

# DSP functions for DAC8 products

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# Summary

The digital boards of DAC8 products are built around an XMOS XU216 device which has extra cores and powerful instructions to perform DSP functions like filtering, cross over or delay. By using the AVDSP framework and its utilities, it is possible to create a DSP program to be uploaded in the DAC8 products. This document explains how this works and provides step by step examples.

## DAC8 DSP firmwares

By default, DAC8 products have two firmwares. One for Xmos XU216 in charge of USB interface and data transmission with DAC and AES inputs; one for managing the front-panel (volume, display, IR remote...) and adjusting DAC registers according to the USB host sample rate.

In order to enable DSP functionalities, a specific version of the XU216 firmware must be installed with the DFU upgrade utility. Then it will be possible to manually upload DSP programs that will interact with internal data flows existing between DAC, AES and USB host in and out.

The DSP enabled DAC8 firmwares are fully compatible with the latest standard DAC8 V1.6 firmware and can also be used without any DSP program activated.

## Versions

For DAC8PRO, two versions are provided. When a single stereo AES input is acceptable, the power available for the DSP program rises to 462 MIPS spread over 7 cores max. Sample rate up to 192kHz is possible. When 8 AES channels are required (standard), the power available for the DSP program is limited to 264 MIPS spread over 4 cores max.

File Name and USB device name	USB OUT	USB IN	D A C	AES spdif	CORES x mips	MIPS (total)	total instructions 48k	total instructions 96k	total instructions 192k
DAC8PRODSP4	8	8	8	8	1 x 106 2 x 88 3 x 75 4 x 66	106 176 226 264	5500	2750	1350
DAC8PRODSP7 DAC8STEREODSP7	8	8	8	4x2	1..4 x 106 5 x 88 6 x 75 7 x 66	422 440 453 462	9625	4812	2406

DAC8STEREODSP7 provides the same configuration as DAC8PRODSP7. This is probably too much for a pure stereo treatment with PEQ, but this provides the flexibility for users who own a custom version of DAC8STEREO with a DAC board from DAC8PRO with the 8 independent connectors available (typical usage as hifi crossover).

## Remarks and known limitations

- The DSP enabled firmwares also accepts 44100, 88200 or 176400 hz.
- DSD playback is never possible (silence) when a DSP program is selected in the menu.
- If the target user DSP program takes too long to accommodate the time between two audio samples (eg 10us at 96k), then the DAC is reconfigured at a lower rate and the extra

samples are skipped (decimation by 2 or 4). To avoid high frequency THD and aliasing due to this basic downsampling, it is better and advised to send the audio stream at a sample rate compatible with the maximum rate supported by the user DSP program activated.

## Upgrading the unit

As of version 1.5, the DAC8 products can be upgraded with the windows DFU utility with following steps:

Connect the USB cable, launch the DFU utility, select the binary file [dac8xxdspx.bin](#) clicking on Browse button, then click Start button. The DAC8 will reboot in a special USB DFU mode and the utility will start flashing the firmware with an indicator showing the progress. The DFU utility will show 0 at the beginning and during about 8 seconds which is the time required to erase the upper part of the flash memory (the factory installed firmware is not erased). Then the counter will progress till the end of the process.

Once complete, wait 1 minute to complete the second flash process for the front panel, and then press the volume button to start the display and verify the presence of the **DSP Prog** selection in the **Filter** menu.

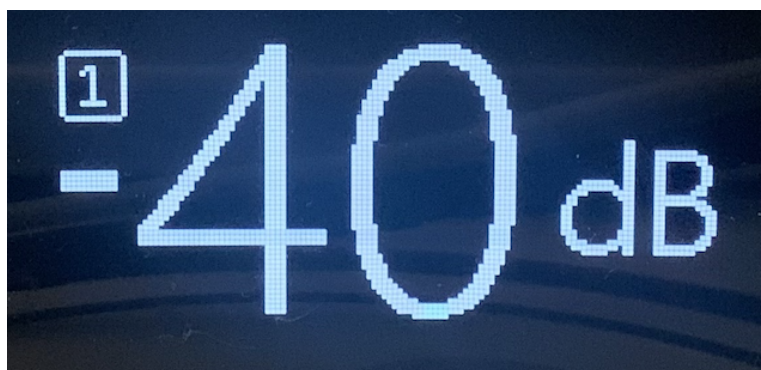


If the flash process fails in the middle, or if the USB cable is disconnected when the counter is progressing, then the DAC8 will reboot and restore the original embedded factory version. This is also a normal way to revert back your unit to its original non-dsp firmware if needed.

Remark : choose carefully the filename.bin for the upgrade process as there is no verification done (not possible). Practically, in case of error the unit will not be bricked but this is not expected.

## Enabling a DSP program

When a DSP program is selected in the **Filter / DSP Prog** menu, it will always appear on the right display in the top left corner of the screen:



This is important information for the user, as the DSP program may be used to send specific frequencies or volume on some channels. To avoid any situation subject to damaging the drivers,

always verify that the expected DSP program is loaded in the DAC8 memory with this indicator before playing music, especially at high volume.

When a non compatible stream is sent to the DSP, like DoP or DSD, the firmware will change the 1 squared logo by a 1 underlined. When uploading a new DSP program with provided utility, the program number is displayed as a squared zero (will be changed by M in future version).

By default the programs 1 to 4 are “empty” and thus no sound will reach the outputs when selecting an empty program.

When selecting “off” in the Filter DSP Prog menu, no DSP treatment will be provided and the DAC will process the audio stream as for a standard DAC8, and then the full audio stream will be sent to the outputs which the end user must consider carefully before returning to “off”.

## Creating a DSP program

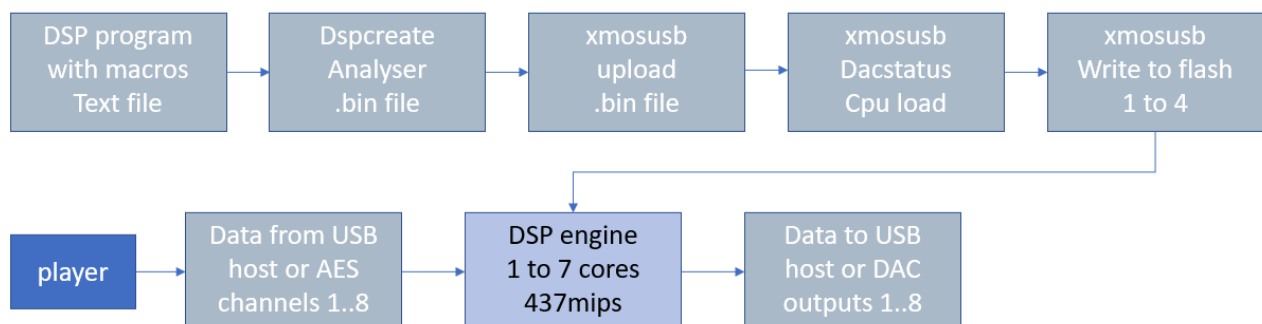
At the time of writing, no graphical user interface is provided to create a DSP flow.

### Steps required

It will require the following steps:

1. defining and organizing the actions expected as a flow of macro instructions that will be executed at each audio sample
2. evaluating cpu load for this flow and grouping / distributing macro-instructions per core
3. using a text editor to write this program in sequences with parameters and code sections
4. converting this file as a binary file with “dspcreate” utility from AVDSP framework
5. uploading the resulting binary file with “xmosusb” command line utility.
6. verifying DAC8PRO status and XMOS cpu load for each core using “xmosusb” utility
7. testing the expected behavior with third party tools like REW using loopback instructions to verify for each channel response, total gains, and verifying clipping behavior.

This looks like an intensive effort at first but this gives the possibility to optimize the treatment and to fit a comfortable crossover solution within a limited MIPS quantity. Routing and mixing is also very flexible and efficient as there is no predefined matrix or framework to follow.



The generic behavior of a DSP flow is to : load a sample, treat it, eventually delay it, store it.

## Input and Output memory locations

A sample can be loaded in the DSP accumulator from any AES input or from any channel provided by the USB host. 16 memory locations are predefined for this.

Transformation can be applied to the DSP accumulators with a set of predefined macro instructions like gain or biquad or saturate.

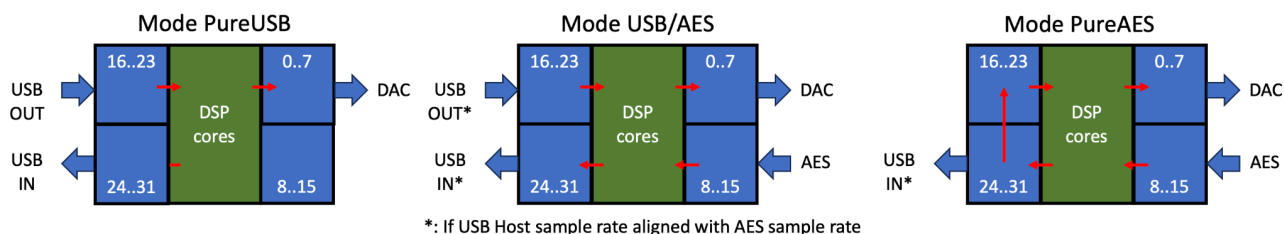
Then the accumulators can go through a fifo pipeline for applying delays (in microseconds).

The resulting accumulator will be stored as an output sample either for the DACs or for the USB host, represented by 16 other predefined memory locations.

Any core can work with any of these 32 (16 input + 16 outputs) predefined memory locations.

Additional memory locations can be created to share value across cpu cores. For example a core can prepare a stereo input signal with gain and peak correction and save the result in a shared memory location for the other cores to act as a crossover for 8 channels.

The following diagram represents the 32 memory locations according to the 3 DAC modes:



## MIPS needed for a typical project

A table in this document represents the list of macro instructions available and the time taken to execute them in native cpu core instructions, which is to be compared directly with MIPS available per core or in total.

As an example, a typical flow for filtering and delaying one channel needs 4 macro instructions, and requires 178 core instructions for 6 biquad sections (e.g. Linkwitz-Riley 4th order followed by 4 peak corrections).

The table below summarizes the cpu instructions available per core depending on the sample rate and depending on the MIPS allocated to a core (which depends on the total number of active cores in the program). An indication is given for a maximum number of typical treatments as above.

MIPS per core	48000hz		96000hz		192000hz	
<b>105,6</b>	2199	12	1099	6	549	3
<b>88,0</b>	1833	10	916	5	458	2
<b>75,4</b>	1570	8	785	4	392	2
<b>66,0</b>	1374	7	687	3	343	1

Remark : To maximize the total MIPS capacity, it is recommended to use multiple cores if possible when the program can be split in similar sections (like a 2x3 crossover solution).

Using 4 cores is optimal, as an example for a loudspeaker crossover solution, one core can prepare the stereo left and right, applying gains and equalization, each of the 3 other cores can

filter, equalize and adjust delay for 2x3 drivers. Other combinations could be done with a subwoofer or to correct 2 headset outputs in addition.

## Writing a DSP program:

A DSP program built with the AVDSP framework is a list of sequential binary values (called “opcode”) that will be interpreted one-by-one by a specific runtime library optimized for XMOS XU216 and included within the DAC8 DSP firmware.

The opcodes are low-level DSP-like instructions (about 60 different), mainly working on an accumulator or transferring data across memory.

The binary file also contains constant definitions like filters parameters or mixer/gain/delay, which are all computed upfront to cope with all possible audio sample rate (no any SRC involved).

The DAC8 front-panel does not provide any mechanisms to modify the filters or gain dynamically during audio listening. All values are embedded in the DSP program binary file and this can be changed only by modifying and uploading a new version of the DSP program.

In order to generate a DSP binary file, a specific command-line utility called `dspcreate` is provided. It accepts either inputs:

- A. A text file representing the DSP flow with a predefined set of simple macro-instruction, or
- B. An object file generated by a C compiler like GCC using the core AVDSP library, enabling full capabilities and extended syntax.

Both methods are compatible with the DAC8 DSP firmware but for simplifying the process, this document describes and focuses on using a text file with a limited set of predefined macro-instructionst.

Analyzing a text file and generating a DSP binary program is done with the following command line:

```
OS prompt > dspcreate -dspformat 2 -dsptext myprogram.txt -binfile  
mybinfile.bin <param>
```

where `<param>` is optional and describes a list of couples `Label=value` which can be used as preprocessing information for the DSP program. For example a cutoff frequency can be passed as `Fc=800` on the command line and will be treated before analyzing `myprogram.txt`.

As explained with more details in next chapters, the binary file generated will be uploaded in the DAC8 RAM memory with the command-line utility “xmosusb” with the following command:

```
OS prompt > xmosusb --dspload mybinfile.bin
```

The status of the DAC after this upload will be given by the command:

```
OS prompt > xmosusb --dacstatus
```

providing the following informations as an example:

```
maximum dsp tasks = 4  
dsp 1: instructions = 131  
dsp 2: instructions = 66  
dsp 3: instructions = 66  
dsp 4: instructions = 0  
maxi instructions = 131 / 520 = 25%fs
```

## DSP program structure:

The text file passed as a parameter with the selector `-dsptext` has to be structured with following sections:

- label definitions for documenting constant parameters (not stored in the final binary file)
- label definitions for filters, or memory parameters which are stored in the binary file
- code sections with macro-instruction for each core.

This structure can be repeated as much as needed according to the maximum number of cores available. The 2 first optional sections can be grouped at the beginning of the file or spread along if they are specific to a core.

### Label value definition:

A DSP program is easier to write and verify when defining labels which represent physical locations or constants to be used in different points of the code section. For example, DAC8PRO supports 8 inputs from the USB host (coming from the player), 8 inputs from the AES channels, 8 outputs to the DAC channels, 8 output to the USB host (for recording). It is a good practice (but not mandatory) to start describing these input-outputs with some nicknames defined with their corresponding memory locations. As an example:

```
LeftIn      16 ; RightIn 17 ; LeftOut 10 ; RightOut 13 ### USB and DAC IOs
LeftLowOut   =LeftOut ; LeftMidOut =LeftOut+1 ; LeftHighOut =LeftOut+2
RightLowOut  =RightOut[0] ; RightMidOut =RightOut[1] ; RightHighOut =RightOut[2]
LeftHeadphone 8 ; RightHeadphone 9
firstGain    -3db
Low_fc 400 ; Mid_fc 2000
```

As seen in this example, a label can be defined directly with a numerical value (eg `LeftIn 16` or `firstGain -3db`), or with an expression (+, -, \*, /) starting with “=”. Multiple definitions can be done on a line with “;” separator. Comments are possible with “#” preceding character.

Remark: when an expression starts with a decibel value, then operators are limited to + and -, and next values in the expression are expected to be also decibel (postfix db).

Numbers can be written in decimal, binary starting with a letter “b” or hexadecimal with “x”.

### Label parameter definition:

There are 2 types of static parameters :filters, or memories.

Filters describe a list of filters to be computed in a row with a biquad routine. The biquad coefficients are computed upfront according to a list of predefined filter names covering most of the usual requirements (Bessel, Butterworth, Linkwitz-Riley, All-pass, peak, notch...). Generic filters can also be combined to form any other filters. As an example:

```
LowPass      LPLR4(Low_fc)
MidPass       HP2(Low_fc, 0.7) HP2(Low_fc, 0.7) LPBU3(Mid_fc)
HighPass      HPBU3(Mid_fc, -2db) HS2(5000, 0.5, +2db)
RoomMode      NOTCH(50, 10) PEAK(80, 0.5, -2db)
```

This represents the settings for a typical 3 way crossover:

- `LowPass` is simply a Linkwitz-Riley 4th order low pass filter with a cutoff frequency of “Low\_fc” (at -6db by design)



- `MidPass` is also a Linkwitz-Riley 4th order high pass filter but made of 2 successive 2nd order high-pass filters (by definition of an HPLR4 using two HP2 with  $Q=0.7$ ), followed by a low pass Butterworth 3rd order filter with cutoff frequency `Mid_fc` (at -3db by design).
- `HighPass` is an high-pass Butterworth 3rd order with an embedded attenuation of -2db after it, followed by a second order high-shelf filter (with  $Q=0.5$  here) with a gain of +2B after 5000hz.
- `RoomMode` defines a notch filter at 50hz with a strong  $Q=10$ , and a -2db reduction for a peak correction at 80hz with a relatively large  $Q=0.5$ .

These 4 filter labels can be used later in the core code section as parameters of the “biquad” macro instruction. Grouping them at the beginning of the program is easier to maintain.

*Remark: any filter can be set with an optional gain (or reduction) parameter. Then its biquad coefficients ( $b_0, b_1, b_2$ ) will be scaled accordingly by the encoder.*

*Filters must be listed on a single line or just below the others by using the backslash | symbol.*

Memory describes a target memory location which can be used to exchange data between cores. As an example, a core can be used for pre-conditioning a stereo signal and then the other core will use these values instead of directly using the 32 Input/output memory locations.

```
stereoMem    MEMORY      2
monoChan     MEMORY
```

This example defines 2 memory locations to store 2 channels related to a stereo signal and a single memory location to store a mono channel.

## Code and core section:

a DSP code section starts with the keyword `core`. All the macro instructions are written one by one on the following lines. multiple instructions can be written on a single line with a “;” separator if this brings better visibility. This is an example for treating the Low channels as per the example parameters above:

```
core
    inputgain    (LeftIn, firstGain)
    biquadLowPass
    output       LeftLowOut
    inputgain    (RightIn, firstGain)
    biquad       LowPass
    output       RightLowOut
end
```

The same code could be duplicated for treating the Mid channels, inside this core or in another core code section. The keyword `end` must be unique in the program. End of a core section is implicit when a new `core` instruction is encountered.

This program below provides an example with one preconditioning core in charge of stereo and headphones, and one other core in charge of the Low filtering. This can be merged or duplicated for mid and high filtering.

```
core
    mixer (LeftIn, -6db) (RightIn, -6db)
    savemem    monoChan
```



```

    inputgain    (LeftIn, firstGain)
    biquad RoomMode
    savexmem     stereoMem[ 0 ]
    inputgain    (RightIn, firstGain)
    biquad RoomMode
    savexmem     stereoMem[ 1 ]
    transfer     (LeftIn, LeftHeadphone) (RightIn,RightHeadphone)
core
    loadxmem     stereoMem[ 0 ]
    biquad       LowPass
    output       LeftLowOut
    loadxmem     stereoMem[ 1 ]
    biquad       LowPass
    output       RightLowOut
end

```

By default, any `output` or `outputgain` instruction will clip the signal between (+1..-1) if the value of the accumulator is outside these bounds. Still this behavior is not satisfying as it could generate a high level of harmonics. Therefore it is highly recommended to tune the gain chain to avoid any clipping situation. See also possibility to use `saturate` or `saturatevol` or `outputvolsat` instructions as explained later in the document.

Remark : the DAC volume is independent of the DSP and acts directly on the DAC outputs, but it is possible to split the attenuation between DSP and DAC as explained later about `saturatevol`.

## Instruction list and details

keyword	description	parameters
<b>core</b>	Define the beginning of a new code section for a new DSP core. A core can be activated or not, depending on a flexible 32 bits condition checked with 1 or 2 parameters. See detailed information later in this document.	optional 1 or 2 parameters representing core condition. First parameter represents the bits set to 1 compatible with this core. The second represents the bit required to be 0 for this core.
<b>end</b>	mark the end of the whole DSP program.	no parameter
<b>transfer</b>	load a sample from a memory location and save it to another.	(in, out) ... multiple couples possible
<b>input</b>	Load a sample from a memory location directly in the main DSP accumulator, without applying conversion or gain.	immediate numerical value or expression representing one of the 32 locations.
<b>output</b>	DSP accumulator value is eventually clamped between -1 .. +1 and saved in one or many memory locations.	immediate numerical value or expression representing one of the 32 locations. Multiple outputs possibly separated by comma.
<b>outputtpdf</b>	add tpdf noise to accumulator and proceed output instruction	out, ... multiple output possible
<b>outputgain</b>	Apply a gain or reduction to DSP accumulator	(out,gain)

	and proceed with output instruction	
<b>outputvol</b>	Apply a portion of the volume and proceed with output instruction. Accumulator is not changed	out , ... multiple output possible
<b>outputvolsat</b>	Combined instruction equivalent to saturatevol and output, but accumulator not changed	out , ... multiple output possible
<b>inputgain</b>	Load a sample from a memory location in the main DSP accumulator and apply a gain or reduction. When multiple couples (in,gain) are provided, they are added all together.	( in, gain) ... 0<= in <32 -8 < gain < +8 -99db < gain < +18db
<b>mixergain</b>	Execute an equivalent but faster version of multiple inputgain instructions. same parameters as inputgain.	( in, gain) ...
<b>mixer</b>	add multiple inputs	list of input with coma
<b>loadxmem</b> <b>loadymem</b>	Load the DSP accumulator X or Y with a value from a given memory location. The unique parameter is a label defined as MEMORY, eventually followed by an [index] number	memory label name with an optional [value] which will be added (as an index of an array)
<b>savexmem</b> <b>saveymem</b>	Store the value of the DSP accumulator X or Y in a given memory location. The unique parameter is a label defined as MEMORY	same as loadxmem
<b>delayus</b> <b>delaydpus</b>	Propagate the DSP accumulator msb through a FIFO data line in order to create a delay line. The parameter represents the number of microseconds. delaydpus perform the same operation on 64bits original data and thus requires twice memory.	delay in microseconds as a numerical value or expression. Value is internally rounded to be a multiple of a sample delay.
<b>delayone</b>	Switch the current DSP accumulator with its value at the previous sample, thus creating a delay of one sample. Used to synchronize outputs across cores when savexmem or loadxmem are used.	no parameter
<b>dcblock</b>	Provides a high pass first order to eliminate any continuous DC signal. The unique parameter is a minimum frequency cutoff. To optimize performance, it is better to include a HP1 filter at the beginning of a biquad filter.	frequency as a value or expression 10 < f < 100
<b>saturate</b>	Eventually modify the DSP accumulator so that the value is constrained between -1..+1 . If a saturation is detected, a gain reduction is applied by steps of 1db.	no parameter
<b>saturategain</b>	Combined instruction, applying a gain or reduction to the DSP accumulator and proceeding with saturate instruction above	gain as an immediate numerical value or as an expression.
<b>saturatevol</b>	Apply a portion of the volume on the accumulator and proceed saturate instruction	no parameter

<b>biquad</b>	Compute one or multiple biquad sections based on the filter defined by a label and given as a parameter	filter label name
<b>param</b>	Restart a label parameter section, enabling definition of labels memory or filters below.	optional numerical number, see specific documentation
<b>shift</b>	shift register X by n bits left if parameter n is positive, or n bit right if n parameter is negative	fixed value in number of bits $-32 < n < +32$
<b>valuex, valuey</b>	load register X or Y with a fixed value	$-8.000 \leq \text{value} < +8.0$
<b>clrxy</b>	clear the 2 registers X and Y	
<b>swapxy</b>	exchange the 2 registers X and Y	
<b>copyxy, copyyx</b>	copy register X to Y , or Y to X	
<b>addxy, addyx</b>	Add two register : $X = X+Y$ , or $Y = X+Y$	
<b>subxy, subyx</b>	Subtract two registers : $X = X - Y$ , or $Y = Y - X$	
<b>mulxy, mulyx</b>	Multiply two 64 bits registers X and Y and store result in X or Y	
<b>divxy, divyx</b>	divide two 64 bits registers X and Y : $X = X / Y$ or $Y = Y / X$	
<b>avgxy, avgyx</b>	Average the two registers : $X=X/2+Y/2$ or $Y=X/2+Y/2$	
<b>negx, negy</b>	compute opposite value : $X = -X$ , or $Y = -Y$ (=180° phase shift)	

## Cpu requirements for DSP macro:

<b>avdsp macro instructions</b>	<b>cpu instructions</b>
initialization and core start	30 or 45 for first one
basic input or output	10
basic transfer between one input-output	6 + 6 per transferred in-out
load sample and apply a gain (inputgain)	14
load multiple sample and apply specific gains (mixer)	14 + 6 for each (input,gain)
biquad filtering (first or second order)	20 + 19 for each filter
saturate accumulator : verify saturation and eventually apply -1db reduction steps	12 + 5 in case of reduction
same with a gain applied before (saturategain)	22 + 5 in case of reduction
saturatevol apply volume and eventually reduce gain and check further saturation	15

fifo pipeline to delay a signal (delayus or delaydpus)	20 for delayus 23 for delaydpus
share data across core through memory (savexmem or loadxmem)	10
fifo pipeline for delaying by one single sample to synchronize core access to memory (delayone)	13
typical basic program for 1 channel: input x biquad sections (eg 4 = LR4 + 2 PEAK) delayus y output z	<b>139</b> for <b>4</b> sections <b>177</b> for <b>6</b> sections <b>215</b> for <b>8</b> sections

## List of supported filter names

type	label name (LP means low pass, HP means highpass)	parameters
Bessel (standard)	LPBE2, LPBE3, LPBE4, LPBE6, LPBE8 HPBE2, HPBE3, HPBE4, HPBE6, HPBE8	Frequency and optional gain
Bessel computed for fc cutoff at -3db	LPBE3db2, LPBE3db3, LPBE3db4, LPBE3db6, LPBE3db8, HPBE3db2 HPBE3db3, HPBE3db4, HPBE3db6, HPBE3db8	
Butterworth	LPBU2, LPBU3, LPBU4, LPBU6, LPBU8, HPBU2, HPBU3, HPBU4, HPBU6, HPBU8	
Linkwitz-Riley	LPLR2, LPLR3, LPLR4, LPLR6, LPLR8 HPLR2, HPLR3, HPLR4, HPLR6, HPLR8,	
classic first order	LP1, HP1, AP1 (allpass)	Frequency and gain
High and Low shelf	LS1, HS1 (1st order)	Frequency and gain
High and Low shelf second order	LS2, HS2	Frequency and Q and gain
classic 2nd order	LP2, HP2, (can be cascaded as needed) AP2, (all pass)	Frequency and Q and optional gain
special 2nd order	PEAK, NOTCH, BPQ, BP0DB (bandpass)	Frequency and Q and optional gain
Linkwitz Transform	LT	F0,Q0,Fp,Qp and optional gain

## First DSP program creation and upload.

Clone the github directory or download and unzip the corresponding package.  
In the different folder you will find command line utilities for your operating system.

You can create a dedicated DSP working folder in which you copy both utilities and the examples.  
Edit the [example1.txt](#) file with your preferred text editor.

with a terminal session or command line window, convert the file as a binary file:

```
dspcreate -dspformat 2 -dsptext example1.txt -binfile ex1.bin
```

Select a DSP prog 1 to 4 in the Filter menu (even if empty, this enables DSP runtime).

A squared 0 is now displayed in the top left corner of the volume screen of the DAC8.

upload the resulting binary file with

```
xmosusb -dspload ex1.bin
```

verify status and cpu load with

```
xmosusb -dacstatus
```

Play music and verify that the sound is now Mono instead of stereo.

Or use REW to play a signal either on the Left(1) or Right(2) channel and check the resulting signal either on channel 1 or 2. Channel 1 is a direct copy of Left and shall be used as the reference.

Channel 2 is the mix of Left and Right inputs in this example.

Once finished, write binary file loaded into a flash memory location between 1 and 4.

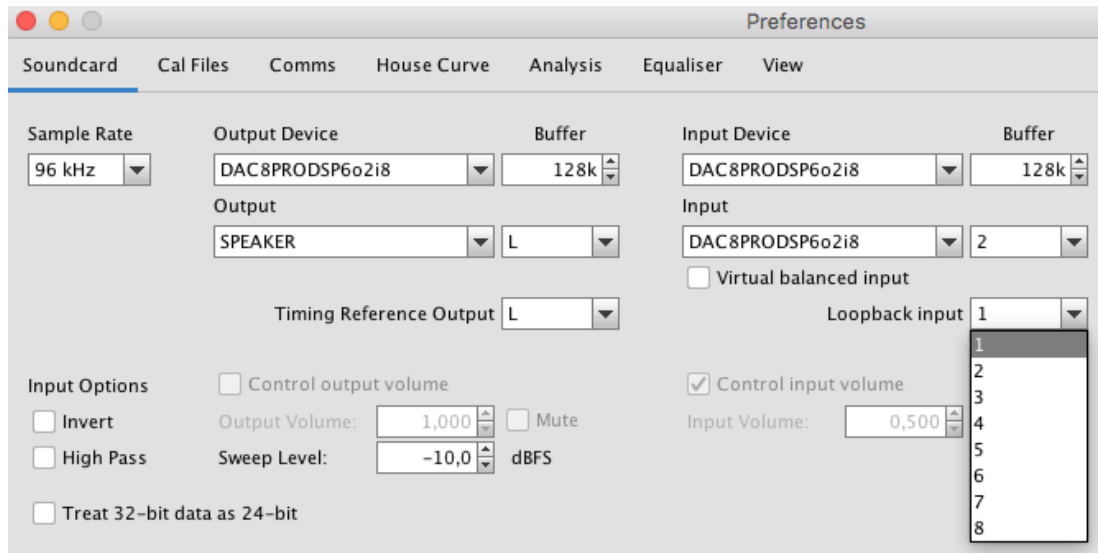
```
xmosusb -dspwrite 1
```

remark: when using instruction [saturate](#) or [saturatevol](#) or [outputvolsat](#), clipping will be detected and displayed during music playback in the top right corner of the right screen with a value in decibel written on a white background.

# Using REW to test a program with loopback

It is important to verify the result of a DSP program with a tool like REW, displaying the response with a frequency sweep, the time response with an impulse or square wave, and to measure group delay of the solution. REW can provide signal on each of the 8 USB-out channels and display FFT or scope view for any of the 8 USB-in channels. It is good practice to provide a time reference signal, with a loopback of USB-Out and USB-in for channel 1 (also called Left).

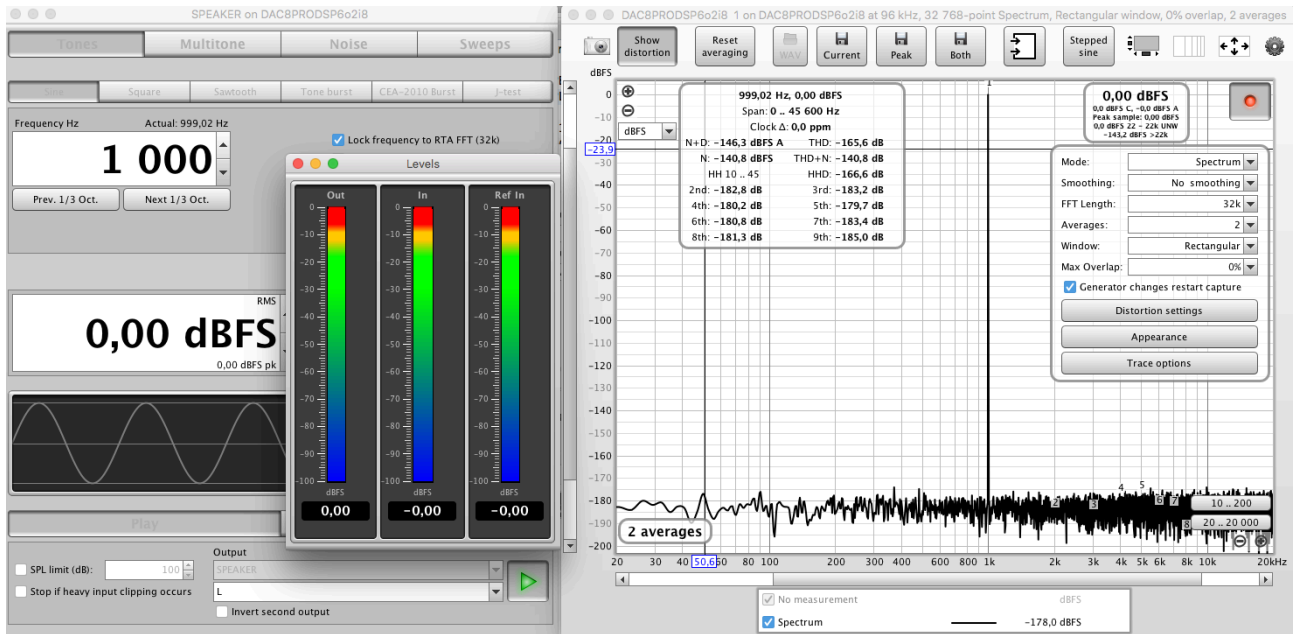
Example of Preference screen :



Here is a simple test program with a [transfer](#) function at the beginning of the program to provide loopback between USB-out 0 and USB-in 0 (16,24). The original signal is also transferred on DAC0 (16,0), a lowpass filter is provided on DAC 1 and USB-in 1, a high pass filter is provided on DAC2 and USB-in 2:

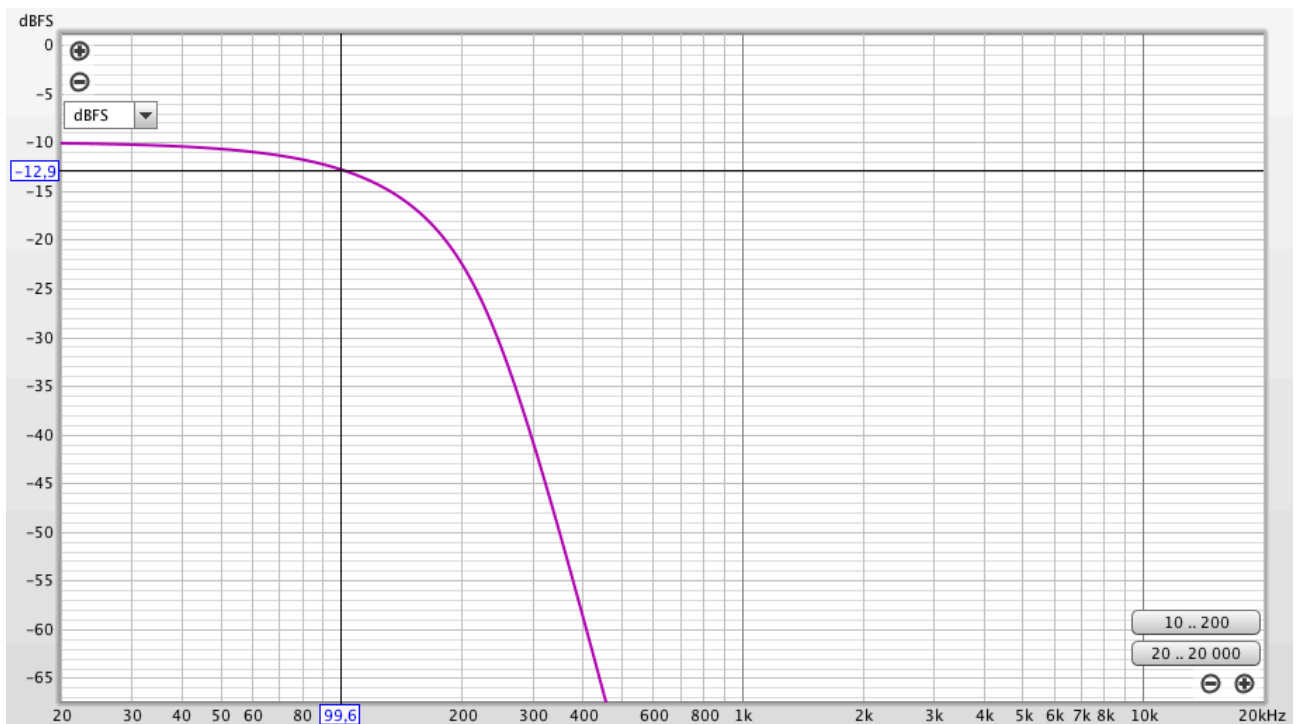
```
lowpass      HPBE8(200)  #bessel filter 8th order (constant group delay)
highpass     HPLR4(400)  #linkwitz-rilley 4th order
core
    transfer (16, 24)(16,0) #this provides fast loop back on USB channel 0
    inputgain (16, 0db)     #load sample from USB out 0
    biquad lowpass          #apply low pass bessel
    output 1 ; output 25    #output result on DAC1 and to USB for test
    inputgain (16, 0db)     #load sample from USB-out 0 (once again)
    biquad highpass         #apply highpass
    output 2 ; output 26    #output result on DAC2 and to USB for test
end
```

Resulting screen when testing loop back with a 0db sine wave as input: no clipping , no THD



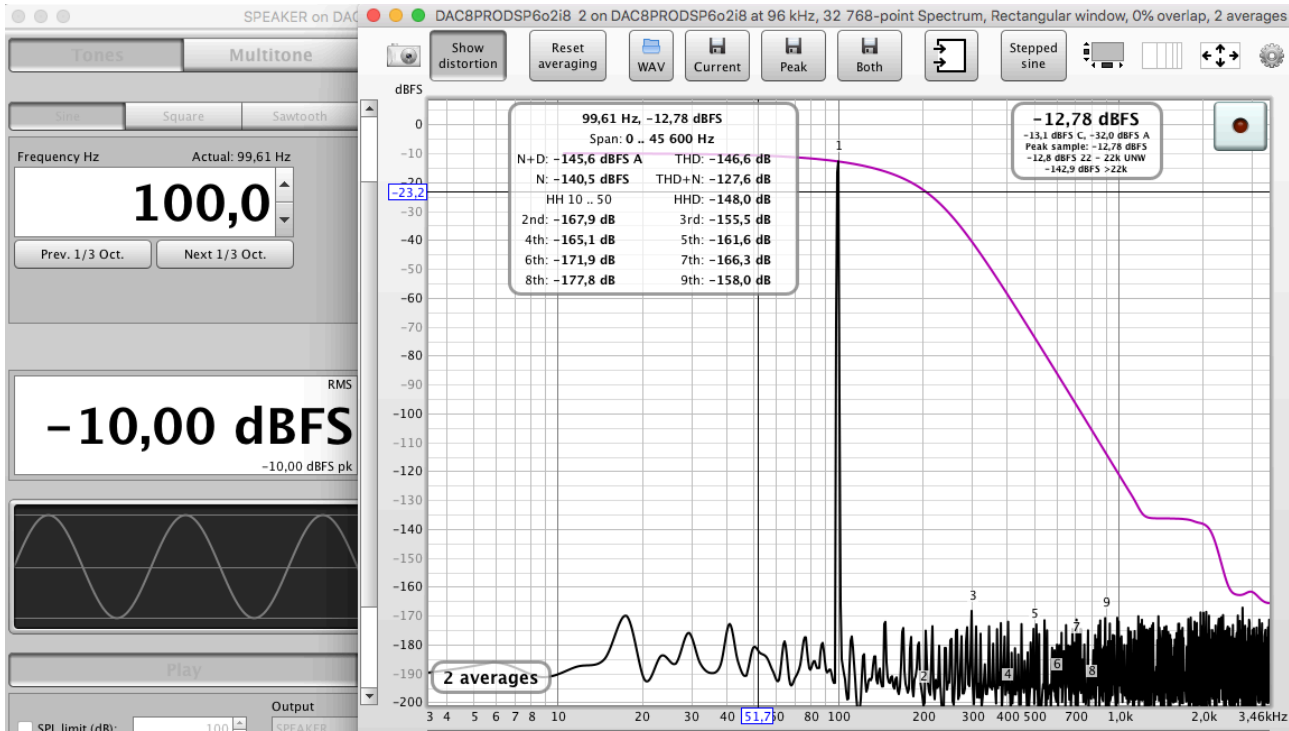
Sweep Measurement on channel 1 with -10db signal in range 10-20000:

LP Bessel 8th response is -2.9@ 100hz, -31@300hz, -77@600hz so 46db/octave (300..600)

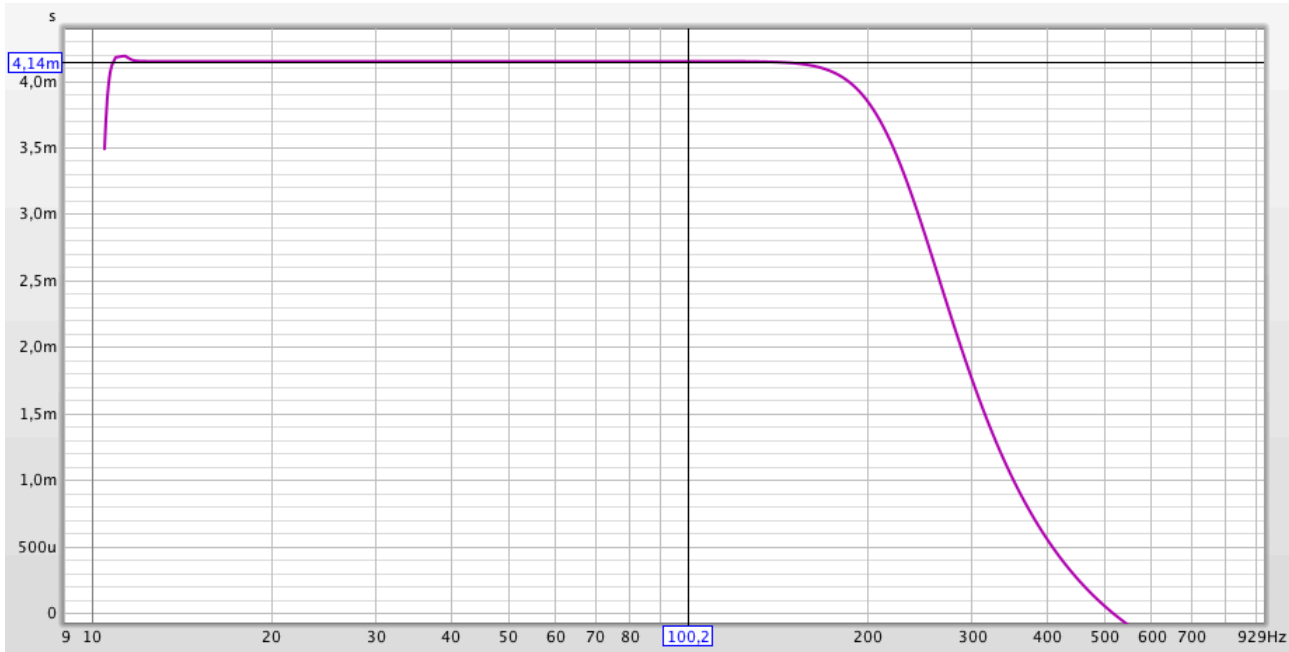




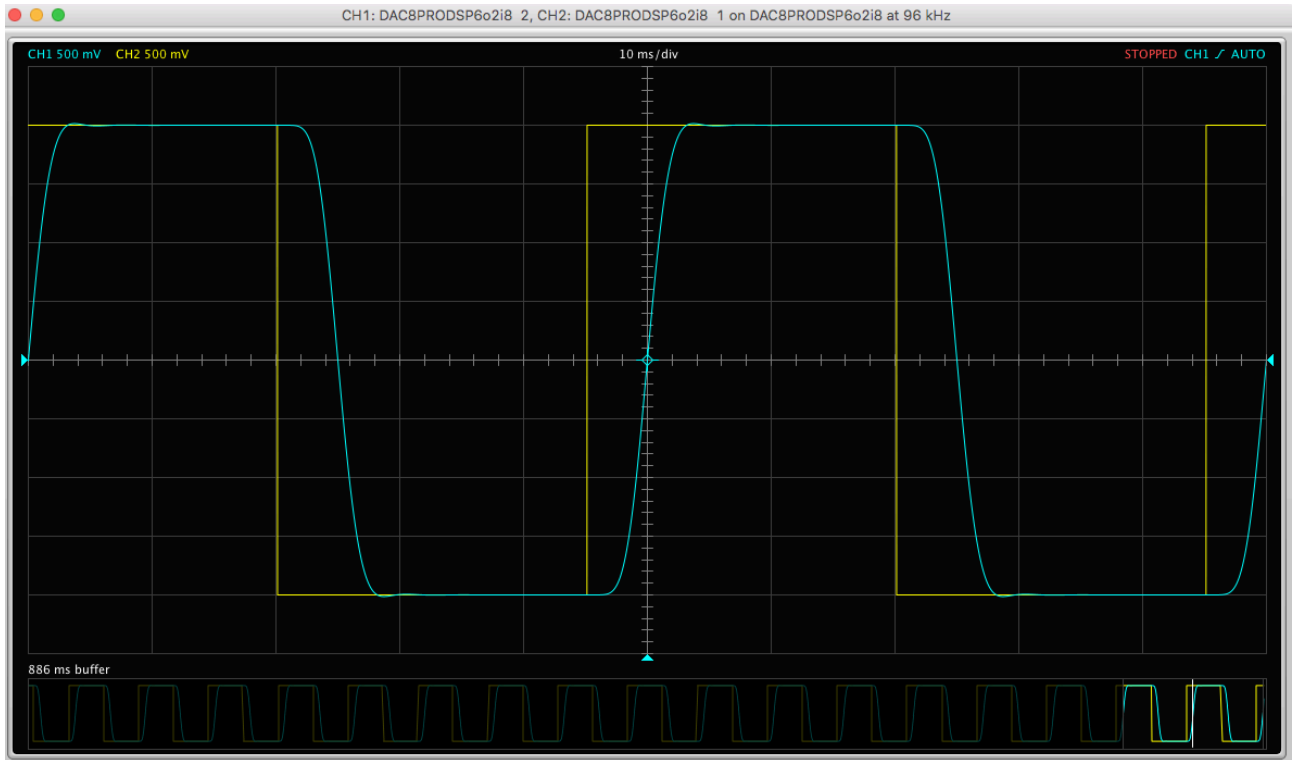
There is no THD for a 100hz test tone (thanks to our specific biquad routine):



As expected, the group delay of the bessel filter is flat below the cutoff frequency, at 4.14ms.



The scope view show a perfect damped step response to a square wave (0db 20hz here) with no clipping:



For the channel 2, response of the high pass LR4:

TBD / WIP

# Operating system specificities.

For both Mac OSX and Linux, it is possible and recommended to copy both utilities in the folder /usr/local/bin and the library in /usr/local/lib with the following commands executed in a terminal or shell window, so the utilities can be launched from any other path location and without needing ./

```
cp xmosusb /usr/local/bin
cp dspcreate /usr/local/bin
cp libavdsp* /usr/local/lib
```

## Mac OSX

Utilities are compiled for x86\_64 but are also compatible with Apple silicon M1 or higher via the transparent Rosetta emulator. Eventually the user might need to change the access rights of the utility with the command:

```
chmod +x xmosusb dspcreate
```

At the time of writing, the utilities have been tested and successfully run on iMac intel core i5 with High Sierra and on Macbook pro M1pro with Sonoma.

Mac OSX usb audio host driver is compatible with DAC8 products in 8 channels mode. Configuring the USB with the Midi utility in another mode like 2 or 6 channels will not change the 32 memory mapping explained in this document.

Xmosusb utility can be used to upload DSP programs while a player is using the same USB device playing sound or music to the DAC (like with REW software). From experience this doesn't impact the USB audio streaming and does not impact the REW java audio driver. It is then possible to develop a DSP program seamlessly without constraints and to do repetitive live tests by loading DSP programs in memory "on the fly".

## Linux

The utilities are compiled and tested for Linux Mint cinnamon x86\_64.

xmosusb utility requires sudo prefix unless the user name is added in the proper usb plugdev group.

Libusb library must be installed separately and visible in the "Path".

example : sudo apt-get install libusb-1.0-0-dev

The dspcreate utility requires libavdspencoder.so library and might need to update your library path by editing and exporting LD\_LIBRARY\_PATH, and just adding a "." to refer to the same folder.

Another alternative is to copy or move libavdspencoder.so to /usr/local/lib/

By extension, copying or moving dspcreate and xmosusb to /usr/local/bin/ gives the possibility to launch them from any working folder.

A version is provided for Raspberry Pi os compiled for aarch64 (V6.1.21-v8+).

Finally a version is also provided for the Raspberry Pi ARM 32 bits os and this was tested with a Volumio 3 image (v3.661).

As for Mac OSX, no special limitations are known for using the xmosusb tool with the USB audio driver simultaneously.

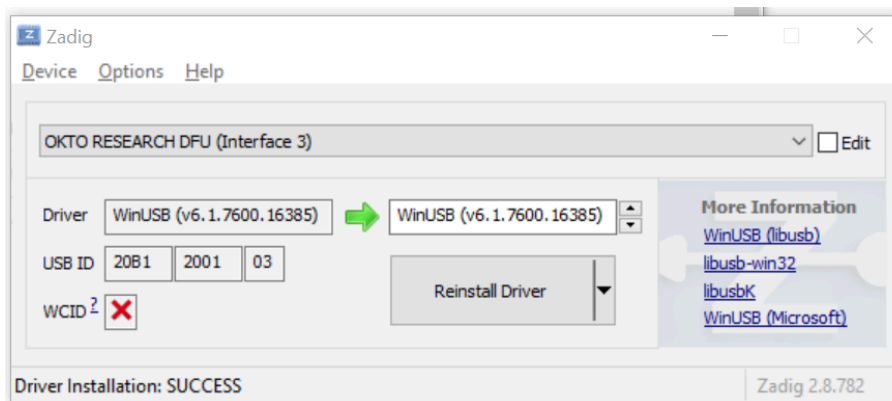
## Windows.

The utilities have been compiled with Mingw64 and can be run directly in a windows cmd shell. Unfortunately, windows driver mechanisms and xmosusb utility using libusb brings some concerns which we have been able to tackle but with some user constraints.

Nevertheless the process explained below can provide a reasonably seamless experience for developing and uploading a DSP program on Windows, but the author recognizes the limitation and recommends using linux or Mac OSX during development and tests phases.

First of all, xmosusb.exe utilizes the open-source libusb library and requires Windows [winusb](#) driver to be installed on the interface 3 (DFU) of the DAC8 USB composite device. This has to be installed with Zadig. (using version 2.8 in this example below).

But this process is conflicting with the OktoResearch USB driver (Thesycon manufacturer) which captures all the usb interfaces. So the OktoResearch usb driver MUST be uninstalled before installing winusb.



Then the xmosusb.exe will discover the DAC8PRODSP properly on the usb bus:

```
C:\XMOS\xmosusb\windows>xmosusb

This utility is using libusb v1.0.26.11724

[0] > VID 20B1, PID 2001, BCD 0160 : OKTO RESEARCH  DAC8PRODSP4  000016
      (0)  usb Audio Control
      (1)  usb Audio Streaming
      (2)  usb Audio Streaming
      (3)  usb DFU
```

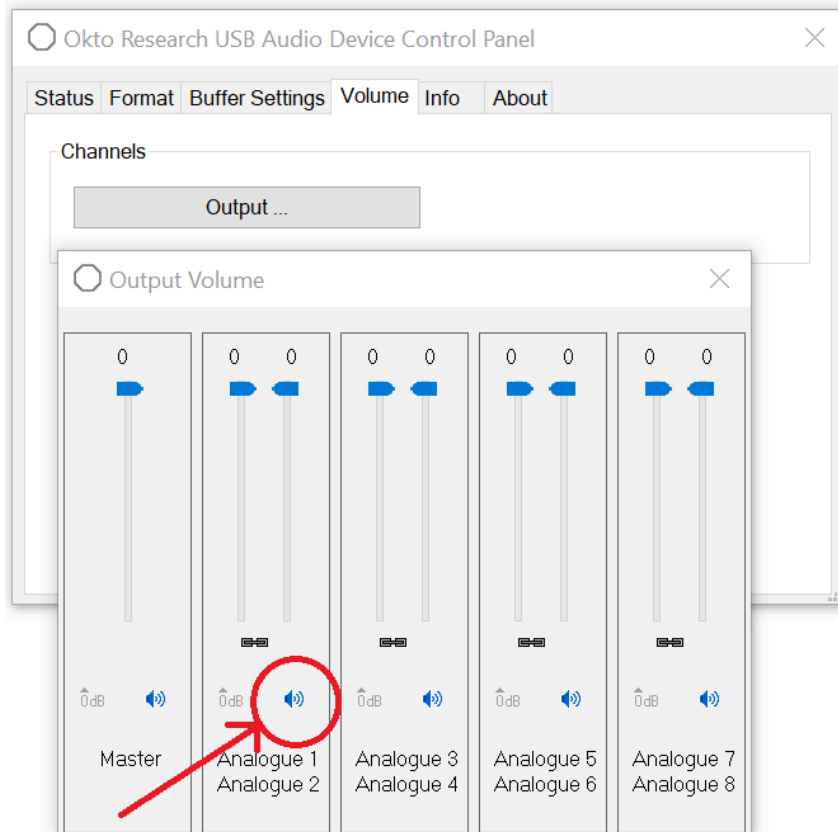
By default the Windows usb audio driver will be installed and will recognize DAC8 products without any issue, but it supports only 2 channels output (playing) and input (recording). This is practically enough to test the DSP program, channel by channel with REW in wasapi mode.

Once the DSP programs are developed, tested, stabilized and written to the DAC8 flash memory, then it is possible to reinstall the OktoResearch usb audio driver to benefit from the 8 channels handling and to use asio capabilities.

## Special USB VID:PID

Because the author realizes that it is painful to uninstall and then reinstall the OktoResearch usb driver during the DSP development phase, a specific mode has been implemented so that the DAC8 DSP can be seen on the USB bus either with its original VID:PID (152A:88C4) or with a temporary and alternate VID:PID (20B1:2001). This gives the possibility to install winusb on this last one and to use xmosusb.exe freely, while the original VID:PID stays attached to the OktoResearch usb audio driver.

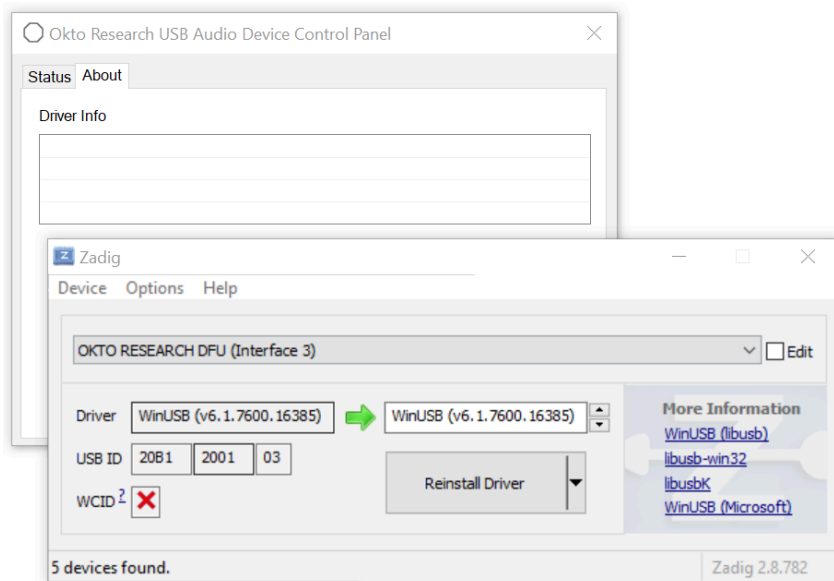
To reboot the DAC8 DSP with this temporary VID:PID, go to the OktoResearch driver control panel, select the Volume tab and click the “output” area to display the volume's vertical cursors.



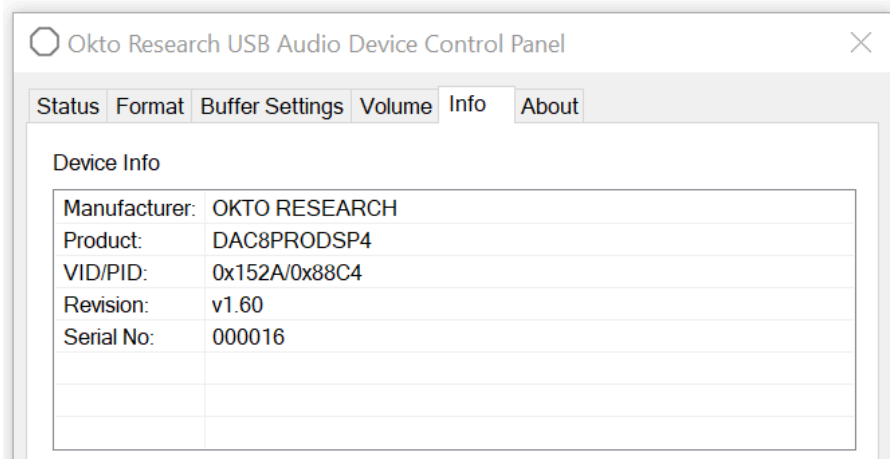
Click on the muting icon for the 2 first channels to mute them, and this will start a 5 seconds period where the USB cable can be disconnected : when reconnecting the usb cable, the dac will re-enumerate with the temporary VID:PID, so it will not be seen by OktoResearch usb audio driver, and windows will install (the first time) its basic audio driver.

remark : If the cable wasn't removed within the 5 seconds period then the DAC8 DSP keeps running with its original VID:PID and this special sequence is canceled. It is possible to restart this process at any time. The DAC8 DSP recognizes the sequence going from unmute to mute on channels 1 & 2 only, the states of the other channels doesn't matter.

Then it is possible to install winusb with zadig on the temporarily detected device:



To restore the original VID:PID, just disconnect and reconnect the usb cable. The DAC8 DSP will immediately reappear in the thesycon driver control panel info box with its original VID:PID.



remark : After re-entering in the normal mode of operation with the original VID:PID, remember to unmute the 2 first channels in the volume/output menu to effectively listen to music !

# xmosusb utility

The xmosusb utility is an extension of the original DFU utility provided by XMOS company. It has been extended to support additional commands. The list below is not exhaustive and provides only the commands which may be used at some point in time with the DAC8 DSP firmware. Each command starts with two successive “-” (minus) characters (for history reasons...):

**-dspload file** : Sends a binary file to xu216 firmware. The binary codes are loaded in xu216 ram memory and eventually overload the latest DSP program loaded from the front panel Filter menu.

**-dspwrite num** : Writes the xu216 ram memory to the flash location “num”. This is the way to save a DSP program into a permanent flash location within DAC8 DSP.

**-dspread num** : Loads a DSP program from the flash location “num” into xu216 ram memory. This program then becomes the one used by xu216, even if the front panel displays another number...

**-flashread page** : Provides a dump of 64 bytes of internal flash memory at a given page position. A page is 64 bytes. DSP programs are written as of page 64 and onwards.

**-flasherase sector** : Erases a 4096 bytes of flash memory at a given sector. A sector size is 4096 bytes. DSP programs are stored in flash starting at sector 1. To erase all DSP programs in flash, just type xmosusb -flasherase 1. Remark: original factory firmware is stored in a specific boot partition and is protected from erasure.

**-dspheader** : Provides a summary of the DSP program currently loaded in xu216 ram memory.

**-dacstatus** : Provides some internal information and instructions used on each xu216 core.

**-xmosload file** : This command can be used to flash an xu216 firmware compatible with DAC8 products, with the same result as using the DFU Windows tool, especially useful for linux or Mac OSX or Raspberry pi platforms. If the provided firmware contains a front panel firmware then it will be flashed during the next boot process. This command cannot and will not verify if the provided binary file is compatible with the target xu216 digital board and therefore there is a potential risk to brick the unit. This command is perfectly safe to use as long as the file provided is compatible with DAC8 product.

**-samdload file** : Sends a binary file to the xu216 cpu to flash the front panel firmware. No any checks are done on the binary file and this command should be utilized only when instructed by OktoResearch to flash a specific version of the front panel firmware without changing the current version of the xmos firmware. The flash process takes about 60 seconds without any indications...

**-samdreflash** : Starts a flash process from the internal xu216 firmware to the front panel device, using the version originally embedded inside the xu216 firmware. This can be useful to restore an original front panel version when restoring a DAC8 to its factory version, or if the front panel was overwritten with a specific custom or OEM version using a previous -samdload command.

if the xmosusb utility seems blocked in an endless waiting loop, just press Ctrl-c to exit...



# dspcreate utility

This utility is part of the AVDSP project, it is used to generate DSP binary files for devices using AVDSP runtime, like DAC8PRODSP. Source code are available on github [fabriceo/avdsp](https://github.com/fabriceo/avdsp).

The following options can be used (each option starts with a single “-” minus character):

**-dspformat x** : forces the DSP encoder to generate either integer or float values for any constant (gains, filter coefficient). value 3 will force generating 32 bits floats so precision is limited to 24 bits. Value 2 will force generating 32 bits integer with a mantissa of 28 bits and an integer part limited to 3 useful bits (-8.0..+7.999). Any value between 16 and 30 can be used to generate a 32 bits integer with a customized mantissa between 16 and 30 bits.

At the time of writing, the DAC8 DSP runtime will convert all the constant values (float or integer) into integer q28 or s3.28 format so it is recommended to just use -dspformat 2

**-dsptext filename<+filename2...>** : Process one or many text files that can be chained with the “+” character (but no space character allowed).

The embedded analyzer recognizes a simplified syntax for label and filter definition and a limited list of AVDSP macros. It generates a list of “opcode” corresponding to a DSP program. The translation into opcodes is printed on the console for information and debugging purposes. In case of syntax error, the line is printed on the console, with an “^” arrow below the token generating the error, and code generation is aborted. At the end of the analysis, a summary is provided with the number of cores used, code size and checksum.

*remark: when chaining multiple source files with the “+” character, it is useful to use the first file as a definition for constants or to label each input output that will be used by the next chained text file(s). For example the file “dac8pro0” or “dac8pro1” in the example folder can be used to define the aes, dac or usb memory location with a convenient name instead of using directly the memory location 0..31. The dac8pro0 will consider the channels from 0 to 7, but the dac8pro1 will name them from 1 to 8, which is more aligned with audio software (like REW for example).*

**-dspprog filename** : open a dynamic library file named filename.so or filename.dylib or filename.dll and execute the code corresponding to a procedure named dspProg(). Such a procedure shall generate the DSP opcode by calling the primitive of the AVDSP library. This more complex and flexible approach is compatible with DAC8 DSP but not documented here.

**-binfile filename** : instructs to save the list of opcodes as a binary “filename”.

**-hexfile filename** : instructs to save the list of opcodes as a C formatted text file which could be included in a specific xmos audio project and immediately embedded inside an xmos firmware. This is typically used to onboard a default DSP program inside a custom firmware.

**-dumpfile filename** : export the DSP program symbols and their address in a text “filename”.

**-fsmin min -fsmay max** : used to force a minimum and/or maximum sampling rate limit. All the filter coefficients and size of the delay pipelines will be pre-computed for each of the sampling rates included within these two boundaries. by default fsmin is set to 44100hz and fsmay is set to 192000hz.

when using `-dsptext` selector, then all remaining information at the end of the command line for `dspcreate` will be used as additional lines of the DSP program, and they will be passed one by one to the analyser and before starting analyzing the main text file. This is useful to pass dynamic parameters like frequency cutoffs, or specific gains on the command line, without modifying a common core text file. Here are some typical command line for DAC8 DSP:

```
dspcreate -dspformat 2 -dsptext example.txt -binfile prog1.bin FC=400 GAIN=-3db  
dspcreate -dspformat 2 -dsptext example.txt -binfile prog2.bin FC=500 GAIN=-2db  
dspcreate -dspformat 2 -dsptext dac8pro1+example.txt -binfile prog3.bin coef=0.6
```

## Remark for developers:

The AVDSP repository on github contains 2 branches, master and develop.

The master branch is the original source code providing compatibility for linux and an early version for xmos.

At this time (May 1st 2020, release 1.0) the `dspcreate` utility did not include the macro interpreter with the `-dsptext` selector.

The develop branch has modified a lot of code to provide better optimization for xmos and to integrate the `-dsptext` selector capabilities. Unfortunately there is still a lot of work to do to merge the 2 branches. Users willing to test the new DAC8 style DSP programs on linux with the AVDSP alsa plugin will have to wait for a merge of the 2 versions...

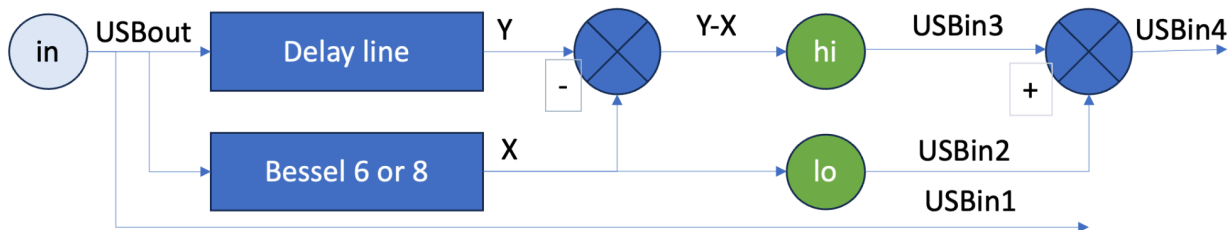
The xmos runtime is now written in assembly and not yet published on the AVDSP develop branch. instead it is embedded in the xmos usb application specifically customized for DAC8 products. Contact the author to get a version of this runtime and some advice for its integration in a custom product. The plan is to remove the specific xmos XS2 instructions from the AVDSP standard runtime and to publish this specific runtime aside (still open source).

# Extra DSP instruction

## example of subtractive filters

The AVDSP runtime includes specific instructions to do some basic math on the 2 DSP accumulators X and Y. This gives the possibility to create special treatments, either experimental or for practical situations.

Subtractive filters are very interesting examples to get crossover with linear phase or constant group delay. Principle:



The Bessel 8 filter provides a flat group delay, and the subtraction after the delay line will give a second order high pass filter. The sum of the 2 resulting signals shows a flat response and a flat group delay. It is possible to adjust the delay line in code below to see the impact on highpass.

```
fc      ?      600    #question mark gives the possibility to overwrite fc in command line
bessel8    LPBE8(fc)  #simple bessel filter order 8 at "fc"
gd      =      986000/fc  #formula for getting group delay for a bessel 8 at fc
core
    input 16      #get sample from usb channel 1
    copyxy        #copy X into Y
    output 24     #feedback to usb for reference
    biquad bessel8    #compute lowpass
    output 25     #output to usb channel 2
    swapxy        #getback Y into X
    delaydpus gd   #dual precision delay line
    subxy         #compute high pass
    output 26     #output to usb channel 3
    addxy         #sum signals to check resulting wave
    output 27     #output to usb channel 4
end
```

## example LXMini crossover 2 ways

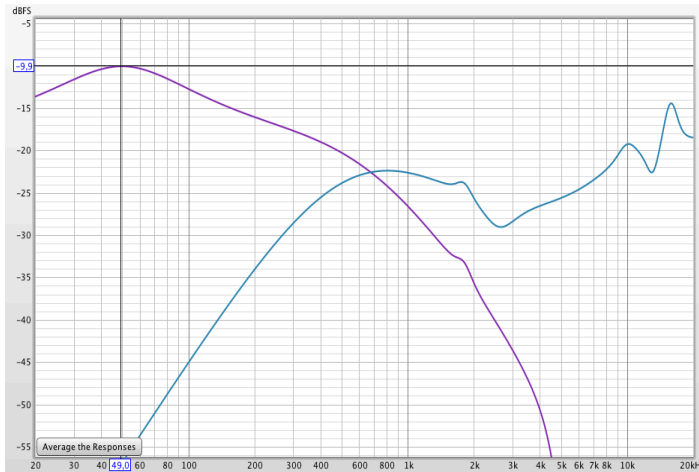
```
ineq    PEAK(1800,7,2db)
loeq    LP2(700,0.5) PEAK(50,0.5,7db) PEAK(5100,8,-16db) PEAK(5800,3,-10db)
hieq    HP2(700,0.5,-1) LS2(1000,0.5,16db) PEAK(2600,2,-4db) HS2(8000,0.7,8.5db)
        PEAK(10000,5,2.3db) PEAK(13100,7,-5db) PEAK(15800,10,7db)
core
    transfer (16,24)      #feedback to host for reference
    inputgain (16,-7db)   #7db less due to PEAK at 50hz
    biquad ineq
    biquad loeq
    output 25             #output to usb host for tests
```

```

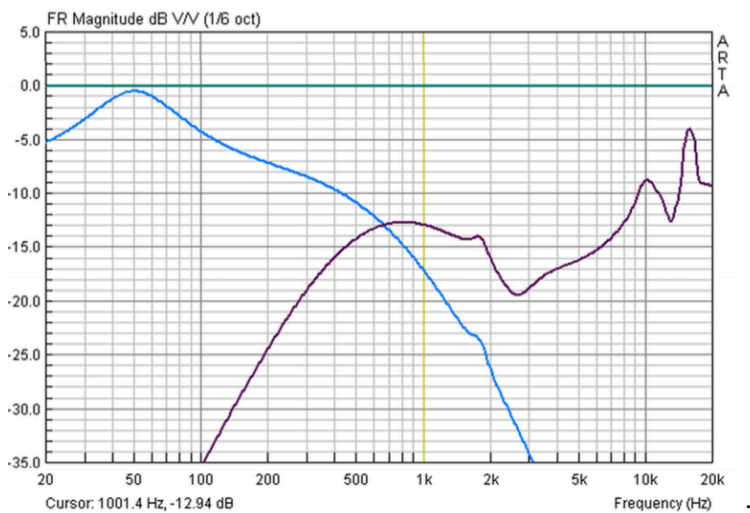
core
    inputgain (16,-17db)    # -17db to equilibrate with woofer
    biquad ineq
    biquad hieq
    output 26                # output to usb host for tests
end

```

measured results in REW:



Original on Linkwitz web site: [https://www.linkwitzlab.com/The\\_Magic/The\\_Magic.htm](https://www.linkwitzlab.com/The_Magic/The_Magic.htm)



example decay convolution (...0.125, 0.25, 0.5)

```

sum    MEMORY 1
coef   0.6
core
    input 16 ; output 24    # feedback to usb host for signal reference
    gain coef ; copyxy
    loadxmem sum ; gain 1-coef ; addxy ; savexmem sum
    output 25                # sent to usb host second channel for sweep measurement
end

```

## Saturate instruction details and example

The following program can be tested with the third party tools REW with “Scope” view, by switching the input channels 1 to 4 and by generating a square wave at 0dbfs. It demonstrates the benefit of using the `saturate` instruction as a way to avoid clipping in all cases.

```
highpass    HPBU2(400)
core
    input 16
    output 24      #loopback for reference
    biquad highpass #the result in the DSP accumulator exceed +1..-1
    copyxy        #save result in accumulator Y
    output 25      # signal is clamped sharp between +1 and -1
    copyyx        #retrieve accumulator Y
    gain -3db      #accumulator is reduced between +0.8..-0.8
    output 26      #clean as biquad routine provides 18db headroom
    copyyx        #retrieve accumulator Y
    saturate       # the result is reduced by up to 5db automatically
    output 27
end
```

When a `saturate` instruction detects an overflow situation it raises a global saturation flag and immediately clamps the sample between +1..-1. Then at the next sample cycle, the DSP runtime will check this flag and eventually increments a saturation counter register.

If a `saturate` instruction sees a number N in this counter register, it reduces the value of the accumulator by N decibels. So the previous hard clipping happens only on one single sample and this is not audible and has no any consequence on the audio chain.

The only way to reset this saturation number register is to switch on/off the DAC, or reload a DSP program, or switch the sampling rate frequency, or cycling a mute/unmute.

The saturation is displayed black on white in the top right corner of the volume display area.

It is recommended to use the `saturate` instruction until all demonstrations are done so that no clipping is produced by the user DSP program. Extensive tests can be done with REW square waves at 0dbfs and reviewing each output with the “Scope” view.

Using `saturate` instruction before any `output` requires additional cpu time but provides a safe solution to avoid any harmonics on outputs linked to potential overflow. This approach of reducing dynamically the output gain by steps of 1db is a unique way to avoid traditional signal compressors, which inherently bring a lot of distortion when the signal comes close to the peak threshold. Once all the gain chains have been adjusted to avoid clipping, the `saturate` instructions can be removed safely from the final DSP program.

By extension, the `saturategain` instruction executes a gain function and then the explained `saturate` behavior.

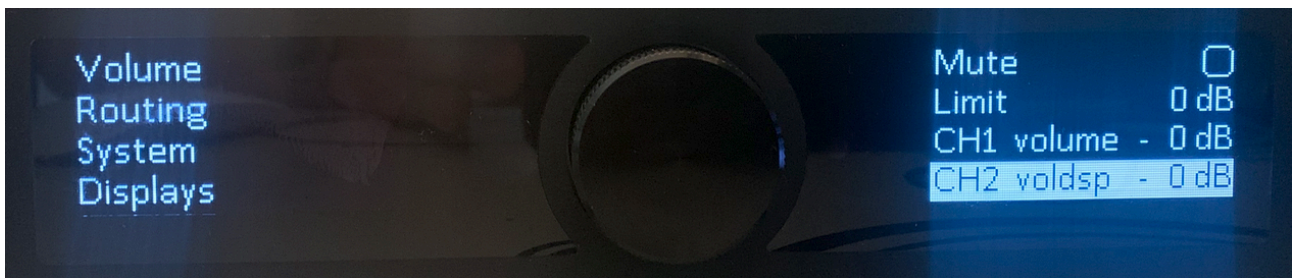
Newly introduced [saturatevol](#), [outputvol](#) and [outputvolsat](#) as of version v1.61:

Some musical programs can show an excess of up to 3db (or even more) due to their encoding, or when they pass through audio filters (or through the DAC chip FIR or ASRC itself!). Also any IIR filter (like biquad) with a Q factor above 0.5 will generate overshoot and will produce output above original input (just try playing a square wave through a butterworth filter to get convince).

The 64 bits treatment with 8 bits headroom implemented in the DAC8DSP during computation will accommodate this situation perfectly, until the result is stored in memory for the DAC as these 8 upper bits have to be removed to keep the signal between +1..-1.

Using the original [saturate](#) instruction is bullet proof to detect these situations, but it will reduce the Dynamic Range of the DAC by simply always removing these excess decibels once they are detected. But this reduction is not really needed if we apply the volume as part of the DSP treatment instead of doing it in the DAC. As an example, if a given music program going through a given filter is generating say 9db of excess, this is not a problem as long as you always listen to a volume between -99 and -9dB. and if you listen sometime at a volume of -7db, the [saturate](#) instruction should just remove 2db.

In order to enable this possibility, the DAC8PRO front panel program has been upgraded to eventually delegate the first 18db of volume treatment to the XMOS DSP. Then the Sabre DAC keeps attenuating the residual part when the volume is between -99 and -18db. This feature can be enabled for any DAC channel, with a long press of the knob when editing a channel volume.



For the channels where this feature is enabled (channel 2 here on this picture), the DSP program is expected to take care of the first 18db of volume reduction and this requires using explicitly one of the 3 new instructions in the treatment chain for these channels.

The new [saturatevol](#) instruction provides the same behavior as [saturate](#) but integrates the volume reduction before detecting the signal clipping, and should be used before any [output](#) instruction when the corresponding channel has been configured as “voldsp”.

By extension and to optimize the CPU treatment it is possible to replace any [output](#) instruction by [outputvolsat](#) which combines both [saturatevol](#) and [output](#) functionality in a single instruction.

By extension, [outputvol](#) applies up to 18db of reduction without testing nor adding saturation. This gives the possibility of using a DSP program having excess gain without taking care of the saturation, considering that most of the time the volume will be much lower than the excess.

remark: [output](#), [outputvol](#), [outputvolsat](#), [outputtpdf](#) instructions have been optimized to allow storing the accumulator value in multiple memory locations, listed on the same line, separated with coma. The [saturate](#), [saturatevol](#) or [outputvolsat](#) provide 1db granularity instead of 6db in previous version and will detect and reduce volume by a maximum of 15db.

## Dithering with tpdf instructions

The `tpdf` instruction provides the possibility to apply N bits dithering with triangular noise.

To use this functionality, the `tpdf` instruction must be defined preferably at the beginning of the first core, with a numerical parameter defining the bit position (8 to 30). This instruction will then compute a signed 31 bits noise value and will apply a mask to keep only (32-N) useful bits. This is done at each sample rate cycle and the noise value computed can then be used in any core.

Then, anywhere in the program and in any core it is possible to use a specific `outputtpdf` instruction which will add this random number to the sample, before storing the value in the target memory location.

It is possible to use the `tpdf` instruction in any core, in addition to the first core : then the number of dithering bits will be specific within this single core. for example:

```
core
    tpdf 20
    input 16
    output 24          #original value
    outputtpdf 25      #20 bits dithered value
core
    input 16
    outputtpdf 26      #20 bits dithered (taken from first core)
    tpdf 18
    input 16
    outputtpdf 27      #18 bits dithered value
core
    input 16
    outputtpdf 28      #20 bits dithered (taken from first core)
end
```

In fact, `outputtpdf` instructions always use the number of dithering bits defined by a previous `tpdf` instruction in its own core, otherwise defined in the first core. If no `tpdf` instruction is defined in the program, the encoder will add one automatically when the first `outputtpdf` instruction is encountered in the program flow. Then the default dithering is arbitrarily chosen to 24 bits.



## Using conditional `core` and `section`

The AVDSP catalog of macros does not include any conditional testing but there is a possibility to dynamically activate or not a core depending on external conditions provided by the DAC firmware in a global status flag and reflecting the DAC modes and status.

By default any `core` declaration is valid and this will use a physical cpu core in the XU216 processor. But it is possible to set a condition with one or two parameters after the keyword `core`. These optional parameters are one or two binary masks, which can be provided as a decimal value or hexadecimal by using the “x” prefix or binary by using the “b” prefix.

The first parameter defines a mask for a bitwise “and” operation with the DAC status flag, and any matching bit set to 1 will enable the core.

The second optional parameter also defines a mask for a bitwise “and” operation with the DAC status flag, but the result of this “and” must be zero to validate the core, otherwise no physical core is allocated during runtime and then the total number of mips is redistributed.

The status flag is reflecting various status and mode as described below:

bit 15..12	dspcores	bit 11..8	AES inputs	bit 7..4	rate	bit 3..0	mode
0001	4	0001	44/48k	0001	PureAES1	0001	PureUSB
0011	5	0010	88/96k	0010	PureAES2	0010	PureUSB2
0111	6	0100	176/192k	0100	PureAES3	0100	AES/USB
1111	7	1000	352/384k	1000	PureAES4	1000	PureAES
b31..28	chanadc	b27..24	chandac	b23..20	toUsb	b19..16	fromUsb
0..15	ADC/AES	0..15	DAC/DSD	0..15	chan/2	0..15	chan/2

As an example, to activate core when the DAC is configured with a sampling rate below 176khz and only when the mode PureAES is selected, the core statement must be written as

```
core 0x300,7 or
```

```
core 0b00110000000,0b0111
```

then all the code below this core statement will be executed or not.

By extension, the instruction `section` gives the possibility to enable a code section within any active core if the conditions are met. example:

```
core
    section 0b1000    #check if PureAES mode is selected
    input 8           #if yes, read first AES channel
    section 3         #check if any USB mode is selected
    input 16          #if yes, read first USB channel from host
    section           #do nothing but mark the end of the section area
    output 0          #code continues here in all case and update DAC
    section 1         #check if PureUSB mode is selected
    output 24         #if yes provide the host with a loopback
end                 #end (or core) also marks the end of section
```

## Creating a program for different Mode (PureUSB, USB/AES PureUSB)

### Understanding In/outs and Outputs in DSP memory

In PureUSB or USB/AES, the audio stream from the USB Host is provided in the memory locations 16..23. In USB/AES, it is possible to use either this stream, or the one coming from AES directly which is stored in 8..15. In PureAES, the AES stream comes from 8..15.

In PureUSB and USB/AES, the left display indicates the channels which are effectively streamed by the USB Host; they are surrounded by a square when the host player starts streaming. The numbers are inverted (black on white background) when a sound presence is detected (not 0).

In PureAES, these 8 numbers are surrounded when an AES/SPdif signal is recognized on the respective AES inputs (not only an electrical connection). This process of detecting Lock and Sound presence is done by the dac8 by reading value of memory location 24..31, therefore it is up to the user and the DSP program to copy or transfer some of the signal to these memory location so they are displayed inverted (black on white) when sound is detected. This is important because this also unmutes the DAC outputs.

On the other end the DAC8 will also recopy these values from 24..31 to 16..23, so in PureAES it is recommended to read sound from 8..15, send something to 24..31 and then read them back from 16..23 as for the other modes.

Based on these statement, the following program is proposed for a passthrough stereo stream:

core

```
section 3 #pureUsb case
transfer (16,24) (17,25)      #provides a loopback to usb host
transfer (16,0) (17,1)       #send stereo to DACs
section 4 #usb/aes
transfer (8,24) (9,25)        #send AES to USB Host
transfer (16,0) (17,1)        #send USB Host to DAC
section 8 #pureAES
transfer (8,24) (9,25)        #send AES to USB host
transfer (16,0) (17,1)        #send USB Host (copy) to DAC
section
```

end

# Optimized fixed point 64 bits math explained

The XMOS XU216 is a powerful micro processor with a 32 bits instruction set and some specific instructions able to handle 64 bits. This is used extensively in the AVDSP runtime (using dual-issue assembler programing) in order to provide a PureDSP treatment with almost no THD.

The audio samples provided from the USB host are either 16, 24 or 32 bits signed integers. The samples provided by the AES inputs are 16 or 24 bits only. They are all represented as 32 bits signed data in memory with format called q31 or s0.31:

original 32 bits audio samples in q31 or s0.31 format	
<b>b31</b>	<b>b30..0</b>
sign	31 usefull bits (192db)

The AVDSP runtime is using two 64bits Accumulators called X and Y in this document. With the standard [input](#) instruction the audio samples are loaded in accumulator X with an 8 bits headroom so the 64bits presentation is q56 or s7.56:

audio samples converted to 64 bits accumulator			
<b>b63...b56</b>	<b>b55...b25</b>		<b>b24..b0</b>
extended sign (00 or FF)	31 usefull bits		25 zeros

A gain value is coded as a 32 bits signed integer, with 1 bit for the sign, 3 bits for the integer part, 28bits for the mantissa, also called q28 or s3.28. This gives the possibility to represent values between +7.999 and -8.0:

32 bits coded values or gain or biquad coefficients as q28 or s3.28		
<b>b31</b>	<b>b30..28</b>	<b>b27..0</b>
sign	3bits = +18db	mantissa (28 usefull bits 168db)

The [inputgain](#) instruction is multiplying a sample s0.31 by a gain s3.28 with a 32x32=64bits multiply instruction which provides a s4.59 base result. The accumulator is then shifted right by 3 to come to s7.56 format, which will be the standard format used during all next treatments.

64 bits accumulator as q56 or s7.56 (+/-127.999 = +42db)		
<b>b63</b>	<b>b62...b56</b>	<b>b55..0</b>
sign (0/1)	integer (7bits)	56 bits accuracy

An [output](#) instructions use specific cpu instructions to quickly saturate and reduce the s7.56 accumulator to a 32bits s0.31 value which is stored in the output location.

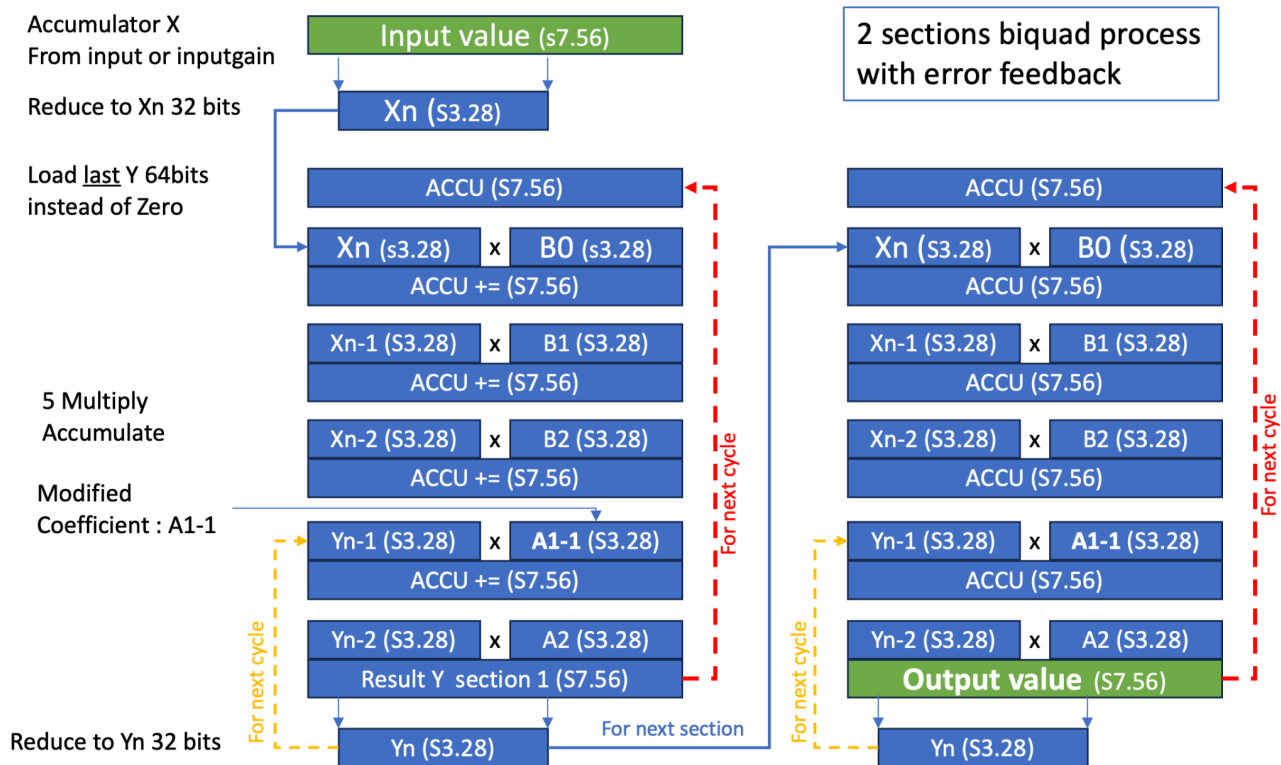
A [gain](#) instruction multiplies the 64bits X coded s7.56 by the 32bits gain coded s3.28 with three multiply instructions in a row resulting in a 96 bits value coded s11.84. This is then shifted right by 28bits to reduce the accumulator to the regular s7.56 format.

An [outputgain](#) instruction also combines three multiply instructions and then reduces the 96bits result to get 32 useful bits before storing them in the output location.

The [mulxy](#) instruction multiplies the two 64bits accumulator X and Y with 5 multiply instructions and keeps only the useful 64 bits so that a s7.56 signal multiplied by a s7.56 signal is reduced as a s7.56 value in the destination accumulator X (or Y with [mulyx](#)).

The **biquad** instruction requires a 32 bits  $X_n$  sample and produces a 64bits  $Y_n$  result by applying the five coefficients multiplication (form II):  $Y_n = X_n.b_0 + X_{n-1}.b_1 + X_{n-2}.b_2 + Y_{n-1}.a_1 + Y_{n-2}.a_2$   
 Usually a filter is a cascade of multiple biquad sections, and each  $Y_n$  output is reduced to a 32 bits sample before being fed as the input of the next section.

The approach is to reduce the precision of the accumulator X coded s7.56 to a 32bits value  $X_n$  coded s3.28 before applying the five multiplies with the coefficient ( $b_0, b_1, b_2, a_1, a_2$ ) coded s3.28. The resulting  $Y_n$  value is coded 64 bits s7.56 and will be reused as is in the next cycle, instead of clearing the accumulator as usually done. To compensate for this, the  $a_1$  coefficient is reduced by 1.0 during the encoding phase. This is an optimized approach to “truncation error feedback” as explained by Jon Dattorro in this document : <https://ccrma.stanford.edu/~dattorro/HiFi.pdf>



The benefit is to get a much larger precision at low frequency or low signal, without requiring 64x32 bits multiply instructions as usually done. The resulting THD for a low pass LR4 filter for high  $f_s$  (192k) is better than -120db in the passband.

This approach is better than using 32 bits IEEE float (24 bits mantissa+7 bits exponents).

Mantissa of 28bits is a good tradeoff to get maximum performance while providing a 42db headroom during basic gain computation and 18db for biquads (remark, all-pass filters require larger coefficient and headroom is then limited to +12db).

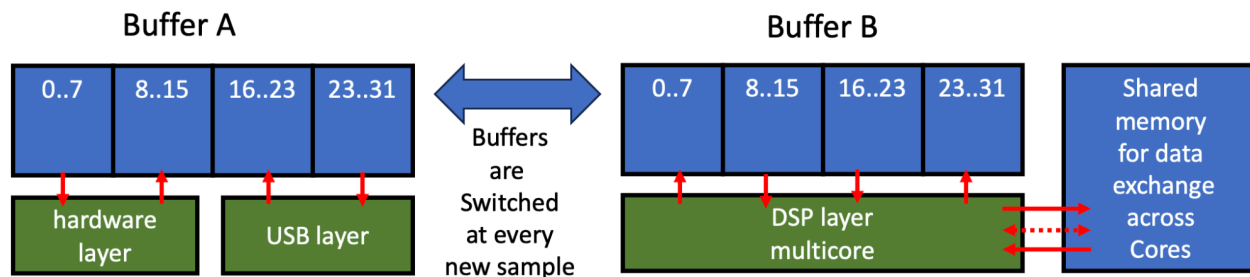
All the optimisation made and the choice of 64 bits integer accumulator gives an excellent precision. This results in almost no measurable distortion on audio signals in the digital domain.

# Memory and Cores, technical information

In order to interface the DSP layer with the USB-DAC-AES layer through the 32 memory locations, a mechanism of double buffering is implemented. This guarantees perfect timing across channels and cores (at the expense of 2 samples delay).

The hardware layer interacts only with buffer A, and the DSP layer interacts only with buffer B. and buffer A and B are switched dynamically at every sample.

The following diagram represents the buffer management:

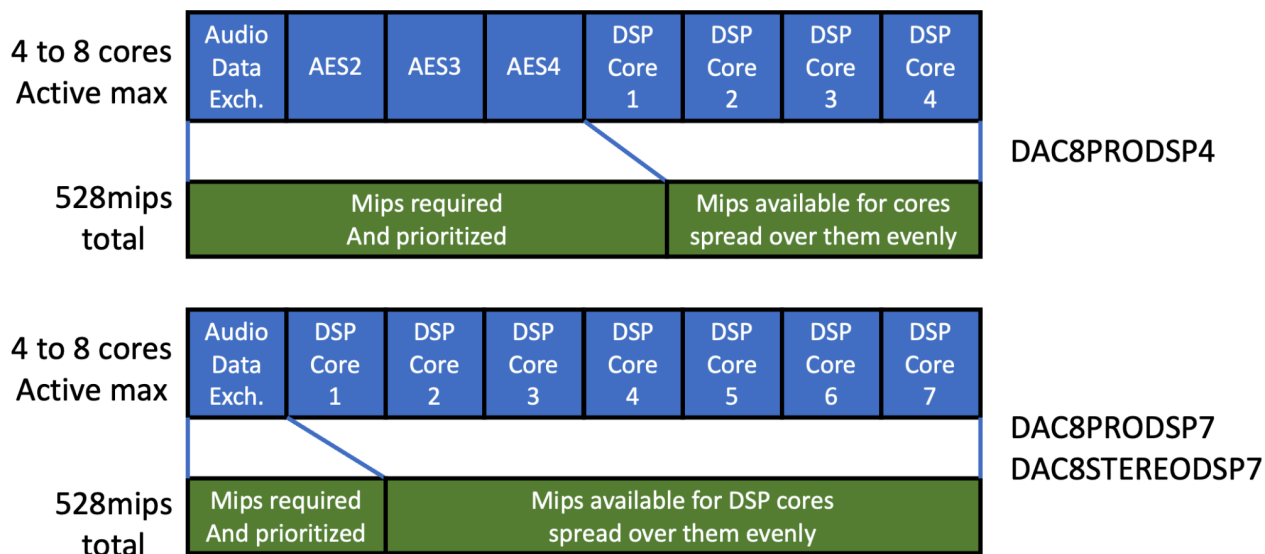


The XMOS provides 8 cores on its Tile 0 to execute audio tasks. The first one is always dedicated to handling data transfer between USB and DACs or AES and USB.

On the DAC8PRO, AES 2,3 and 4 each require a core to treat the AES/SPDIF biphasic mark signal. Due to this, the DAC8PRODSP4 firmware provides only 4 cores for DSP.

If AES 2,3,4 are not used in parallel of AES1 (as a 8 channels media) then the firmware DAC8PRODSP7 can be used instead, providing 7 cores for DSP.

The Data handling and AES treatment are always prioritized at the scheduler level and thus the user's DSP program and number of instructions used can never impact these prioritized tasks. The DSP program will inherit from the remaining Mips only and they will be spread evenly across the DSP cores used in the program. But if a core doesn't use all the instructions potentially available, the remaining mips become available for the other cores. This gives full flexibility to allocate instruction in any core, but within the limits of 106mips per core.



# Known limitation or issues or bug and support

## Analyzer, opcode generator

The `-dsptext` selector of the `dspcreate` utility is relatively new in the AVDSP project and has been developed to make things easier to design an equalization and crossover solution.

A set of macro has been defined to cover most of the directives from the original AVDSP library and the overall syntax is chosen to be as simple as possible. In addition, a concept of labels, filters and memory is defined and it is possible to type mathematical expressions (without parenthesis).

This evolution is voluntarily not a complex development as the interpreter fits in about 1000 lines. The users are welcome to report issues, bugs or request for enhancement using the "issue" of the original github repo : <https://github.com/fabriceo/AVDSP/issues>  
But this will be treated on a best effort basis by the author and without guarantee of action.

## Performances

The overall performance of the xu216 chip considering the possibility to have 2x8 virtual processors and a capacity of 2000 MIPS at 500mhz is great. But it is not at the level of a specialized DSP chip like ADSP21489 or OMAP138L or equivalent. Therefore the user has to optimize the workflow and to distribute the workload on different cores with the only assistance of the `--dacstatus` report. The provided example "maxload.txt" demonstrate that it is possible to realize the following:

192k, 8 dac outputs : 6 biquads for each output and a delay line.

96k, 8 dac outputs : 20 biquads for each outputs and a delay line.

48k, 8 dac and 8 aes channels : 20 biquads for each input and output.

This is probably good enough for a majority of users and this is why it was decided to release this software. The effort of combining instructions and spreading them over cores is rewarding.

## Limitations

Unfortunately it is not possible to provide useful FIR filtering with the xu216. If required, the user shall investigate other alternatives with a front end player including this capability (like brutefir). At the time of writing, no graphical interface is proposed. Considering the performance limitation which requires optimization of the workload and core distribution, the effort to generate a list of opcodes based on a generic graphical environment is quite serious. But it would be possible.

## Downsampling/decimation

Because of the explained performance limitations, it was important to provide a solution for automatically reducing the DAC sampling rate according to the user DSP cpu requirements. And this works well, for example the DAC might decide to operate at 48000 hz to cope with a very complex DSP program. Then it is recommended that the music sent to the DAC is resampled to this frequency. Otherwise the DAC will downsample the audio stream, to divide the number of samples by 2 or 4. At the time of writing the downsampling process is very basic. This is not enough to remove aliasing and this can generate distorsion in the high frequencies. A future version might address this with a dedicated core (on tile1) to execute decimation with a 100+ taps FIR filter on some channels (up to 8 at 48k but less at 96k).

## Support for DAC8 DSP

All support will be done preferably via user community (ASR forum), or by creating an issue in the github repo: [https://github.com/fabriceo/AVDSP\\_DAC8/issues](https://github.com/fabriceo/AVDSP_DAC8/issues) or email at [avdspproject@gmail.com](mailto:avdspproject@gmail.com)

## Révisions & history

### Documentation

DATE	REV	Changes
August 4th, 2024	161	Introduce saturatevol, outputvol and outputvolsat and 18db volume spread across DAC and DSP. dspcreate now accept backslash \ to continue syntax on next line. DSP memory extended to 38kwords to accommodate long delay lines (up to 0.18 seconds in total ~ 60 meters, at 192khz available for all channels). saturatetpdf and saturategaintpdf removed.
May 18,2024	160_2	Removing DAC8STEREODSP4 and adding technical information on core mips allocation. changes in core and section conditions.
May 7,2024	160_1	Adding headlines and table of content, and remarks about sample rate limitations for DAC8PRODSP4
May 5, 2024	160_0	first release, information compatible with DAC8 DSP firmware V1.60

Master document and latest version in gdrive:

[https://docs.google.com/document/d/13nhfehX73qjWsr-vC3V8dsLwfl4rJwBqnygRnYIMKMI/edit?usp=drive\\_link](https://docs.google.com/document/d/13nhfehX73qjWsr-vC3V8dsLwfl4rJwBqnygRnYIMKMI/edit?usp=drive_link)

PDF document on github:

[https://github.com/fabriceo/AVDSP\\_DAC8/tree/main/documents](https://github.com/fabriceo/AVDSP_DAC8/tree/main/documents)



# DAC8 Firmwares release notes:

## Version 161

Based on official V160

Front panel upgraded to enable "voldsp" when setting channel volume (long press).

Some display glitch corrected (input selected and selection).

xmos dsp code upgraded to optimize multiple outputs in single instruction.

instruction outputgaintpdf removed.

introduction of digital volume attenuation (max18db in this version) with either outputvol or outputvolsat or saturatevol instructions.

introduction of saturatevol and outputvolsat to detect up to 15db of saturation after volume reduction. Saturation granularity now by 1db instead of 6db.

Correction of a critical bug when delayus and delaydps were used with value zero.

Extension of all available RAM, providing up to 38kwords for dsp program and data.

Dspcreate utility upgraded, new opcodes generated and introduction of backslash "\" to provide flexibility on defining filters by extending definition on next line. Due to optimizations and new instructions each dsp program requires recompilation with dspcreate utility.

xmosusb utility upgraded to better support xmosload and to print dsp program size available in dacstatus.

known bugs:

dspcreate might interpret hexadecimal numbers starting with x as labels in some cases.

Potential future developments wip or planned:

- 1) Introduce large settings definition by extending the param instruction, in order to customize dac input selection and input name displayed, and to enable loudness feature as a biquad extension with dynamic settings depending on volume.
- 2) Consolidation of DAC8PRODSP4 and DAC8PRODSP7 firmware to enable dynamic selection of either 8 channels AES inputs (requiring 3 cores) or 4 individual AES (7 dsp cores available).
- 3) Decimation with FIR filtering
- 4) Compute of biquad filters coefficients at dsp runtime in xmos, to reduce dsp program size and enable dynamic filter parameters in front panel.
- 5) Front panel menus extension for defining a basic crossover treatment with input, output, biquads and delays.

previous versions

v160 preliminary distribution