1	line1_2
line2_1	line2_2
line3_1	line3_2
mic1	line1_3
dia1	mic2
	dia2

Example 1; basic configuration for VS1005 Developer Board:

```
AUIADC s 48000 line1_1 line1_3
```

Example 2; basic configuration for VS1005 BreakOut Board:

```
AUIADC s 48000 line1_1 line1_2
```

Example 3; FM radio configuration for VS1005 BreakOut Board. Note that separate software is needed to tune the FM receive channel:

```
AUIADC s 32000 fm dec6
```

Note that input selection and sample rate can also be controlled using the AUINPUT program (Chapter 9.1).

7.5 Analog Input 3-Channel ADC Audio Driver

7.5.1 Driver AUI3ADC.DL3

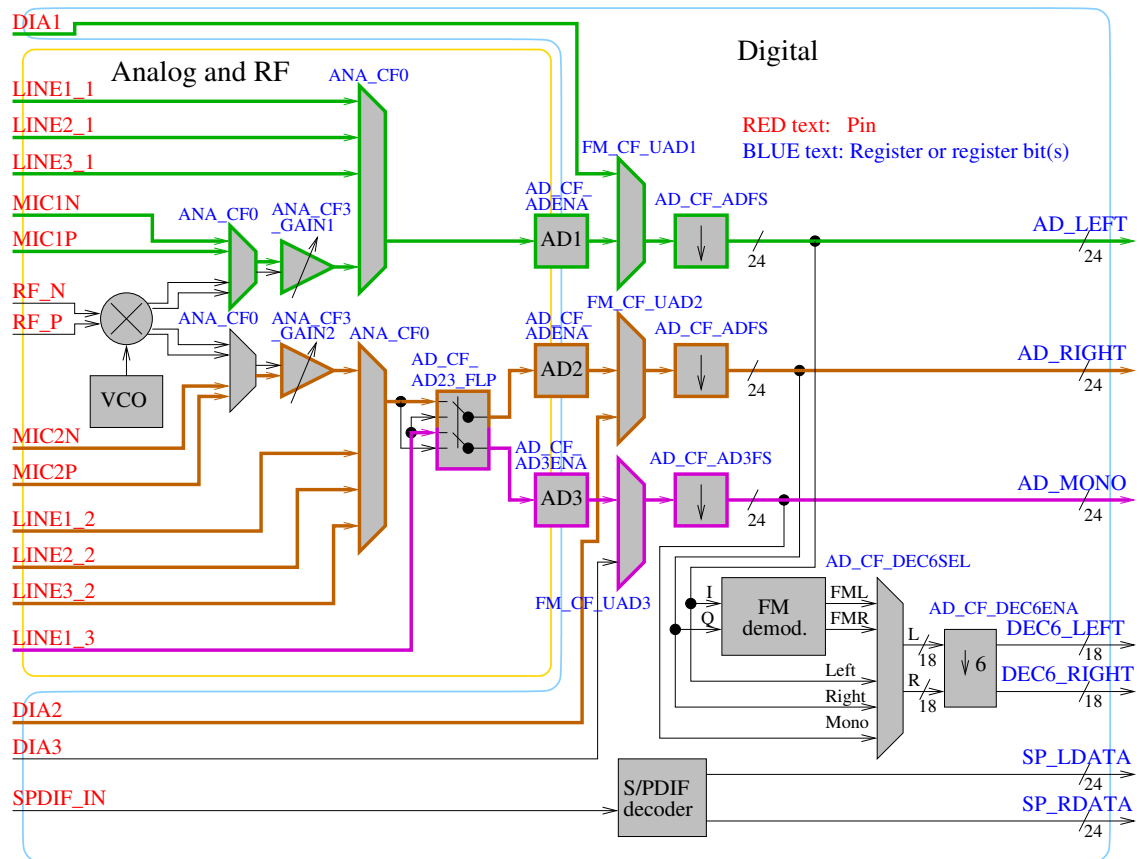


Figure 6: AUI3ADC.DL3 selectable input signal paths shown in **bold green** for channel 0 (AD_LEFT), **bold brown** for channel 1 (AD_RIGHT), and **bold magenta** for channel 2 (AD_MONO).

The AUI3ADC.DL3 driver is much like the AIOADC.DL3 driver presented in Chapter 7.4.1, but with some crucial differences.

AUI3ADC.DL3 lets the user to select a 3-channel input from a multitude of analog and some digital sources. The sources must be set after the driver has started. Any **green** source in Figure 6 may be combined with any **brown** source and the **magenta** source to form a 3-channel signal.

The 3-channel output of this driver can either be read by the User Application as 3-word triplets, or handed down to a driver capable of converting the number of channels to a more standard one, like the one presented in Chapter 8.7, *Matrix driver: 3 Channels to 2 Channels*.

Supported sample rates are 192, 96, 48, and 24 kHz. With this driver, it is not possible to use the hardware down-by-6 decimator to create other sample rates.

Unlike with AUIADC.DL3, no hardware RF FM demodulation is provided. If the user needs to decode a stereo RF FM signal, a sample rate of 192 kHz must be set and the IQ signal provided in output channels 0 and 1 must be decoded with software. Also note that even if RF is selected for FM radio input, all of the FM hardware is not started by the driver. So you will still need a dedicated FM Receiver program to e.g. tune the FM radio.

Optionally, digital microphone inputs DIA1 and DIA2 may be used instead of the analog inputs. The 1-bit signals in the megahertz domain from the microphones are fed to the high-quality digital low-pass filtering path of VS1005.

On the VS1005 DevBoard, LINE1_1 and LINE1_3 are used as the default analog inputs; they can be routed by this driver to outputs channels 0 and 2. On the VS1005 BreakOut Board, LINE1_1 and LINE1_2 are used; they can be routed by this driver to output channels 0 and 1.

Input selection can also be controlled using the AUINPUT program (Chapter 9.1).

AUIADC.DL3 Command Line Parameters

If “s” is provided as a command line parameter, then the driver will become a *system* driver, i.e. it will connect to the standard file handle *stdaudioin* so that all software may automatically connect to it.

AUIADC.DL3 Selectable Audio Channels

Input selection and sample rate can be controlled with `ioctl()` calls from C or using the AUINPUT program (Chapter 9.1).

To select the inputs for channels 0 and 1, one left and one right element from the following list must be selected. In addition, `line1_3` will always be read to channel 2:

Left Elements (output channel 0)	Right Elements (output channel 1)
line1_1	line1_2
line2_1	line2_2
line3_1	line3_2
mic1	mic2
dia1	dia2

Example 1; configuration for `line1_1`, `line1_2`, and `line1_3`:

```
AUIADC s
RUN AUINPUT -r48000 line1_1 line1_2
```

Example 2; voice quality configuration for a stereo mic and `line1_3`:

```
AUIADC s
RUN AUINPUT -r24000 mic1 mic2
```

7.6 I2S Audio Drivers

I2S Audio drivers allows for I2S operation in both master and slave mode. Whenever possible, it is recommended to use master mode, because that way VS1005 has exact control over the sample rate.

The sample rate and number of bits (16/32) may be controlled with `ioctl()` commands `IOCTL_AUDIO_SET_RATE_AND_BITS` (recommended), `IOCTL_AUDIO_SET_IRATE`, `IOCTL_AUDIO_SET_ORATE`, and `IOCTL_AUDIO_SET_BITS`. In master mode, sample rates 24, 48, 96, and 192 kHz are supported.

In slave mode, the other end selects the sample rate, which is the same for both I2S input and output. If the user wants to monitor audio using analog output, they need to use the Slave Audio Input Synchronization Driver (Chapter 7.9).

With the exception of `AUOI2SMA.DL3` and `AUOI2SMV.DL3`, all drivers connect to `stdaudioin` and/or `stdaudioout` if started with parameter “s”. Otherwise, the drivers need to be opened and accessed manually.

Summary of I2S drivers					
Name	M	In	Out	Sys	Notes
AUOI2SMA	X		X		Automatic HW DAC/DAOSET duplication to I2S
AUOI2SMV	X		X		Automatic DAC duplication to I2S w/ manual volume control
AUOI2SM	X		X	X	Master output
AUOI2SS			X	X	Slave output
AUII2SM	X	X		X	Master input
AUII2SS		X		X	Slave input
AUXI2SM	X	X	X	X	Master input / output
AUXI2SS		X	X	X	Slave input / output

Name Name of the driver.

M Driver uses I2S in Master Mode, i.e. it generates its own clock signals. If not crossed, driver uses I2S in Slave Mode.

In Driver implements I2S input.

Out Driver implements I2S output.

Sys Driver can connect to `stdaudioin` (if input driver) and/or `stdaudioout` (if output driver) if parameter “s” is added to the command line.

Master drivers are limited to only a few standard sample rates, e.g. 48000 and 96000 Hz while Slave drivers can adapt to a wide range of sample rates.

7.6.1 Driver AUOI2SMA.DL3

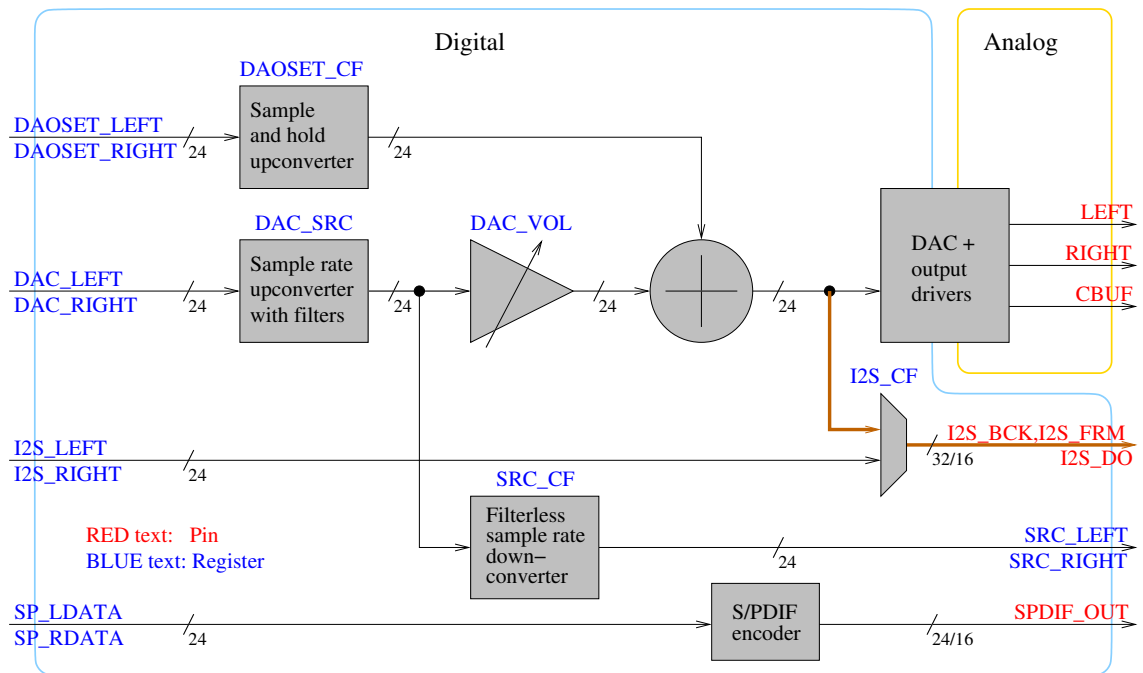


Figure 7: AUOI2SMA.DL3 audio path shown in **bold brown**

AUOI2SMA.DL3 is a driver that makes it possible to add easy I2S support. As Figure 7 shows, the driver activates an automatic audio hardware path. The sum of the DAC and DAOSET drivers are send to the DAC volume control, then this result is sent to I2S. To function, the driver needs a DAC (e.g. AUODAC.DL3) and/or DAOSET (e.g. AUOOSSET.DL3) driver to be active.

The sample rate is set to a default of 96000 Hz / 32 bits. If either “96000” or “48000” is specified on the command line, the sample rate is set when the driver is starting and cannot be modified while the driver is running. Anything played back through VS1005's analog audio path is converted to the target sample rate by VS1005 hardware.

Because this driver simply activates an existing audio hardware path, it doesn't require any extra CPU when running.

Example config.txt snippet for automatically transmitting all audio to I2S:

```
AUODAC s
AUOI2SMA 96000
```

Then run a program from the VSOS Shell command line, like:

```
S:>cd d:
D: SD/SD Card
D:>PlayDir
```

Example config.txt snippet for listening to audio coming through I2S:

```
AUODAC s
AUII2SS s
AUXSYNCS
AUXPLAY
```


7.6.2 Driver AUOI2SMV.DL3

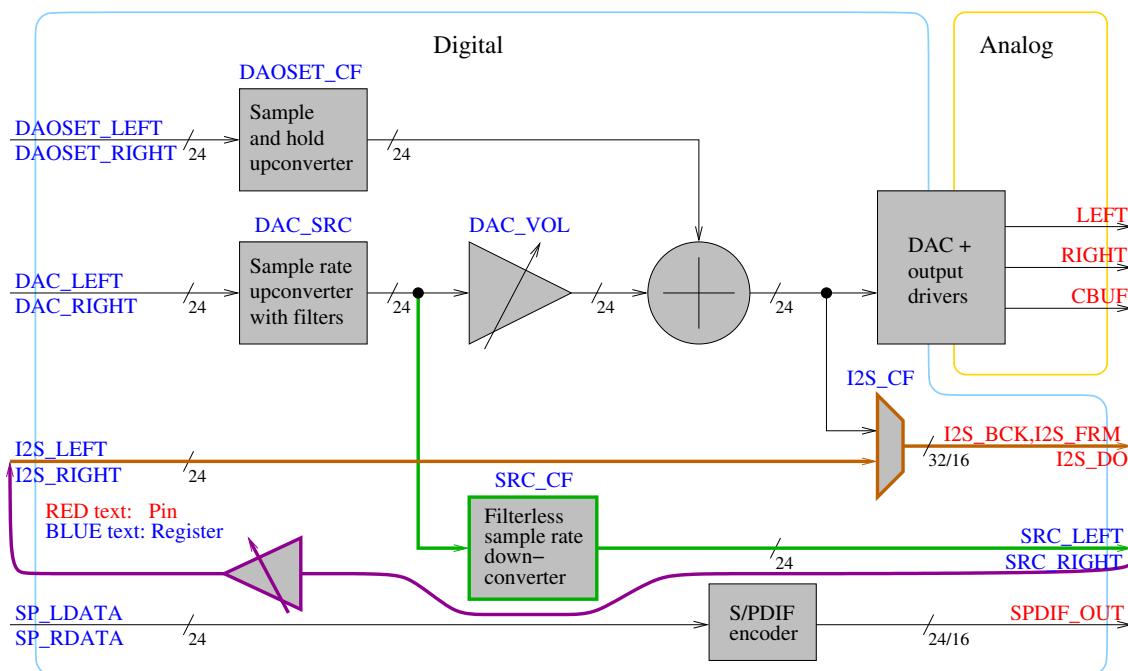


Figure 8: AUOI2SMV.DL3 audio path shown in **bold brown**. Software driver connecting to the filterless sample rate converter (**bold green**) shown in **bold magenta**

AUOI2SMV.DL3 is a driver that makes it possible to add easy I2S support. As Figure 8 shows, the driver creates an audio path that copies to I2S everything that is sent to the DAC audio path. To function, it needs a DAC (e.g. AUODAC.DL3) driver to be active.

The sample rate is set to a default of 96000 Hz / 32 bits. If either “96000” or “48000” is specified on the command line, the sample rate is set when the driver is starting and cannot be modified while the driver is running. Anything played back through VS1005’s analog audio path is converted to the target sample rate by VS1005 hardware.

Example config.txt snippet for automatically transmitting DAC audio also to I2S:

```
AUODAC s
AUOI2SMV 96000
```

Then run a program from the VSOS Shell command line, like:

```
S:>cd d:
D: SD/SD Card
D:>PlayDirP -daui2smv
```

Note:

You may change hardware volume for the DAC output with keys ‘<’ and ‘>’, and for the software volume for the I2S with keys ‘d’ and ‘u’. To see how to implement separate volume controls, refer to the source code of PlayDirP.

Example config.txt snippet for listening to audio coming through I2S:

```
AUODAC s
AUII2SS s
AUXSYNCS
AUXPLAY
```

7.6.3 Driver AUOI2SM.DL3

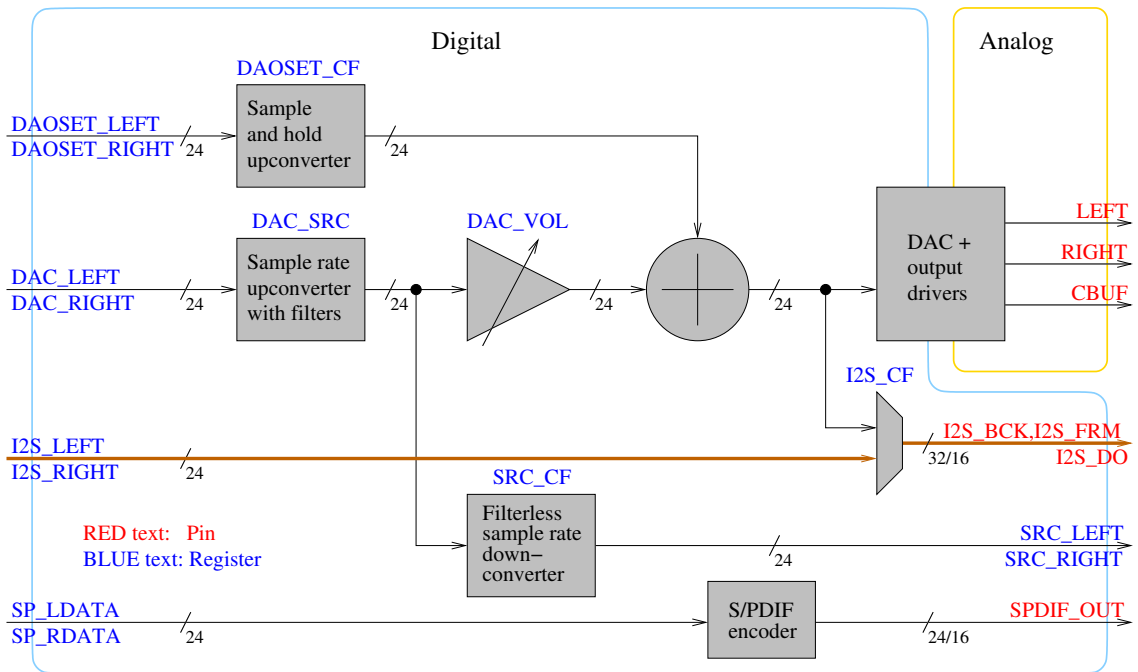


Figure 9: AUOI2SM.DL3 audio path shown in **bold brown**

AUOI2SM.DL3 makes it possible to send independent audio to the DAC and I2S. Note, however, that that driver can only support the basic master mode sample rates (e.g. not 44100 Hz).

Figure 9 shows the manual audio path activated by the AUOI2SM.DL3 driver.

7.6.4 Driver AUOI2SS.DL3

The AUOI2SS.DL3 is otherwise similar to AUOI2SM.DL3 (Chapter 7.6.3), except that the driver operates in slave mode.

In slave mode the user has no control over sample rate, so the audio cannot be fed anywhere else without resynchronization except the I2S output. Currently there does not exist a driver to synchronize I2S slave output with DAC output. Also there is no driver to synchronize inputs with I2S slave output.

7.6.5 Driver AUII2SM.DL3

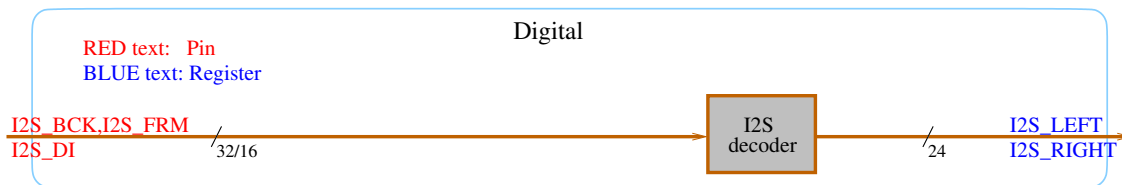


Figure 10: AUII2SM.DL3 audio path shown in **bold brown**

AUII2SM.DL3 makes it possible to read audio data in master mode, as shown in Figure 10.

7.6.6 Driver AUII2SS.DL3

The AUII2SS.DL3 is otherwise similar to AUII2SM.DL3 (Chapter 7.6.5), except that the driver operates in slave mode.

In slave mode the user has no control over sample rate, so the audio cannot be fed anywhere else without resynchronization except the I2S output. To synchronize I2S slave audio with the analog audio output driver AUODAC.DL3 (Chapter 7.2.1), use the AUXSYNCS.DL3 synchronization driver (Chapter 7.9.1).

7.6.7 Driver AUXI2SM.DL3

The AUXI2SM.DL3 audio driver handles both I2S input and output in master mode, as shown in Figures 9 and 10.

The I2S input and output are always kept in sync, so software using both the input and output doesn't need to do synchronization. Also, because the exact I2S sample rates 24 and 48 kHz are directly supported by VS1005's analog audio output path, as well as the analog audio input path, once in sync they will stay in sync.

7.6.8 Driver AUXI2SS.DL3

The AUXI2SS.DL3 is otherwise similar to AUXI2SM.DL3 (Chapter 7.6.7), except that the driver operates in slave mode.

In slave mode the user has no control over sample rate, so the audio cannot be fed anywhere else without resynchronization except the I2S output. To synchronize I2S slave audio with the analog audio output driver AUODAC.DL3 (Chapter 7.2.1), use the AUXSYNCS.DL3 synchronization driver (Chapter 7.9.1).

7.7 S/PDIF Audio Drivers

S/PDIF drivers allow receiving and transmitting audio using a coaxial or optical S/PDIF bus.

S/PDIF is a one-way channels, so the transmitter always controls the clocking of the audio. For this reason, and for certain hardware reasons, those drivers that need to either support synchronizing S/PDIF output to input, or to support 44.1 or 88.2 kHz sample rates, need to set VS1005's master clock to either 56.448 or 61.440 MHz.

With the exception of AUOXSPDA.DL3, all drivers connect to *stdaudioin* and/or *stdaudioout* if started with parameter "s". Otherwise, the drivers need to be opened and accessed manually.

Only one S/PDIF driver may be in use at any given time. It is not possible to run one input and one output driver, and expect the system to do anything sensible.

All S/PDIF drivers are incompatible with USB operation, because USB requires that CLKI = 60.000 MHz, and no standard sample rates can be implemented with this clock rate.

Summary of S/PDIF drivers							
Name	Sample rates / kHz				Modifies SysClk ¹	Exact rates ²	Notes
	44.1	48	88.2	96			
AUOSPDA		X		X		X	³ Automatic output
AUISPD	X	X	X	X	X		Generic input
AUXSPD	X	X	X	X	X		Generic I/O, sync in & out
AUXSPD48		X		X	X		Limited I/O, sync in & out
AUOSP48S		X			X		Output, sync with input
AUOSPD48		X				X	Output at exactly 48 kHz

¹ The driver modifies System Clock to either 56.448 MHz (for 44.1 or 88.2 kHz operation) or 61.440 MHz (for 48 or 96 kHz operation). The driver is incompatible with FM receiver software.

² The driver sample rate is as accurate as the input clock's 12.288 MHz is.

³ Audio sample rate may be anything up to 96 kHz. It is converted by hardware to the target sample rate.

7.7.1 Driver AUOSPDA.DL3

AUOSPDA.DL3 captures audio that is being sent to the DAC audio path, and copies it automatically to the S/PDIF output.

Figure 11 shows the automatic audio path built by the driver. The driver copies the audio going to the DAC driver, and sends it through a software volume control to the S/PDIF output. To function, it needs a DAC (e.g. AUODAC.DL3) driver to be installed.

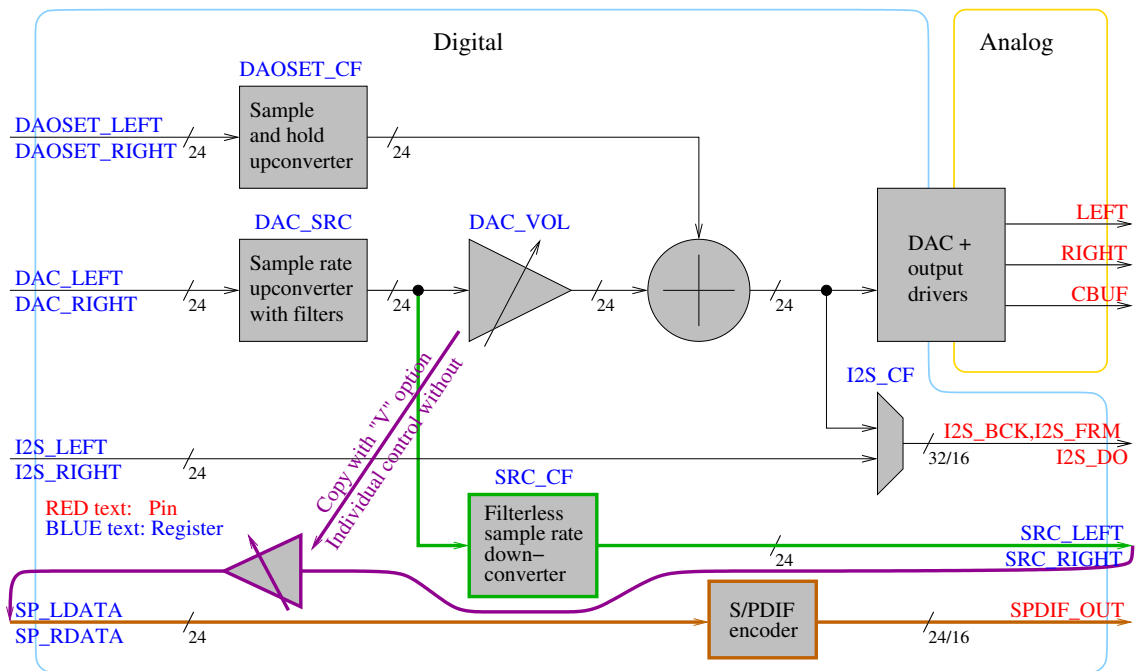


Figure 11: AUOSPDA.DL3 audio path shown in **bold brown**. Software driver connecting to the filterless sample rate converter (**bold green**) shown in **bold magenta**

The sample rate is set by default to 96000 Hz, and anything played back is converted to the target sample rate by the high-quality VS1005 Filterless sample rate downconverter, then through a software volume control to the SP_LDATAL/SP_RDATAL registers. As long as the audio that is being played back has a sample rate that is not higher than the S/PDIF output sample rate, no aliasing will occur, and sound quality will remain good.

If the driver is started with parameter “48000”, it will use an output rate of 48 kHz. Only use this option if no audio that you play back has a sample rate over 48 kHz.

The driver can be opened manually, in which case it has a separate volume control that can be used. As a default, full output volume is used. However, if the driver is started with parameter “v”, it will automatically copy any volume setting sent to *stdaudioout*.

If the driver has not started with the “v” option, the user may set the volume from C by opening a file pointer to it, then calling *stdio()* to set the volume (see README.TXT of the driver for details on how to do that), then finally closing the file pointer / driver. Alternatively volume may be set from the VSOS Shell using *AuOutput* (Chapter 9.2), as in the following example that sets volume to -12.5 dB of maximum level:

```
S:>auoutput -dauospda -l-12.5
```

7.7.2 Driver AUISPD.DL3

AUISPD.DL3 enables S/PDIF input. It supports 44.1 kHz, 48 kHz, 88.2 kHz, and 96 kHz sample rates.

This driver automatically sets the VSDSP core clock to enable S/PDIF operation. It is incompatible with any USB drivers or FM Radio receiver software.

Example of how to activate under VSOS Shell so that input from S/PDIF is automatically played back to the DAC, and the DAC is kept synchronized with the input:

```
S:>driver +auodac s
S:>driver +auispd s
S:>driver +auxsyncs
S:>driver +auxplay
S:>auinput
stdaudioin:      0x23dc, auispd::audioFile=0x0c63(3171)
->Identify():    0x43b7, auxsyncs::Identify returns "AUXSYNCS"
->op:            0x23e3, auispd::audioFileOps=0x0000(0)
->Ioctl():       0x41ee, auxsyncs::AudioIoctl
->Read():        0x40f6, auispd::AudioRead
Sample rate:     47995
Bits per sample: 16
Channels:        unknown (assuming 2)
Buffer size:     512 16-bit words (256 16-bit stereo samples)
Buffer fill:     84 16-bit words (42 16-bit stereo samples)
Sample counter:  1068008
Overflows:       4170
S:>
```

7.7.3 Driver AUXSPD.DL3

AUXSPD.DL3 enables S/PDIF input and output, and synchronizes the output with the input. It supports 44.1 kHz, 48 kHz, 88.2 kHz, and 96 kHz sample rates.

Because this driver automatically synchronizes its output with its input, there is no need to run a separate synchronization driver like AUXSYNCS.DL3.

This driver automatically sets the VSDSP core clock to enable S/PDIF operation. It is incompatible with any USB drivers or FM Radio receiver software.

Example of how to activate under VSOS Shell so that input from S/PDIF is automatically played back to the S/PDIF output:

```
S:>driver +auxspd s
S:>driver +auxplay
S:>auinput
stdaudioin:      0x279f, auxspd::audioFile=0x0c63(3171)
->Identify():    0x40ed, auxspd::Identify returns "AUXSPD"
->op:            0x27a7, auxspd::audioFileOps=0x0000(0)
->Ioctl():       0x3f69, auxspd::AudioIoctl
->Read():        0x4059, auxspd::AudioRead
Sample rate:     48010
Bits per sample: 16
Channels:        unknown (assuming 2)
```

```

Buffer size:      512 16-bit words (256 16-bit stereo samples)
Buffer fill:      82 16-bit words (41 16-bit stereo samples)
Sample counter:   654782
Overflows:        1320
S:>

```

7.7.4 Driver AUXSPD48.DL3

Like AUXSPD.DL3 (Chapter 7.7.3), but limited to 48 and 96 kHz, and for this reason slightly smaller.

7.7.5 Driver AUOSP48S.DL3

AUOSP48S.DL3 enables S/PDIF output, and synchronizes the output with an input of another audio driver, which should nominally run at 48 kHz. An example use case for this driver is when the input is I2S in slave mode (Chapter 7.6.6, *Driver AU12SS.DL3*), and when it is known beforehand that the nominal sample rate of the input is always 48 kHz.

Because this driver automatically synchronizes its output with an input, there is no need to run a separate synchronization driver like AUXSYNCS.DL3.

This driver automatically sets the VSDSP core clock to enable S/PDIF operation. It is incompatible with any USB drivers or FM Radio receiver software.

Example of how to activate under VSOS Shell so that input from I2S (slave mode) is automatically played back to the S/PDIF output (note: nothing is played through analog audio): the input:

```

S:>driver +au12ss s
S:>driver +auosp48s s
S:>driver +auxplay
S:>

```

7.7.6 Driver AUOSPD48.DL3

AUOSPD48.DL3 enables S/PDIF output at exactly 48 kHz.

Example of how to activate under VSOS Shell so that input from the ADC is automatically played back to the S/PDIF output (note: nothing is played through analog audio):

```

S:>driver +au1adc s
S:>driver +auospd48 s
S:>driver +auxplay
S:>

```

7.8 Pulse Width Modulation Output Driver

The Pulse Width Modulation audio driver converts its input to a sigma-delta encoded mono signal, and outputs that signal through VS1005's PWM output pin (pin 88). If the PWM pin is followed by a proper RC low-pass filter, the PWM output can be used to implement a high-quality so-called 0.1-channel subwoofer output.

For best results, the accompanying filter should have its -3 dB point at approximately 200 Hz or lower.

7.8.1 Driver AUOPWM.DL3

AUOPWM.DL3 offers a sigma-delta encoded PWM output running at exactly 48 kHz. The useful bandwidth of the output is in the range of 0...200 Hz.

7.9 Slave Audio Input Synchronization Driver

When inputting audio data in slave mode (using for example the I2S audio input slave driver `AUII2SS.DL3`), the exact sample rate of the audio is usually not known. Even if the nominal sample rate is known, mismatches between master transmitter and the VS1005 receiver clock crystals causes there to always be a mismatch between them (example: transmitter nominally sends 48000 Hz, but because of a clock mismatch the receiver sees the data at 48002.3 Hz).

This speed mismatch will eventually cause an audio buffer underflow or overflow, which may cause audible clicks or other kinds of distortion.

The slave audio input synchronization drivers are intended to remove the synchronization issue.

7.9.1 Driver `AUXSYNCS.DL3`

The Slave Audio Input Synchronization Driver `AUXSYNCS.DL3` synchronizes a slave audio input driver with the analog Earphone/Line Out driver `AUODAC.DL3`.

Before starting the Sync Driver, the user must first load and connect a slave audio input driver to `stdaudioin`, and the analog output driver to `stdaudioout`. When the driver is loaded, it will automatically adjust the analog output sample rate according to the input. The adjustment range is up to 97500 Hz, so standard sample rates up to 96 kHz can be received. The Sync Driver can dynamically change its sample rate if the input sample rate changes.

Example `config.txt` file clip:

```
# Load I2S Slave Input driver and make it stdaudioin
AUII2SS s
# Load Line Out / Earphone output driver and make it stdaudioout
AUODAC s
# Connect and synchronize stdaudioout with stdaudioin slave
AUXSYNCS
```

The same can be done using the VSOS Shell using the following commands:

```
S:>driver +auii2ss s
S:>driver +auodac s
S:>driver +auxsyncs
```

`AUXSYNCS.DL3` has been tested with the I2S Slave Input drivers, but it is designed to be usable with any generic slave input driver that offers a near-constant data rate. It may not work properly with input drivers with large data bursts.

7.10 Audio Input to Output Copying Driver

Sometimes it's useful to play back audio data from an input to an output in the background. This can be done by an audio copying driver.

7.10.1 Driver AUXPLAY.DL3

The AUXPLAY.DL3 driver reads data from *stdaudioin* and copies it to *stdaudioout*. While seemingly trivial, it does so in the background, allowing the user to do other operations while sound is being played back.

Normally the driver reports to *stdout* if there are input buffer overflows or output buffer underflows. The amount of the overflows/underflows are given in stereo samples (so e.g. +4800 at a sample rate of 48000 means 1/10s). The reports use the following format:

```
AUXSPLAY: In overflow +4088  
AUXSPLAY: Out underflow +4034
```

To disable overflow and underflow reporting, give the 'q' parameter to AUXSPLAY.DL3.

8 Audio Filter Drivers

Audio filter drivers connect to an audio source or sink, and offer additional functionality, like filtering.

Audio filter drivers are named using the following format:

FTdyyyyy.DL3

where

Symbol	Description
d	Driver direction: I = input, O = output, X = Input/Output
yyyyy	Driver name, max 5 characters

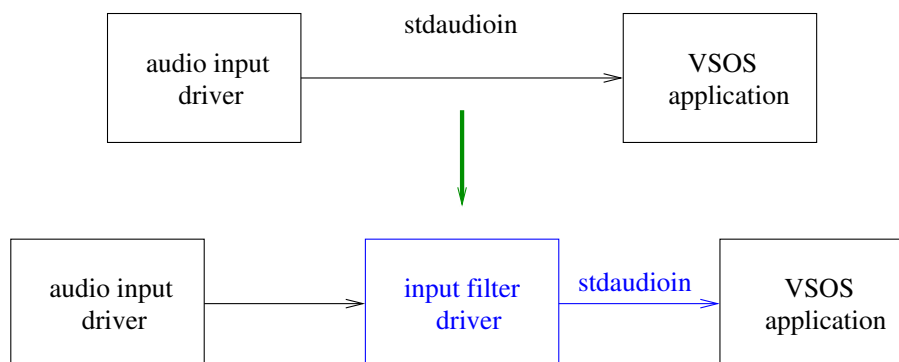


Figure 12: An input filter driver connects to the *stdaudioin* chain

All filter input drivers connect directly between the current *stdaudioin* program chain and the user program, as shown in Figure 12. The base driver responsible for *stdaudioin* (e.g. AUIADC.DL3) must be loaded before the filter driver.

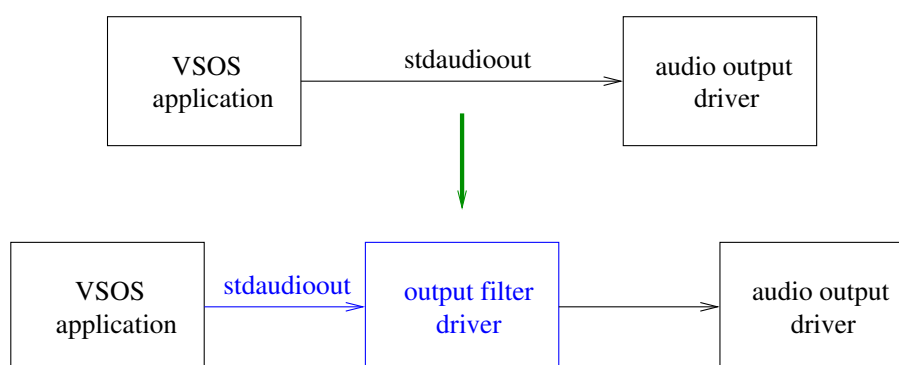


Figure 13: An output filter driver connects to the *stdaudioout* chain

All filter output drivers connect directly between the user program and the current *stdaudioout* program chain, as shown in Figure 13. The base driver responsible for *stdaudioout* (e.g. AUODAC.DL3) must be loaded before the filter driver.

Audio filters must be removed in the reverse order of loading.

Below is a command line example of audio and filter driver allocation and removal:

```
S:>auinput
E: No stdaudioin or NULL ptr
S:>driver +audiadc s
S:>auinput
stdaudioin:      0x2392, audiadc::audioFile=0x0c63(3171)
->Identify():    0x414e, audiadc::Identify returns "AUIADC"
->op:            0x2399, audiadc::audioFileOps=0x0000(0)
->Ioctl():       0x4023, audiadc::AudioIoctl
->Read():        0x4104, audiadc::AudioRead
Sample rate:     48000
Bits per sample: 16
Channels:        unknown (assuming 2)
Buffer size:     512 16-bit words (256 16-bit stereo samples)
Buffer fill:     508 16-bit words (254 16-bit stereo samples)
Sample counter:  51484
Overflows:       51232
S:>driver +ftiagc
S:>auinput
stdaudioin:      0x2541, FTIAGC::audioFile=0x0863(2147)
->Identify():    0x4644, FTIAGC::Identify returns "FTIAGC32"
->op:            0x2569, FTIAGC::audioFileOps=0x0000(0)
->Ioctl():       0x4508, FTIAGC::AudioIoctl
->Read():        0x4597, FTIAGC::AudioRead
[... rest of auinput printouts cut for brevity ...]
S:>driver -ftiagc
S:>auinput
stdaudioin:      0x2392, audiadc::audioFile=0x0c63(3171)
->Identify():    0x414e, audiadc::Identify returns "AUIADC"
->op:            0x2399, audiadc::audioFileOps=0x0000(0)
->Ioctl():       0x4023, audiadc::AudioIoctl
->Read():        0x4104, audiadc::AudioRead
[... rest of auinput printouts cut for brevity ...]
S:>driver -audiadc
S:>auinput
E: No stdaudioin or NULL ptr
```

8.1 Equalizer Filter Driver

The Equalizer Filter Drivers implements a high-quality, multiband equalizer to VS1005's output audio path.

The package itself contains detailed PDF documentation; please read it for details.

8.1.1 Driver FTOEQU.DL3

The Equalizer driver FTOEQU.DL3 connects to *stdaudioout* as shown in Figure 13 on page 35.

The package itself contains detailed PDF documentation; please read it for details.

8.1.2 Control Program SETEQU.DL3

```
Usage: SetEqu [-i|-o] [n [flags centerF gain qFactor]] [-h]
-i      Set stdaudioin
-o      Set stdaudioout (default)
n       Use filter number n (1 ... MAX_FILTERS)
flags   1=left, 2=right
centerF Center frequency in Hz
gain    Gain in dB (-12.0 ... 12.0)
qFactor Q Factor (0.1 ... 4.0)
-h      Show this help
```

Examples:

```
setequ 1 3 400 -6.0 0.5 # Set filter 1, L+R, 400 Hz, -6 dB, Q 0.5
setequ 1 0              # Clear filter 1
setequ 1                # Show filter 1
setequ                  # Show all filters
```

SETEQU.DL3 is a program to set and/or display the equalizer parameters.

Note that the equalizer is a relatively expensive function, so the user should take notice of free CPU time if adding more than a basic bass/treble controller.

The package itself contains detailed PDF documentation; please read it for details.

8.2 DC Offset / AGC Filter Drivers

When audio is digitized, two technical issues are DC Offset and Large Dynamic Range.

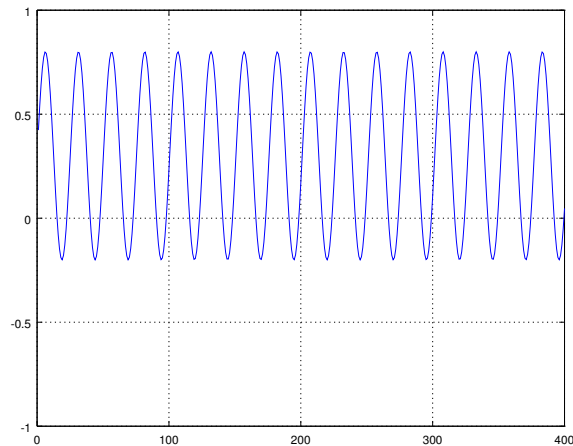


Figure 14: Audio with exaggerated DC offset

In an ideal world DC Offset wouldn't happen. However, in the real world, signals almost always have a slight DC offset. Note, how the sine wave in Figure 14 does not move evenly around the center point, but has an offset of about +0.35. While the figure has been greatly exaggerated, this is a real phenomenon caused by a myriad of different reasons.

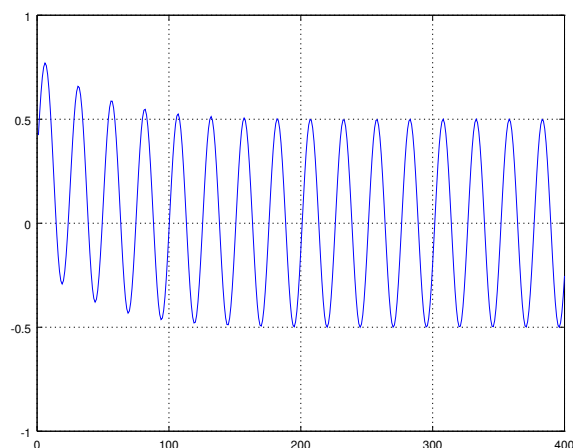


Figure 15: Audio with DC blocking

DC offset may cause many issues, including increased power consumption, audible cracks and pops, wearing down of speaker elements, and non-ideal audio compression. Because of this, it is best to remove the audio offset with a DC Blocker algorithm, as shown in Figure 15. Notice how the offset disappear after a little while (in this case, it

has vanished practically completely by sample 150).

Another issue in audio is excessive dynamic range. This is not a problem when recording well-mixed, pre-recorded music, but it may be a big issue when recording speech from the microphone. To compensate for the audio level differences of close and far away speakers, and Automatic Gain Control (AGC) unit may often be useful. Note, however, that AGC should not be used for HiFi recording applications!

8.2.1 Driver FTIDCBL.DL3

The DC Block driver FTIDCBL.DL3 connects to *stdaudioin* as shown in Figure 12 on page 35.

The driver may be controlled either through C `ioctl()` function calls as described in the README.TXT file for the driver itself, or from the VSOS Shell using the SETAGC.DL3 command.

8.2.2 Driver FTIAGC.DL3

In addition to the DC Block driver described in 8.2.1, the AGC driver offers an Automatic Gain Control function.

The driver may be controlled either through C `ioctl()` function calls as described in the README.TXT file for the driver itself, or from the VSOS Shell using the SETAGC.DL3 command.

8.2.3 Control Program SETAGC.DL3

```
Usage: SetAgc [-i|-o] [-a x|-d x|-t x|-max x|-min x|-d x] [-h]
-i      Set stdaudioin (default)
-o      Set stdaudioout
-a x    Set attack (ms)
-d x    Set decay (ms)
-t x    Set target level (dB)
-max x  Set maximum gain (dB)
-min x  Set minimum gain (dB)
-b x    Set DC Block Filter (0x4000 = HiFi, 0x8000 = Speech,
                                0x0      = Auto, 0xC00x = Set to x)
-h      Show this help
```

With no parameters SetAgc will show current values

Sets/Prints AGC and/or DC Block Filter parameters. For the DC Block Filters only the -b setting option is available.

8.3 Pitch Shifter / Speed Shifter Filter Driver

The FtPitch package offers a pitch and speed shifter that connects to stdout. The speed shifter can nominally be controlled to speeds between 0.68x and 1.64x of realtime, and the pitch shifter can nominally be controlled between 0.61x and 1.47x of normal pitch.

Features and limitations:

- Speed divided by pitch (speed/pitch) must be between 0.68 and 1.64.
- Pitch shifting alters sample rate. If the resulting sample exceeds 96 kHz, playback will be at incorrect speed.
- The shifter has been optimized to work best for audio where sample rate is between 32 and 48 kHz.

8.3.1 Driver FTOPITCH.DL3

The Pitch shifter driver FTOPITCH.DL3 connects to *stdaudioout* as shown in Figure 13 on page 35.

The driver may be controlled either through C `ioctl()` function calls as described in the README.TXT file for the driver itself, or from the VSOS Shell using the SETPITCH.DL3 command.

8.3.2 Control Program SETPITCH.DL3

```
Usage: SetPitch [-i|-o] [-sx] [-px] [-h]
-i      Set stdaudioin
-o      Set stdaudioout (default)
-sx     Set speed to x times normal (0.68 - 1.64 if pitch=1.0)
-px     Set pitch to x times normal (0.61 - 1.47 if speed=1.0)
-h      Show this help
```

Note:

Correct playback requires that $0.68 \leq \text{speed/pitch} \leq 1.644$.

Sets/Prints Pitch and Speed Shifter parameters. Example:

```
S:>driver +ftopitch
S:>setpitch
Pitch 1.000
Speed 1.000
S:>setpitch -p1.1 -s0.9
S:>setpitch
Pitch 1.100
Speed 0.900
```


8.4 Reverb Generator Filter Drivers

The FtRev package offers a reverb-style echo generator that connects to *stdaudioin* or *stdaudioout*. Many parameters of the Reverb Generator may be modified.

8.4.1 Driver FTIREV.DL3

Features and limitations:

- Works up to 48 kHz 32 bits.
- Requires about 32 MIPS when running at 48 kHz 16 bits.

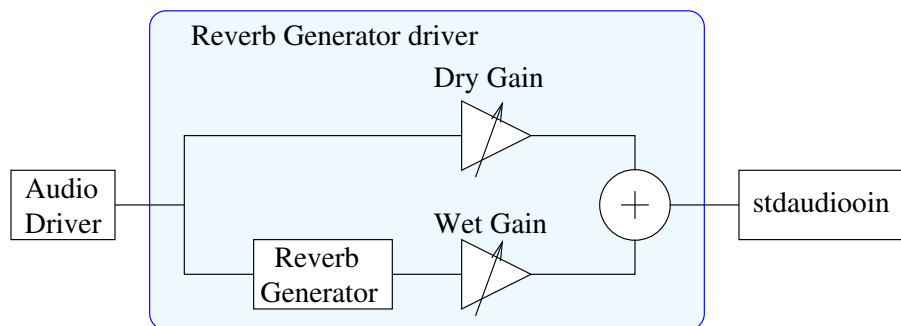


Figure 16: Reverb Generator FTIREV signal paths

The Reverb Generator driver FTIREV.DL3 connects to *stdaudioin* as shown in Figure 12 on page 35. The Reverb Generator signal paths are shown in Figure 16.

The driver may be controlled either through C `ioctl()` function calls as described in the README.TXT file for the driver itself, or from the VSOS Shell using the SETREV.DL3 command.

Note: To easily test how modifying parameters affects sound, you can start the automatic playback driver AUXPLAY (Chapter 7.10.1) as follows:

```
S:>driver +ftirev
S:>driver +auxplay
S:>setrev -i -v -s600 -d0 -w1024 -t65535 -f25000 -r85
ROOM:
(-r) First reflection:      85 ms
(-s) Room size           :   600 cm (1-32767)
(-t) Reverb time         :  65535 ms (1-65535)
(-f) Room softness       :  25000   (0=hard-65535=soft)
(-d) Dry gain            :     0    (0-32767, 1024=1)
(-w) Wet gain            :   1024   (0-32767, 1024=1)
    Sample rate         :  48000 Hz
```

```

Delay pairs      :      7
Ext. mem. size   :      0 bytes
Ext. mem. read   : 0x0000
Ext. mem. write  : 0x0000

```

S:>

8.4.2 Driver FTOREV.DL3

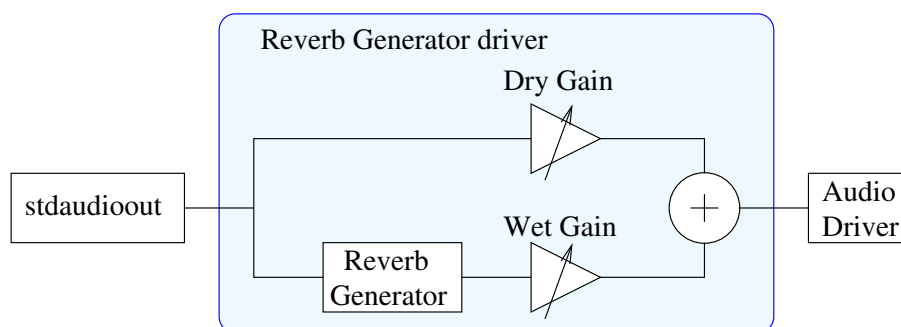


Figure 17: Reverb Generator FTOREV signal paths

The Reverb Generator driver FTOREV.DL3 is similar to FTIREV.DL3 presented in Chapter 8.4.1, except that it connects to *stdaudioout* in a way shown in Figure 13 on page 35 instead of *stdauioin*. The Reverb Generator signal paths are shown in Figure 17.

Note: To easily test how modifying parameters affects sound, you can start the automatic playback driver AUXPLAY (Chapter 7.10.1) as follows:

```

S:>driver +ftorev
S:>driver +auxplay
S:>setrev -v -s600 -d0 -w1024 -t65535 -f25000 -r85
ROOM:
(-r) First reflection:      85 ms
(-s) Room size          :    600 cm (1-32767)
(-t) Reverb time        :   65535 ms (1-65535)
(-f) Room softness     :   25000    (0=hard-65535=soft)
(-d) Dry gain          :      0    (0-32767, 1024=1)
(-w) Wet gain          :   1024    (0-32767, 1024=1)
Sample rate           :   48000 Hz
Delay pairs           :      7
Ext. mem. size        :      0 bytes
Ext. mem. read        : 0x0000
Ext. mem. write       : 0x0000

```

S:>

8.4.3 Driver FTIREV23.DL3

Features and limitations:

- FTIREV23 is like FTIREV (Chapter 8.4.1), but makes it possible to create larger and thus more believable rooms.
- Uses VS23S010 or VS23S040 S-RAM IC for buffering.
- Optimized for 48 kHz, but works up to 96 kHz mode.
- Requires about 48 MIPS when running at 48 kHz 16 bits.
- Requires about 59 MIPS when running at 96 kHz 32 bits.
- If sample rate is greater than 48 kHz (typ. 96 kHz), the first reflection option (-f in SETREV, Chapter 8.4.5) is not available.

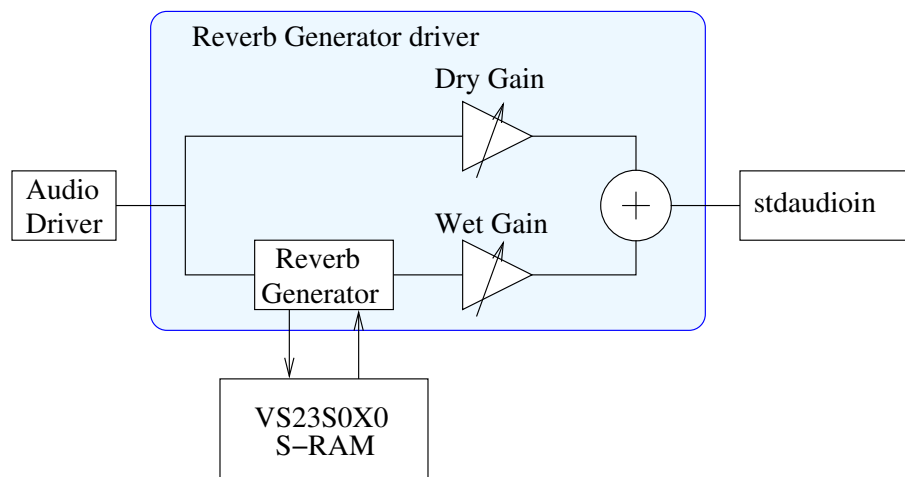


Figure 18: Reverb Generator FTIREV23 signal paths

The Reverb Generator driver FTIREV23.DL3 is like FTIREV.DL3 except that it uses an external VS23S010 or VS23S040 S-RAM IC for buffering, making it possible to create larger rooms than with FTIREV.DL3. The Reverb Generator signal paths are shown in Figure 18.

Running FTIREV23 at 96 kHz 32 bits

The FTIREV23 Reverb Generator supports sample rates up to 96 kHz and bit depths up to 32 bits. However, if used at these parameters, it requires lots of calculating power, and when system overhead (typically 20 MIPS) is counted in, the clock requirement is typically around 80 MHz.

An example of how to start the driver in 96 kHz 32-bit mode successfully from config.txt is shown below:

```

RUN SETCLOCK -193 80
AUODAC s
AUIADC s
RUN AUOUTPUT -b32 -r96000 -s2048
RUN AUIINPUT -b32 -r96000 -s2048
FTOREV23
AUXPLAY

```

The same can be achieved from the command line as follows. Here you can also see that the system requires almost 79 MHz to run:

```

S:>setclock -193 80
S:>driver +auodac s
S:>driver +auiadc s
S:>auoutput -b32 -r96000 -s2048
S:>auinput -b32 -r96000 -s2048
S:>driver +ftirev23
S:>driver +auxplay
S:>setclock -t
CPU speed: effective speed 7.33/86.02 MHz = 8.5%, overhead 78.68 MHz
S:>

```

8.4.4 Driver FTOREV23.DL3

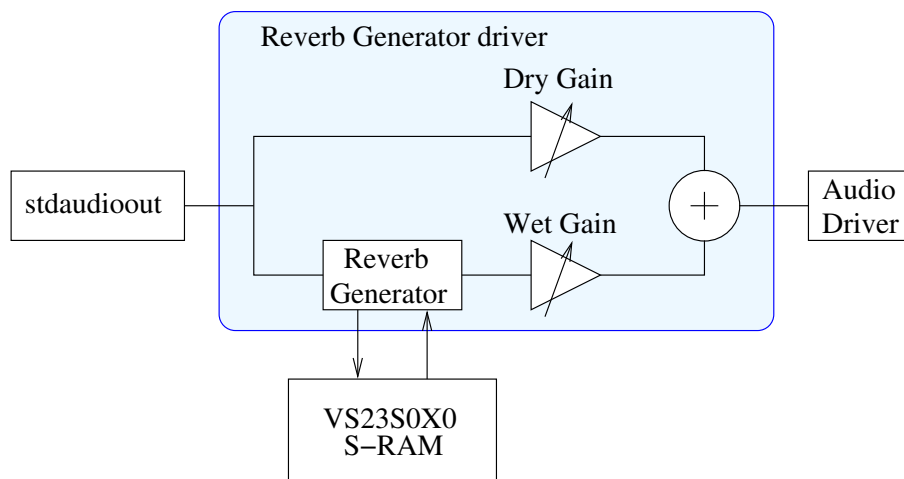


Figure 19: Reverb Generator FTOREV23 signal paths

The Reverb Generator driver FTOREV23.DL3 is like FTIREV23.DL3 in Chapter 8.4.3 except that it connects stdaudioout instead of stdaudioin. The Reverb Generator signal paths are shown in Figure 19.

8.4.5 Control Program SETREV.DL3

```
Usage: SetRev [-i|-o] [-v|+v] [-sx|-tx|-fx|-dx|-wx] [-h]
-i      Set stdaudioin
-o      Set stdaudioout (default)
-rx     Set first reflection time in milliseconds
-sx     Set room size to x cm (200-1200 recommended)
-tx     Set reverb Time to x ms (100-5000 recommended)
-fx     Set room wall soFtness (0 = hard, 65535 = soft)
-dx     Set Dry gain (0-65535, 1024 = 1)
-wx     Set Wet gain (0-65535, 1024 = 1)
-v|+v   Verbose on/off
-h      Show this help
```

Note:

It is recommended that Dry gain + Wet gain would not be much over 1024 to avoid distortion.

```
S:>setrev
```

```
ROOM:
```

```
(-r) First reflection:      20 ms
(-s) Room size           :   600 cm (1-32767)
(-t) Reverb time         :  1000 ms (1-65535)
(-f) Room softness       :  32767   (0=hard-65535=soft)
(-d) Dry gain            :   1024   (0-32767, 1024=1)
(-w) Wet gain            :    256   (0-32767, 1024=1)
      Sample rate        :  48000 Hz
      Delay pairs        :         7
```

The user-adjustable parameters are as follows.

First Reflection Time (-r, 1...200)

First Reflection Time tells how many milliseconds it takes before the first reflection reaches the listener. By making this number large, the user can simulate a stadium-like environment or a hall where lots of reverberation comes from the other end of the hall.

Room Size (-s, 1...32767)

Room Size is the approximate room size in centimeters. The larger the room, the more indistinct, or hall-like, the reverb is.

Note that room size is limited by the amount of free data memory there is available in the system. When you run SetRev, the displayed parameter "Delay pairs" tells how well

the reverb driver has been able to set its filters. In an ideal case, “Delay pairs” should be 8. Anything below 4 usually gives a somewhat artificial result. Also, if you define a room that is way too large to being implemented, it will automatically be resized.

In the example below, we try to make a “room” 300 meters wide and the first echo should come only after 500 milliseconds. But, depending on the driver we may end up with a room that is smaller, and with a shorter pre-echo time. Note also the “Delay pair” counter: it preferably be 8, and anything below 4 usually isn’t enough to create a natural result. Note that the driver FTOREV23.DL3 doesn’t have the room size limitation.

```
S:>setrev -s30000 -r500 -v
```

```
ROOM:
```

```
(-r) First reflection:      85 ms
(-s) Room size           : 9842 cm (1-32767)
(-t) Reverb time         : 1000 ms (1-65535)
(-f) Room softness       : 32767 (0=hard-65535=soft)
(-d) Dry gain            : 1024 (0-32767, 1024=1)
(-w) Wet gain            : 256 (0-32767, 1024=1)
    Sample rate          : 48000 Hz
    Delay pairs          :      1
```

Reverb Time (-t, 1...65535)

Reverb Time tells how many milliseconds it will take for the reverberation to fade -60 dB from the original level. For some insane effects, try to set the reverb time to 10 or 60 seconds!

Room Softness (-f, 0...65535)

Room Softness defines the softness of the wall material in the room. In a soft room, higher frequencies will attenuate faster than low frequencies, making the room feel warmer.

Dry Gain (-d, 0...32768)

Dry Gain is the gain setting for the direct input to output audio path. 1024 is the nominal gain: the original sound is passed through with no volume change.

To avoid distortion, it is recommended that Dry Gain + Wet Gain \leq 1024, or at least not much over 1024.

Wet Gain (-w, 0...32768))

Wet Gain is the gain setting for the reverb signal. 1024 is the nominal gain.

To avoid distortion, it is recommended that Dry Gain + Wet Gain \leq 1024, or at least not much over 1024.

SETREV.DL3 Examples

The following examples sets reverb parameters for *stdaudioin*. If running an output driver, use “-o” option instead of “-i” to connect to *stdaudioout*.

Example 1; stdaudioin, mild effect:

```
S:>setrev -i -v -r2 -s600 -t1000 -f20000 -d960 -w64
```

Example 2; stdaudioin, moderate effect:

```
S:>setrev -i -v -r85 -s600 -t1000 -f32768 -d768 -w256
```

Example 3; stdaudioin, strong effect:

```
S:>setrev -i -v -r100 -s1000 -t5000 -f65500 -d512 -w512
```

Example 4; stdaudioin, nightmarishly strong effect:

```
S:>setrev -i -v -r100 -s2000 -t20000 -f10000 -d64 -w960
```

8.5 Noise Killer Filter Driver

Because of the way stereo information is transmitted on FM radio, stereo reception is always more susceptible to white noise and other artifacts than mono reception. A way to reduce or remove the noise is to either dampen the stereo effect at the receiver, or to just turn FM stereo reception off. The FtNoiseKiller package offers an adaptive FM stereo radio noise killer algorithm that doesn't destroy the stereo image.

8.5.1 Driver FTINOISE.DL3

Features and limitations:

- Optimized for 32 kHz operation.
- Requires about 25 MIPS at 32 kHz 16 bits.
- Can only handle 16-bit audio (if audio is set to 32 bits, the noise killer is disabled).

The noise killer driver FTINOISE.DL3 connects to *stdaudioin* as shown in Figure 12 on page 35.

The driver may be controlled either through C `ioctl()` function calls as described in the README.TXT file for the driver itself, or from the VSOS Shell using the SETNOISE.DL3 command.

Note: To easily test how the algorithm works, you can start the RDS Radio receiver (v1.05 or higher) after activating the noise killer driver:

```
S:>driver +ftinoise
S:>rdsradio
```

Now you can turn the noise killer off by pushing '0', and back on by pushing '5' (or '4' or '3' if reception is poor).

8.5.2 Control Program SETNOISE.DL3

```
Usage: SetNoise [-i|-o] [-v|+v] [-nx] [-h]
-i          Set stdaudioin (default)
-o          Set stdaudioout
-nx         Set noise killer level (default: 50 dB, 0 = off)
-v|+v       Verbose on/off
-h          Show this help
```

Example:


```
S:>setnoise
Noise killer at 50 dB
S:>setnoise -n0 -v
Noise killer at 0 dB
S:>
```

The default for the noise killer is a signal-to-noise ratio of 50 dB. If the reception is poor, lower numbers may be required. Note that by the value of 30 dB, the stereo image mostly disappears. Setting the noise killer to 0 dB will disable it.

8.6 Mono / Differential Filter Drivers

The FtMono audio drivers makes it possible to convert a stereo signal into a mono signal, and optionally inverting either or both of its outputs to get a differential signal. This is helpful e.g. when connecting VS1005's analog outputs to a differential mono amplifier.

The drivers may be controlled either through C ioctl() function calls as described in the README.TXT file for the driver itself, or from the VSOS Shell using the SETMONO.DL3 command.

8.6.1 Driver FTIMONO.DL3

The mono / differential driver FTIMONO.DL3 connects to *stdaudioin* as shown in Figure 12 on page 35.

8.6.2 Driver FTOMONO.DL3

The mono / differential driver FTOMONO.DL3 connects to *stdaudioout* as shown in Figure 13 on page 35.

8.6.3 Control Program SETMONO.DL3

```
Usage: SetMono [-o] [-i] [lr|ll|rr|rl|mono] [il] [ir] [-h]
-i      Set stdaudioin
-o      Set stdaudioout (default)
lr      Normal LR stereo
ll      Copy Left to output
rr      Copy Right to output
rl      Swap Left and Right
mono    Output mean of Left and Right
il      Invert Left output
ir      Invert Right output
-h      Show this help
```

With no parameters set, current flags are shown

Example that starts the output driver, then we set it to mono mode and invert the right channel for differential output:

```
S:>AuOutput
stdaudioout: 0x2056, auodac::audioFile=0x0c43(3139)
->Identify(): 0x3cb1, auodac::Identify returns "AUODAC"
->op: 0x205f, auodac::audioFileOps=0x0000(0)
```

```
->Ioctl(): 0x3b69, auodac::AudioIoctl
->Write(): 0x3c67, auodac::AudioWrite
Sample rate: 48000
Bits per sample: 16
Channels: unknown (assuming 2)
Buffer size: 4096 16-bit words (2048 16-bit stereo samples)
Buffer fill: 4 16-bit words (2 16-bit stereo samples)
Sample counter: 528719
Underflows: 526675
Volume: +0.0 dB of maximum level
S:>driver +ftomono
S:>AuOutput
stdaudioout: 0x23e4, FtOMono::audioFile=0x0843(2115)
->Identify(): 0x3cb1, auodac::Identify returns "AUODAC"
->op: 0x23df, FtOMono::audioFileOps=0x0000(0)
->Ioctl(): 0x437d, FtOMono::AudioIoctl
->Write(): 0x43c8, FtOMono::AudioWrite
Sample rate: 48000
Bits per sample: 16
Channels: unknown (assuming 2)
Buffer size: 4096 16-bit words (2048 16-bit stereo samples)
Buffer fill: 4 16-bit words (2 16-bit stereo samples)
Sample counter: 3410130
Underflows: 3408087
Volume: +0.0 dB of maximum level
S:>SetMono
Mono flags: lr
S:>SetMono mono ir
S:>SetMono
Mono flags: mono ir
```

8.7 Matrix driver: 3 Channels to 2 Channels

The Ft3To2 audio drivers matrixes a 3-channels input signal to a 2-channel output. A gain between -32...32 can be applied to each matrix point.

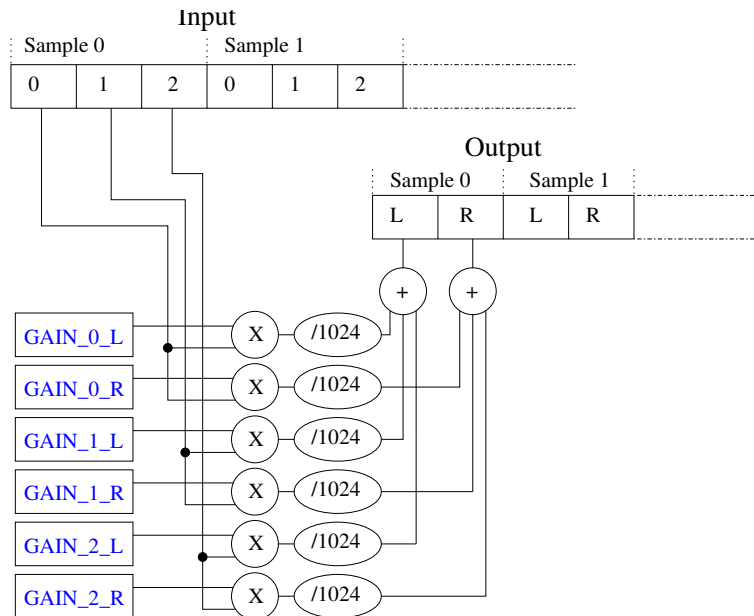


Figure 20: Ft3To2 driver's matrix

Figure 20 shows the matrix operation that is performed between the input and output. The gains can be set by the user.

The drivers may be controlled either through C `ioctl()` function calls as described in the README.TXT file for the driver itself, or by using the VSOS Shell control command SET3TO2.DL3.

8.7.1 Driver FTI3TO2.DL3

The matrix driver FTI3TO2.DL3 connects to *stdaudioin* as shown in Figure 12 on page 35.

This driver is particularly useful for downmixing the output of the 3-channel analog input audio driver AUI3ADC.DL3 (Chapter 7.5.1) to a more conventional 2-channel stereo signal.

8.7.2 Driver FTO3TO2.DL3

The matrix driver FTO3TO2.DL3 connects to *stdaudioout* as shown in Figure 13 on page 35.

8.7.3 Control Program SET3TO2.DL3

```
S:>Set3To2 -h
Usage: Set3To2 [-o|-i|-sc1,...|-v|+v|-h]
-i Use stdaudioin
-o Use stdaudioout (default)
-sc1,... Set matrix coefficients
-h Show this help
-v|+v Verbose on/off
```

With no parameters, shows current coeffs with example of how to use "-s"

Example that demonstrates how to read and downmix 3 channels on the VS1005 Developer Board. The example uses the 3-channel ADC driver AUI3ADC.DL3 (Chapter 7.5) to activate MIC1 and MIC2 on the board (Note: JP5 and JP6 both must have a jumper set to MIC), and also read line1_3 and play it as a mono signal.

```
S:>auinput
E: No stdaudioin or NULL ptr
S:>driver +aui3adc s
S:>auinput
stdaudioin:      0x2392, aui3adc::audioFile=0x0c63(3171)
->Identify():    0x416d, aui3adc::Identify returns "AUI3ADC"
->op:            0x239a, aui3adc::audioFileOps=0x0000(0)
->Ioctl():       0x4044, aui3adc::AudioIoctl
->Read():        0x4128, aui3adc::AudioRead
Sample rate:     48000
Bits per sample: 16
Channels:        3
Buffer size:     510 16-bit words (255 16-bit stereo samples)
Buffer fill:     504 16-bit words (252 16-bit stereo samples)
Sample counter:  506835
Overflows:       506669
S:>driver +fti3to2
S:>set3to2 -i -s1024,0,0,1024,512,512
S:>auinput -r48000 -s512 mic1 mic2
S:>auinput
stdaudioin:      0x2503, FtI3To2::audioFile=0x0823(2083)
->Identify():    0x416d, aui3adc::Identify returns "AUI3ADC"
->op:            0x24fe, FtI3To2::audioFileOps=0x0000(0)
->Ioctl():       0x44dc, FtI3To2::AudioIoctl
->Read():        0x456a, FtI3To2::AudioRead
Sample rate:     48000
Bits per sample: 16
Channels:        unknown (assuming 2)
Buffer size:     512 16-bit words (256 16-bit stereo samples)
Buffer fill:     508 16-bit words (254 16-bit stereo samples)
Sample counter:  2951878
Overflows:       2951285
S:>driver +auxplay
```

8.8 DAC Slew Limiter Driver

There are some rare cases where the output to the AUODAC driver (Chapter 7.2.1) may cause distortion in the DAC. This only happens when an almost full scale and very high frequency signal is generated. Such a signal doesn't practically ever exist at higher sample rates like 44.1 or 48 kHz. However, at 8 kHz this may sometimes happen.

To avoid any issues with DAC distortion, loading this driver after the AUODAC driver will prevent DAC overflow. The driver will only affect high-level, high-frequency signals, so normally it will pass audio through without touching it.

8.8.1 Driver FTOLIMIT.DL3

When activated, the driver will look for pathological signals to the DAC, and modify them if found. This driver only makes sense in conjunction with the AUODAC driver (Chapter 7.2.1).

9 Audio Control Programs

These programs are useful for displaying and changing audio parameters, as well as debugging audio interfaces. They are parts of the AuControl solution.

9.1 Control Program AUINPUT.DL3

```
Usage: AuInput [-ddrv|-pfp|-rrate|-bbits|-sbufsize|-cch|chconf|-v|+v|-h]
-ddrv Connect to audio driver DRV.DL3
-pfp Set input audio driver pointer to fp (use with caution!)
-rrate Set sample rate to rate
-bbits Number of bits (16 or 32)
-sbufSz Set buffer size to bufSz 16-bit words
-cch Set number of channels to ch
-v|+v Verbose on|off
chconf Audio channel config (only with AUIADC driver, see definitions below)
-h Show this help
```

chconf needs either one stereo element, or one left and one right element.

Stereo elements:

- fm

Left elements:

- line1_1, line2_1, line3_1, mic1, dia1

Right elements:

- line1_2, line2_2, line3_2, line1_3, mic2, dia2, dia3

Example:

```
auinput line1_1 line1_3
```

AUINPUT lets the user display control several parameters of *stdaudioin*, or any unlocked audio input driver, or file pointer if it is known. If used with the analog input drivers AUIADC (Chapter 7.4.1) or AUI3ADC (Chapter 7.5.1), AUINPUT can also be used to configure the input channels' multiplexers.

If called without any command line arguments that change a value, AUINPUT will display the status of the audio driver as shown below

```
S:>auinput
stdaudioin:      0x203a, auui2ss::audioFile=3171(0xc63)
->Identify():    0x3b4f, auxsyncs::Identify returns "AUXSYNCS"
->op:            0x2041, auui2ss::audioFileOps=0(0x0)
->Ioctl():       0x3992, auxsyncs::AudioIoctl
->Read():        0x38cf, auui2ss::AudioRead
Sample rate:     48000
Bits per sample: 16
Channels:        unknown (assuming 2)
```

```

Buffer size:      512 16-bit words (256 16-bit stereo samples)
Buffer fill:      508 16-bit words (254 16-bit stereo samples)
Sample counter:   235803492
Overflows:        123022

```

In this example, slave audio synchronization driver AUXSYNCS.DL3 (Chapter 7.9.1) has been loaded on top of AUI2SS.DL3 (Chapter 7.6.6), replacing two of its methods, Identify() and Ioctl().

9.2 Control Program AUOUTPUT.DL3

```

Usage: AuOutput [-ddrv|-pfp|-rrate|-bbits|-sbufSize|-cch|-lvol|-v|+v|-h]
-ddrv Connect to audio driver DRV.DL3
-pfp Set output audio file pointer to fp (use with caution!)
-rrate Set sample rate to rate
-bbits Number of bits (16 or 32)
-sbufSz Set buffer size to bufSz 16-bit words
-cch Set number of channels to ch
-lvol Volume Level of maximum (vol = -128 .. 127.5)
-v|+v Verbose on|off
-h Show this help

```

AUOUTPUT lets the user display control several parameters of *stdaudioout*, or any unlocked audio input driver, or file pointer if it is known.

If called without any command line arguments that change a value, AUOUTPUT will display the status of the audio driver as shown below

```

S:>auoutput
stdaudioout:      0x1fea, auodac::audioFile=3139(0xc43)
->Identify():      0x3b4f, auxsyncs::Identify returns "AUXSYNCS"
->op:              0x1ff1, auodac::audioFileOps=0(0x0)
->Ioctl():          0x355b, auodac::AudioIoctl
->Write():          0x39fb, auxsyncs::AudioWrite
Sample rate:      47793
Bits per sample:  16
Channels:         unknown (assuming 2)
Buffer size:      4096 16-bit words (2048 16-bit stereo samples)
Buffer fill:      4 16-bit words (2 16-bit stereo samples)
Sample counter:   235977115
Underflows:       177796
Volume:           +0.0 dB of maximum level

```

In this example, slave audio synchronization driver AUXSYNCS.DL3 (Chapter 7.9.1) has been loaded on top of AUODAC.DL3 (Chapter 7.2.1), replacing two of its methods, Identify() and Write().

Note: To display symbol information, AUINPUT requires library TRACE.DL3.

10 Configuration Examples

Here are some configuration examples for loading different audio drivers.

For full options for each of these programs, have a look at the README.TXT / PDF file for each of the drivers.

10.1 Minimal config.sys for Playback

```
# Audio DAC out driver
AUODAC s
```

Note the “s” parameter after the AUODAC.DL3 driver. This “s” parameter marks that the driver should become a *system* driver. In other words, it should connect to the system file stdaudioout so that all subsequent writes to stdaudioout will go through this driver.

10.2 config.sys for Playback with Bass/Treble Controls and automatic I2S + S/PDIF Outputs

```
# Audio DAC out driver
AUODAC s
# I2S automatic out; automatic is hardware, so doesn't require CPU
AUOI2SMA
# S/PDIF automatic out, parameter can be either 48000 or 96000 (default)
# If "v" is defined, stdaudioout volume control is copied to S/PDIF,
# otherwise it needs to be controlled manually (otherwise it stays at
# maximum level)
AUOSPDA 96000 v
# Equalizer, set 100 and 10000 Hz to +6 dB with Q Factor 0.7
FTOEQU
RUN SETEQU 1 3 100 +6 0.7
RUN SETEQU 2 3 10000 -6 0.7
```

In this example, only AUODAC.DL3 was defines as the *system* driver with the “s” option because AUOI2SMA.DL3 and AUOSPDA.DL3 both automatically copy anything written to the DAC by the AUODAC.DL3 driver, and thus they don't get individual audio data handles.

10.3 Basic config.sys for Recording

```
# New 2015 audio DAC out driver
AUODAC s
# New 2015 audio ADC in driver
AUIADC s 48000 line1_1 line1_3
# DC Block; use at least this with analog input even if not using AGC
FTIDCBL
```

In this example, both AUODAC.DL3 and AUIADC.DL3 have the *system* “s” option, so they will occupy standard audio handles stdaudioout and stdaudioin, respectively.

In addition to the “s” option, AUIADC.DL3 can also take a sample rate definition as well as an input channel definition. More details are provided in Chapter 7.4.1, *Driver AUIADC.DL3*.

10.4 Versatile config.sys for Recording with AGC and I2S + S/PDIF Outputs

```
# New 2015 audio DAC out driver
AUODAC s
# New 2015 audio ADC in driver
AUIADC s 48000 line1_1 line1_3
# I2S automatic out; automatic is hardware, so doesn't require CPU
AUOI2SMA
# S/PDIF automatic out, parameter can be either 48000 or 96000 (default)
# If "v" is defined, stdaudioout volume control is copied to S/PDIF,
# otherwise it needs to be controlled manually (otherwise it stays at
# maximum level)
AUOSPDA 96000 v
# DC Block + AGC unit to stdaudioin
FTIAGC
```

10.5 config.sys for Playback/Recording from I2S in Slave Mode, and Monitoring to DAC with Automatic Synchronization

```
# Load I2S Slave Input driver and make it stdaudioin
AUII2SS s
# Load Line Out / Earphone output driver and make it stdaudioout
AUODAC s
# Connect and synchronize stdaudioout with stdaudioin slave
AUXSYNCS
# Copy stdaudioin to stdaudioout
# If loaded with 'q' parameter, buffer under-/overflows are not reported
AUXPLAY
```

10.6 Loading/Unloading Drivers Using the VSOS Shell

Using the VSOS Shell Environment, you can use the DRIVER.DL3 program to load drivers to memory, and to later unload them.

If possible, you should always unload drivers in the reverse order of loading them. This is particularly true with drivers that connect to other drivers, like AUXSYNCS which connects to both the *stdaudioin* and *stdaudioout* drivers (in this case AUII2SS and AUODAC, respectively), and AUXPLAY which also uses *stdaudioin* and *stdaudioout*

Example: to load the drivers in Chapter 10.5, run the following commands:

```
S:>driver +auii2ss s
S:>driver +auodac s
S:>driver +auxsyncs
S:>driver +auxplay
```

To unload the drivers, enter the following commands:

```
S:>driver -auxplay
S:>driver -auxsyncs
S:>driver -auodac
S:>driver -auii2ss
```

11 VSOS Audio ioctl() Controls

VSOS Audio Drivers can be controlled from C language using `ioctl()` controls declared in `<aucommon.h>`.

There are many more definitions in the `#include` file `<aucommon.h>`. Refer to the documentation of the specific drivers you use for exact details on what of these functions they support and how to get access to a file pointer for that driver.

The `ioctl()` function prototype is

```
s_int16 ioctl(void *p, register int request, register char *arg);
```

where `p` is the file or device pointer (e.g. `stdaudioin` or `stdaudioout`), `request` is the type of the request, and `arg` is the optional argument.

`ioctl()` returns `S_ERROR` (-1) for an error (there was an error in the parameters, or the `ioctl()` for the `request` doesn't exist in this driver), any other value for success.

Generally, for functions that set a value, if `arg` is a pointer or a 16-bit value, it is casted to `c_char *` and passed to the function (e.g. `IOCTL_AUDIO_SET_BITS` in Chapter 11.2.5). If `arg` is a larger entity (e.g. 32-bit number), a pointer to the value is passed instead (e.g. `IOCTL_AUDIO_SET_ORATE` in Chapter 11.2.3).

Again, generally, for functions that return a 16-bit value where `S_ERROR` (-1) isn't included in the valid value range, the value is returned directly (e.g. `IOCTL_AUDIO_GET_BITS` in Chapter 11.2.4). Otherwise, the user needs to transmit a pointer to the return value in `arg` (e.g. `IOCTL_AUDIO_GET_ORATE` in Chapter 11.2.2). Not that in both cases `ioctl()` returns `S_ERROR` (-1) if there was an error in the call.

11.1 Resetting a Driver

11.1.1 IOCTL_RESTART

Restart driver. Normally this needs never be done.

Example:

```
ioctl(fp, IOCTL_RESTART, NULL);
```

11.2 Controlling Sample Rate and Bit Width

11.2.1 IOCTL_AUDIO_SET_RATE_AND_BITS

Set sample rate and number of bits. This is the recommended way of setting the sample rate and bit width with drivers like e.g I2S where there is a limit to sample rate and bit width combinations. Note that the sample rate / bit width argument may be larger than what can be fit into 16 bits, so it needs to be passed through a pointer.

Some drivers have very restricted number of sample rates supported. If you want to see what sample rate actually was set by the hardware, it is recommended to do a IOCTL_AUDIO_GET_IRATE or IOCTL_AUDIO_GET_ORATE call to see what you actually got.

- labs(rateBits) = sampleRate, may be in fractional sample rate format (Chapter 11.7).
- if rateBits < 0, then use 32-bit I/O
- Sets both input and output sample rate, if applicable
- Not available with Slave Mode drivers

Example:

```
s_int32 rateBits = -48000; /* Set to 48000 Hz, 32 bits */
if (ioctl(fp, IOCTL_AUDIO_SET_RATE_AND_BITS, (char *)&rateBits)) {
    printf("Couldn't set sample rate and bits\n");
}
```

11.2.2 IOCTL_AUDIO_GET_IRATE, IOCTL_AUDIO_GET_ORATE

Get integer part of the current sample rate. Note that sample rate may be larger than what can fit into 16 bits, so it needs to be passed through a 32-bit pointer.

Some drivers have very restricted number of sample rates supported. If you want to see what sample rate actually was set by the hardware, it is recommended to do a IOCTL_AUDIO_GET_IRATE or IOCTL_AUDIO_GET_ORATE call to see what you actually got.

- Not available with Slave Mode drivers

Example for input driver:

```
s_int32 sampleRate;
if (ioctl(fp, IOCTL_AUDIO_GET_IRATE, (char *)&sampleRate)) {
    printf("Couldn't get sample rate\n");
}
```

Example for output driver:

```
s_int32 sampleRate;
if (ioctl(fp, IOCTL_AUDIO_GET_ORATE, (char *)&sampleRate)) {
    printf("Couldn't get sample rate\n");
}
```

11.2.3 IOCTL_AUDIO_SET_IRATE, IOCTL_AUDIO_SET_ORATE

Set sample rate, which may be in fractional sample rate format (Chapter 11.7). Note that sample rate may be larger than what can fit into 16 bits, so it needs to be passed through a 32-bit pointer.

- Only for Master Mode drivers
- It is recommended to use IOCTL_AUDIO_SET_RATE_AND_BITS instead

Example for input driver:

```
s_int32 sampleRate = 48000;
if (ioctl(fp, IOCTL_AUDIO_SET_IRATE, (char *)&sampleRate)) {
    printf("Couldn't set sample rate\n");
}
```

Example for output driver:

```
s_int32 sampleRate = 48000;
if (ioctl(fp, IOCTL_AUDIO_SET_ORATE, (char *)&sampleRate)) {
    printf("Couldn't set sample rate\n");
}
```

11.2.4 IOCTL_AUDIO_GET_BITS

Get number of bits for driver. If the driver only supports 16-bit mode, it may not implement this function call.

Example:

```
s_int16 bits = ioctl(fp, IOCTL_AUDIO_GET_BITS, NULL);
if (bits < 0) bits = 16;
```

11.2.5 IOCTL_AUDIO_SET_BITS

Set number of bits for driver.

Example:

- bits may be 16 or 32
- With Master Mode drivers it is recommended to use IOCTL_AUDIO_SET_RATE_AND_BITS instead

Example:

```
if (ioctl(fp, IOCTL_AUDIO_SET_BITS, (char *)32)) {
    printf("Couldn't set bits\n");
}
```

11.3 Controlling Number of Audio Channels

These functions are relevant to drivers that can handle other than normal 2-channel audio. 2-channel drivers don't need to implement these function calls.

11.3.1 IOCTL_AUDIO_GET_ICHANNELS, IOCTL_AUDIO_GET_OCHANNELS

Get number of audio channels of a driver. If the driver only supports 2-channel audio, it may not implement this function call.

Example for input driver:

```
s_int16 channels = ioctl(fp, IOCTL_AUDIO_GET_ICHANNELS, NULL);  
if (channels < 0) channels = 2;
```

Example for output driver:

```
s_int16 channels = ioctl(fp, IOCTL_AUDIO_GET_OCHANNELS, NULL);  
if (channels < 0) channels = 2;
```

11.3.2 IOCTL_AUDIO_SET_ICHANNELS, IOCTL_AUDIO_SET_OCHANNELS

Set number of bits audio channels. As of the writing of this (2023-02-28) no drivers support this function.

Example for input driver:

```
if (ioctl(fp, IOCTL_AUDIO_SET_ICHANNELS, (char *) (6))) {  
    printf("Couldn't set number of channels\n");  
}
```

Example for output driver:

```
if (ioctl(fp, IOCTL_AUDIO_SET_OCHANNELS, (char *) (6))) {  
    printf("Couldn't set number of channels\n");  
}
```

11.4 Controlling Audio Buffers

11.4.1 IOCTL_AUDIO_GET_INPUT_BUFFER_FILL

Get input buffer fill state in 16-bit words.

- Only for drivers with input capability

Example:

```
iBufFill = ioctl(fp, IOCTL_AUDIO_GET_INPUT_BUFFER_FILL, NULL);
```

11.4.2 IOCTL_AUDIO_GET_INPUT_BUFFER_SIZE

Get input buffer size in 16-bit words.

- Only for drivers with input capability

Example:

```
iBufSize = ioctl(fp, IOCTL_AUDIO_GET_INPUT_BUFFER_SIZE, NULL);
```

11.4.3 IOCTL_AUDIO_SET_INPUT_BUFFER_SIZE

Set input buffer size in 16-bit words.

- Only for drivers with input capability

Example:

```
if (ioctl(fp, IOCTL_AUDIO_SET_INPUT_BUFFER_SIZE, (char *) (1024))) {  
    printf("Couldn't set input buffer size\n");  
}
```

11.4.4 IOCTL_AUDIO_GET_OUTPUT_BUFFER_FREE

Get how many 16-bit words there are free in the output buffer.

- Only for drivers with DSP output capability

Example:

```
iBufFill = ioctl(fp, IOCTL_AUDIO_GET_OUTPUT_BUFFER_FREE, NULL);
```


11.4.5 IOCTL_AUDIO_GET_OUTPUT_BUFFER_SIZE

Get output buffer size in 16-bit words.

- Only for drivers with DSP output capability

Example:

```
oBufSize = ioctl(fp, IOCTL_AUDIO_GET_OUTPUT_BUFFER_SIZE, NULL);
```

11.4.6 IOCTL_AUDIO_SET_OUTPUT_BUFFER_SIZE

Set output buffer size in 16-bit words.

- Only for drivers with DSP output capability

Example:

```
if (ioctl(fp, IOCTL_AUDIO_SET_OUTPUT_BUFFER_SIZE, (char *)1024)) {  
    printf("Couldn't set output buffer size\n");  
}
```

11.5 Volume Control

11.5.1 IOCTL_AUDIO_GET_VOLUME

Get volume. Volume is a number between 0 - 511 where 256 is full-scale, and each successive number represents a volume gain step of -0.5 dB. See table below:

IOCTL_AUDIO_GET_VOLUME argument table		
Argument	Amplification	Description
0	+128.0 dB	Insane amplification
1	+127.5 dB	Insane amplification minus 0.5 dB
...
255	+0.5 dB	Slightly louder than full-scale volume
256	0.0 dB	Full-scale volume
257	-0.5 dB	Almost full-scale volume
...
509	-126.0 dB	Very silent
510	$-\infty$ dB	No sound, may not turn off driver
511	$-\infty$ dB	No sound, may turn off driver

A driver may limit the range it actually accepts for its volume settings. E.g. the analog output driver AUODAC only supports the range between 256 (0.0 dB) and 511 (analog driver power-down). As another example, the S/PDIF driver supports the range between 208 (+24.0 dB) and 511 (silence). If a driver does not support the whole range, it will automatically limit itself so you can still call it with the extreme values.

511 is a special value that allows e.g. the audio driver to turn itself off (supported by e.g. AUODAC). Use with caution!

Example:

```
volume = ioctl(fp, IOCTL_AUDIO_GET_VOLUME, NULL);
```

11.5.2 IOCTL_AUDIO_SET_VOLUME

Set volume. Scale for volume is the same as for IOCTL_AUDIO_GET_VOLUME (Chapter 11.5.1).

Example:

```
/* Set full scale volume */
if (ioctl(fp, IOCTL_AUDIO_SET_VOLUME, (char *) (256))) {
    printf("Couldn't set volume\n");
}
```

11.6 Miscellaneous Controls

11.6.1 IOCTL_AUDIO_GET_SAMPLE_COUNTER

Get sample counter. This value may be used to synchronize input and output (e.g. by the driver AUXSYNCS, Chapter 7.9.1).

Example:

```
s_int32 sampleCounter;
if (ioctl(fp, IOCTL_AUDIO_GET_SAMPLE_COUNTER, (char *)&sampleCounter)) {
    printf("Couldn't get sample counter\n");
}
```

11.6.2 IOCTL_AUDIO_GET_OVERFLOW

Get overflow sample counter for the input buffer.

If this number changes while an audio input program is running, this is an indication of a program performance or input/output buffer size issue.

If nobody consumes samples from the input audio driver, this value increases at the rate of the sample counter that can be read with IOCTL_AUDIO_GET_SAMPLE_COUNTER.

- Only for drivers with input

Example:

```
s_int32 overFlow;
if (ioctl(fp, IOCTL_AUDIO_GET_OVERFLOW, (char *)&overFlow)) {
    printf("Couldn't get overflow counter\n");
}
```

11.6.3 IOCTL_AUDIO_GET_UNDERFLOW

Get underflow sample counter for the output buffer.

If this number changes while an audio output program is running, this is an indication of a program performance or input/output buffer size issue.

If nobody produces samples for the output audio driver, this value increases at the rate of the sample counter that can be read with IOCTL_AUDIO_GET_SAMPLE_COUNTER.

- Only for drivers with output

Example:

```
s_int32 underFlow;
if (ioctl(fp, IOCTL_AUDIO_GET_UNDERFLOW, (char *)&underFlow)) {
    printf("Couldn't get underflow counter\n");
}
```

11.6.4 IOCTL_AUDIO_SELECT_INPUT

Select analog input when using analog input driver AUIADC. Parameter bitmask must have one stereo element, or one left and one right element. Definitions can be found in <aucommon.h> .

Stereo elements:

- AID_FM

Left elements:

- AID_LINE1_1, AID_LINE3_1, AID_LINE2_1, AID_MIC1, AID_DIA1

Right elements:

- AID_LINE1_2, AID_LINE3_2, AID_LINE2_2, AID_MIC2, AID_DIA2, AID_DIA3, AID_LINE1_3
- This ioctl() is only applicable to the AUIADC driver.
- Optionally, AID_DEC6 may also be defined. It activates the high-quality down-by-6 decimator.

Example:

```
s_int32 sampleCounter;
if (ioctl(fp, IOCTL_AUDIO_SELECT_INPUT, (char *) (AID_LINE1_1 | AID_LINE1_3))) {
    printf("Couldn't select input\n");
}
```

11.7 Fractional Sample Rates

For most audio drivers, setting the sample rate with an accuracy of 1 Hz is enough. However, some drivers are internally capable of setting the sample rate with better accuracy. As an example the analog output driver AUODAC.DL3 can set the sample rate with an accuracy of approximately 0.09 Hz. This makes a driver more useful when streaming audio in slave mode, e.g. when using the AUXSYNCS.DL3 synchronization driver.

Because being able to set the sample rate with higher than 1 Hz accuracy was a new VSOS feature for 2016, it was important to maintain compatibility with older software that is incapable of setting the sample rate with sub-hertz accuracy.

To set a fractional sample rate, `ioctl()`'s `IOCTL_AUDIO_SET_RATE_AND_BITS`, `IOCTL_AUDIO_SET_IRATE`, and `IOCTL_AUDIO_SET_ORATE` all can take their parameters in a 32-bit integer-compatible fractional representation, where bits 30:24 of the sample rate parameter represent 1/128 Hz increments, as shown in the following table.

32-bit fractional sample rate representation		
Bits	Range	Description
31	0	Not used, set to 0
30:24	0..127	Sample rate fractions in 1/128 Hz
23:0	0..16777215	Sample rate integer part in Hz

32-bit fractional sample rate examples	
Sample rate	Representation
44100 Hz	0x0000ac44
$44100 \frac{1}{128}$ Hz	0x0100ac44
44100.5 Hz	0x4000ac44
$44100 \frac{127}{128}$ Hz	0x7f00ac44

Audio drivers which are not interested in the sample rate's fractional part, mask away bits 30:24 from `ioctl()` sample rate setting parameters.

To maintain compatibility with software unaware of the fractional sample rate presentation format, `IOCTL_AUDIO_GET_IRATE` and `IOCTL_AUDIO_GET_ORATE` only return the integer portion of the sample rate.

12 Controlling Audio from VSOS Shell with UiMessages

When using the VSOS Shell, some audio functions may be controlled even if running a VSOS program that doesn't take audio controls. If the TTY is not in RAW mode, the following escape sequences defined in <uimessages.h> may be sent to the shell.

12.1 Setting Volume anywhere from VSOS Shell

Note that here means sending ASCII code 2, invoked in most terminal emulation programs by pushing Ctrl-B.

Volume up by 1/2 dB:

111ms

Volume down by 1/2 dB:

112ms

Set attenuation to -HH/2 dB, where HH is a hexadecimal number:

206mHHs

Example:

To set volume to -20 dB, you need to send 40 = 0x28:

206m28s

12.2 Sending Equalizer Controls from VSOS Shell

The filters are accessed with UiMessages that have the following format, where X is the filter number (0..f), and YY is the 16-bit signed value presented as an unsigned 16-bit hexadecimal number. 21XmYYs

Example:

Let's assume we have the following configuration lines in config.txt:

```
RUN SETEQU 1 3 100 0 0.7
```

```
RUN SETEQU 2 3 10000 0 0.7
```

Now, to set bass (filter channel 1) to +6 dB (6), send the following command:

210m6s

To set treble (filter channel 2) to -12 dB (0xff4), send the following command:

211mfff4s

Up To 16 channels may be accesses with messages ranging from 0x210 to 0x21f.

13 Audio Decoders

Library audiodec automatically chooses between many Audio Decoders when presented an audio file. The libraries, their respective decode audio formats, and their clock rate requirements, are presented below.

NOTE: The clock speeds have been tested with a Class 4 SD card and “typical test files”. While VLSI believes the information to be accurate, clock rates should still be interpreted as estimates. The estimates are given for a system with a typical interrupt load and with a 8 KiW audio output buffer. An example S:CONFIG.TXT configuration file that sets the system up for best playback audio performance is provided in file config_audio_decoders.txt in the *VSOS Root and Libraries Source Code* package.

Audio Decoders		
LibName	Format	Description
decaac	AAC	AAC in ADTS and MP4 containers (.aac, .m4a, .mp4, .3gpp)
decac3	AC3	AC3 decoded into stereo
decaiff	AIFF	Apple uncompressed PCM format
decalac	ALAC	Apple lossless in MP4 (.mp4, .m4a) or CAFF (.caf) container
decapex	APE	Monkey's audio
decddsd	DSD	DSD bitstream files in .DSF and .DFF container, LSb first only
decflac	FLAC	Free Lossless Audio Codec
decmp3	MP3	MPEG audio layer 3
decopus	Opus RAW	VLSI version of RAW Opus data
decvorb	Ogg Vorbis	Vorbis audio in Ogg container
decwav	RIFF WAV	Many RIFF WAV subformats
decwma	WMA	Windows Media Audio
mp4file	-	Determines if MP4 file contains ALAC or AAC

NOTE: For formats where there may be more than 2 audio channels, only files up to 2 audio channels are supported.

Library decaac subformats and clock requirements	
Clock	Description
30 MHz	AAC up to 48 kHz, 280 kbit/s

Library decaiff subformats and clock requirements	
Clock	Description
12 MHz	AIFF up to 96 kHz 16-bit
18 MHz	AIFF up to 96 kHz 24-bit
37 MHz	AIFF up to 192 kHz 24-bit
61 MHz	AIFF up to 352 kHz 24-bit

Library decac3 subformats and clock requirements	
Clock	Description
– MHz	5.1 channels at 48 kHz, – kbit/s

Library decalac subformats and clock requirements	
Clock	Description
37 MHz	Apple lossless up to 48 kHz 16-bit
74 MHz	Apple lossless up to 96 kHz 24-bit

Library decape subformats and clock requirements	
Clock	Description
61 MHz	Monkey's Audio up to 48 kHz 24-bit, profile Fast
67 MHz	Monkey's Audio up to 48 kHz 24-bit, profile Normal
79 MHz	Monkey's Audio up to 48 kHz 24-bit, profile High
N/A	Monkey's Audio, profiles Extra High and Insane

Library decdsd subformats and clock requirements	
Clock	Description
49 MHz	DSD64 (2.8 MHz, 1-bit)
86 MHz	DSD128 (5.6 MHz, 1-bit)
92 MHz	DSD256 (11.3 MHz, 1-bit)

Library decflac subformats and clock requirements	
Clock	Description
12 MHz	FLAC up to 16 kHz, 16-bit
18 MHz	FLAC up to 32 kHz, 16-bit
25 MHz	FLAC up to 48 kHz, 16-bit
37 MHz	FLAC up to 96 kHz, 16-bit
43 MHz	FLAC up to 96 kHz, 24-bit

Library decmp3 subformats and clock requirements	
Clock	Description
12 MHz	MP3 at 8 kHz, 8 kbit/s
31 MHz	MP3 up to 48 kHz, 320 kbit/s

Library decopus subformats and clock requirements	
Clock	Description
– MHz	Mono, 8 kHz, – kbit/s
– MHz	Mono, 16 kHz, – kbit/s

Library decvorb subformats and clock requirements	
Clock	Description
12 MHz	Ogg Vorbis up to 16 kHz, 73 kbit/s
18 MHz	Ogg Vorbis up to 32 kHz, 151 kbit/s
37 MHz	Ogg Vorbis up to 48 kHz, 346 kbit/s
55 MHz	Ogg Vorbis up to 96 kHz, 362 kbit/s

Library decwav subformats and clock requirements	
Clock	Description
12 MHz	RIFF WAV up to 96 kHz 16-bit
18 MHz	RIFF WAV up to 96 kHz 24-bit
31 MHz	RIFF WAV up to 192 kHz 24-bit (e.g. DXD format)
55 MHz	RIFF WAV up to 352 kHz 24-bit (e.g. DXD format)
68 MHz	RIFF WAV up to 352 kHz 32-bit floating-point (e.g. DXD format)

Library decwma subformats and clock requirements	
Clock	Description
61 MHz	All WMA files in VLSI Solution's internal test suite

13.1 Decoder Loop Functionality

Some of the audio decoders include a chance to play a part of the audio file in a loop.

Depending on the decoder, there may or may not be support for the

The list of audio decoders that contains loop functionality, and the level of support, is provided in the following table:

Audio decoders with loop functionality				
LibName	Set timing ¹	Sample accurate ²	Smooth ³	Comments
decvorb	Yes	Yes	No	-
decwav	Yes	Yes ⁴	No	-

¹ If this feature is not available, the decoder is only able to loop the complete audio file. To make sure user software is compatible with potential future versions of the driver which may start supporting the Set Timing feature, Loop structure should be set as follows:

```
loop->startSeconds = loop->endSeconds = loop->endSamples = 0;
loop->endSeconds = 0xFFFFFFFFU;
```

² If this feature is available, looping is sample-accurate. If not available, loop start and stop points may vary slightly.

³ If this feature is available, loop supports the CFL_DECLICK flag which declicks the loop but is not sample accurate. If this feature is missing from the decoder, flag CFL_DECLICK is ignored.

⁴ Exception: IMA ADPCM is not sample accurate.

An example of how to use the loop feature is provided in solution PlayFileLoop in the *VSOS Root and Libraries Source Code* package. Read the README.TXT file for details.

14 Audio Encoders

There are currently two Audio Encoders. They are for Ogg Vorbis and MP3 formats. Both are intended to operate properly at the 60 MHz standard operating speed. For details of how to use them, see the source code for the VSIDE solution Rec (more information for Rec is available in the *VSOS Shell document*).

14.1 ENCVORB.DL3 - Ogg Vorbis Encoder

ENCVORB.DL3 offers a high-quality encoder for the free end open Ogg Vorbis audio format. This is the recommended format for those users that don't specifically need the MP3 format, and for whom the variable bitrate property of Ogg Vorbis is not a problem.

The Ogg Vorbis encoder is a Variable BitRate encoder, and works best when given an encoding quality value. The range for the quality is from 0 and 10 (10 is the best; qualities above 6 may require a higher clock speed than 60 MHz). If set to Constant bitrate, the encoder will convert that to an approximate quality value, and still use Variable BitRate.

14.2 ENCMP3.DL3 - MP3 Encoder (VS1205 only)

ENCMP3.DL3 offers a high-quality encoder for the popular MP3 audio format. While not capable of getting quite the same quality as Ogg Vorbis when using similar bitrates, the MP3 encoder still offers high fidelity sound at bitrates between 160-192 kbit/s, and acceptable speech quality at very much lower bitrates.

The MP3 encoder can operate either with a Variable BitRate or Constant BitRate encoder depending on whether a quality or bitrate value is set. For best quality per bit, Variable BitRate is recommended.

14.3 ENCOPUS.DL3 - Opus Raw Encoder

ENCOPUS.DL3 is a speech encoder that implements Opus Silk-encoding for highly compressed speech. It provides intelligible speech at bitrates below 10 kbit/s.

The storage format is not the usual Ogg Encapsulation because it would either introduce a prohibitive system delay or, alternatively, inefficient compression. Instead VLSI's proprietary Opus RAW format variant is used.

14.4 ENCFLAC.DL3 - FLAC Encoder

ENCFLAC.DL3 offers a lossless encoder for 16-bit audio up to 48 kHz. Typically a 48 kHz 16-bit stream is compressed from 1.536 Mbit/s to 0.8-1.3 Mbit/s. Because encoding is

lossless, compression efficiency depends on the audio data.

Because the bitrates are much higher than for the Ogg Vorbis or MP3 encoders, storing the result to e.g. an SD card may require a separate buffer memory.

15 Latest Document Version Changes

This chapter describes the latest changes to this document.

Version 3.67, 2026-04-23

- Added Chapter 8.8, *DAC Slew Limiter Driver*.

Version 3.66a, 2023-02-28

- Added Chapter 7.5, *Analog Input 3-Channel ADC Audio Driver*.
- Added displaying number of channels to Chapter 9, *Audio Control Programs*.
- Added Chapter 11.3, *Controlling Number of Audio Channels*.
- Revised Chapter 7, *Audio Drivers*, and added example Chapter 7.1.1, *Examples of Loading and Unloading Audio Drivers*.
- Added description of command line parameters to Chapter 7.4, *Analog Input ADC Audio Driver*.
- Added Chapter 8.7, *Matrix driver: 3 Channels to 2 Channels*.
- Clarified text as well as Figures 12, 13 and added example to Chapter 8, *Audio Filter Drivers*.
- All audio drivers that dynamically allocate their audio buffers have been updated so that they can allocate buffers sizes that are not powers of 2.

Version 3.66, 2023-02-14

- Updated version number for VSOS 3.66.

Version 3.65b, 2022-03-24

- Added new drivers FTIREV.DL3 and FTIREV23 to Chapter 8.4, *Reverb Generator Audio Drivers*.

Version 3.65a, 2022-03-23

- Rewrote introduction to Chapter 7.6, *I2S Audio Drivers*, and added a new driver, AUOI2SMV.DL3.

Version 3.65, 2021-12-23

- Added Chapter 7.8, *Pulse Width Modulation Output Driver*.
- Added Chapter 8.6, *Mono / Differential Audio Drivers*.
- Added AC3 and Opus Raw to Chapter 13, *Audio Decoders*.
- Added Opus Raw Chapter 14.3, *ENCOPUS.DL3*.

Version 3.60, 2020-10-13

- Better explanation of sample rate availability for driver AUODAC.DL3 in Chapter 7.2.1, *Driver AUODAC.DL3*.
- Added mention of new volume control for driver AUOOSSET.DL3 in Chapter 7.3.1, *Driver AUOOSSET.DL3*.
- Other, minor modifications and typo corrections.

Version 3.58, 2019-08-24

- Added mention that all S/PDIF drivers are incompatible with USB in Chapter 7.7, *S/PDIF Audio Drivers*.
- Replaced incorrect text `IOCTL_AUDIO_GET_OUTPUT_BUFFER_SIZE` with `IOCTL_SET_OUTPUT_BUFFER_SIZE` in Chapter 11.4.6, *IOCTL_SET_OUTPUT_BUFFER_SIZE*.

Version 3.57, 2019-04-10

Minor corrections, updated for VSOS 3.57.

Version 3.55b, 2018-06-12

Added Chapter 8.5, *Noise Killer Drivers*.

Version 3.55a, 2018-04-05

- Added new first reflection flag “-f” to Reverb Generators in Chapter 8.4, *Reverb Generator Audio Drivers*.
- Added another Reverb Generator Driver and Chapter 8.4.4, *Driver FTOREV23*.

Version 3.55, 2018-04-05

Added Chapter 8.4, *Reverb Generator Audio Drivers*.

16 Contact Information

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