UM1655
User manual

Omni2 multichannel library software expansion for STM32Cube

Introduction

The Omni2 multichannel library user manual describes the software interface and requirements for the integration of the module into a main program like the Audio STM32Cube expansion software and provides a rough understanding of the underlying algorithm.

The Omni2 multichannel library implements the multichannel audio virtualization from mono to 7.1 input signals, including the stereo widening effect for stereo inputs.

The Omni2 multichannel library is part of the X-CUBE-AUDIO firmware package.

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1 Module overview

1.1 Algorithm function

The module provides functions to handle mono to stereo expansion, stereo widening and multichannel audio virtualization depending on the used library.

Table 1 describes the supported sampling rates and the input/output multichannel formats:

Table 1. Supported multichannel formats

Library	Audio effect	Channel conversions	Supported sampling frequencies
OMNI2_MC_CMx_IAR.a OMNI2_MC_32b_CMx_IAR.a OMNI2_MC_CMx_GCC.a OMNI2_MC_32b_CMx_GCC.a OMNI2_MC_CMx_Keil.lib OMNI2_MC_32b_CMx_Keil.lib	Mono2Stereo	1.0 to 2.0	48 kHz
		1.0 to 3.0 (2.0 + center)	
	Stereo Widening	2.0 to 2.0	
		2.0 to 3.0 (2.0 + center)	
		3.x to 2.0	
		3.x to 3.0 (2.0 + center)	
	Stereo Widening for matrix encoded input	2.0t to 2.0	
		2.0t to 3.0 (2.0 + center)	
	Multichannel Virtualization	5.1 to 2.0	
		5.1 to 3.0 (2.0 + center)	
		7.1 to 2.0	
		7.1 to 3.0 (2.0 + center)	

The *Figure 1* presents the effect perception with only two physical loudspeakers.

Figure 1. Mono to stereo perception for mono inputs

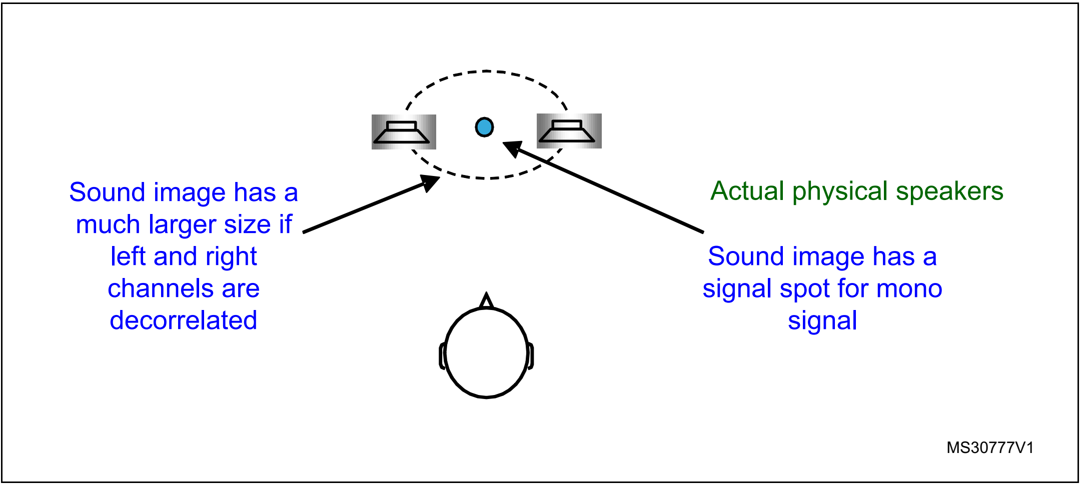

Sound image has a much larger size if left and right channels are decorrelated
Actual physical speakers
Sound image has a signal spot for mono signal
MS30777V1

Figure 2. Stereo widening perception for stereo inputs

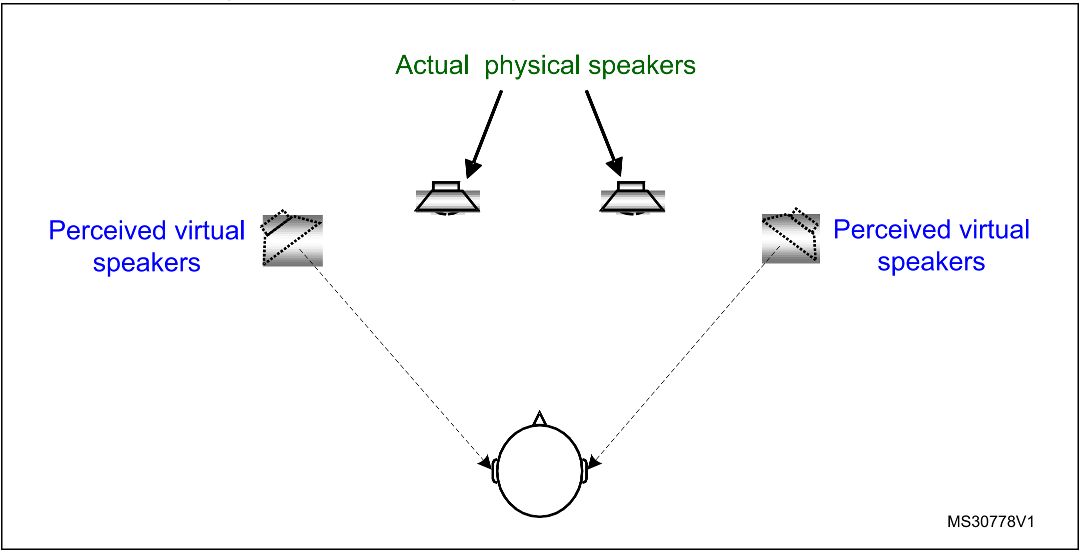
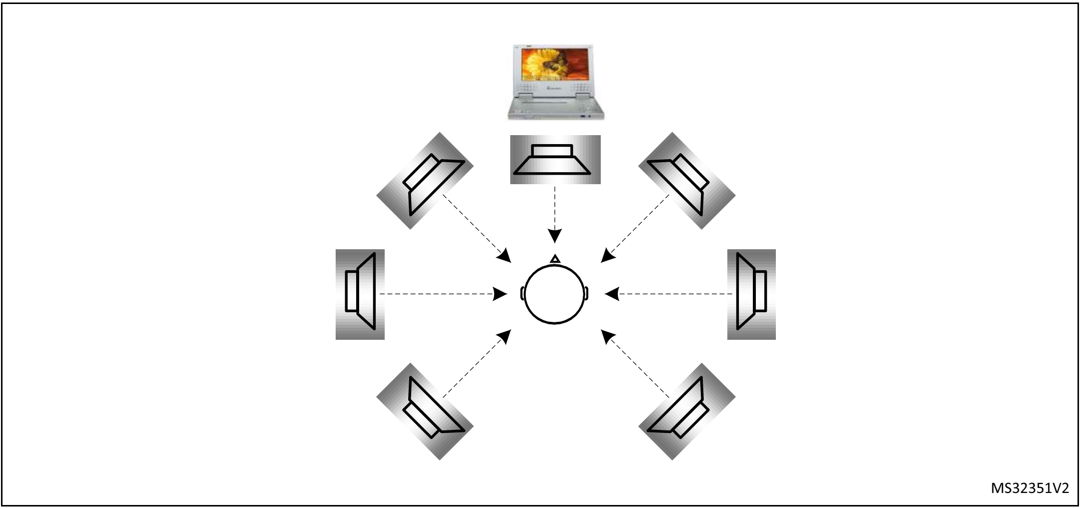


Figure 3. Virtualizer perception (up to 7.1 channels)



The virtualizer perception (up to 7.1 channels) gives the listener the impression of a multi-speaker sensation with stereo speakers.

The listening angle corresponds to the angle between the listener and the physical speakers, *Section 4.1: Recommended setup for stereo widening effect*. “_LS” refers to Largely Spaced speakers, that is about 30 degrees listening angle, “_CS” refers to Closely Spaced speakers, that is about 20 degrees listening angle and “_VCS” refers to Very Closely Spaced speakers, that is about 10 degrees listening angle.

1.2 Module configuration

The module supports mono and multichannel interleaved 16-bit and 32-bit I/O data up to 7.1 format at a 48 kHz sampling frequency.

Several versions of the module are available depending on the I/O format, the Cortex Core and the used tool chain:

- OMNI2_MC_CM4_IAR.a / OMNI2_MC_CM4_GCC.a / OMNI2_MC_CM4_Keil.lib: for 16 bits input/output buffers and it runs on any STM32 microcontroller featuring a core with Cortex-M4 instruction set.
- OMNI2_MC_32b_CM4_IAR.a / OMNI2_MC_32b_CM4_GCC.a / OMNI2_MC_32b_CM4_Keil.lib: for 32 bits input/output buffers and it runs on any STM32 microcontroller featuring a core with Cortex-M4 instruction set.
- OMNI2_MC_CM7_IAR.a / OMNI2_MC_CM7_GCC.a / OMNI2_MC_CM7_Keil.lib: for 16 bits input/output buffers and it runs on any STM32 microcontroller featuring a core with Cortex-M7 instruction set.
- OMNI2_MC_32b_CM7_IAR.a / OMNI2_MC_32b_CM7_GCC.a / OMNI2_MC_32b_CM7_Keil.lib: for 32 bits input/output buffers and it runs on any STM32 microcontroller featuring a core with Cortex-M7 instruction set.

1.3 Resources summary

Table 2 contains Flash, stack, RAM and frequency requirements.

Those footprints are measured on board, using IAR Embedded Workbench for ARM v7.40 (IAR Embedded Workbench common components v7.2).

Table 2. Resources summary

-	Use case @ 48 kHz	Core	Flash code (.text)	Flash data (.rodata)	Stack	Persistent RAM	Scratch RAM	Frequency (MHz)
Multichannel virtualization	1.0=>2.0	M4	8136 Bytes	2064 Bytes	310 Bytes	3100 Bytes	1344 Bytes	4.8
		M7	**8150 Bytes**					**4.1**
	2.0=>2.0 largely spaced speakers	M4	8136 Bytes					15.5
		M7	**8150 Bytes**					**9.8**
	2.0=>2.0 closely spaced speakers	M4	8136 Bytes					17.5
		M7	**8150 Bytes**					**10.5**
	2.0=>2.0 very closely spaced speakers	M4	8136 Bytes					17.5
		M7	**8150 Bytes**					**10.5**
	5.1=>2.0 largely spaced speakers	M4	8136 Bytes					25.2
		M7	**8150 Bytes**					**14.3**
	5.1=>2.0 closely spaced speakers	M4	8136 Bytes					27.5
		M7	**8150 Bytes**					**15.2**
	5.1=>2.0 very closely spaced speakers	M4	8136 Bytes					27.2
		M7	**8150 Bytes**					**15.2**
	7.1=>2.0 largely spaced speakers	M4	8136 Bytes					28
		M7	**8150 Bytes**					**15.1**
	7.1=>2.0 closely spaced speakers	M4	8136 Bytes					37
		M7	**8150 Bytes**					**19.7**
	7.1=>2.0 very closely spaced speakers	M4	8136 Bytes					37
		M7	**8150 Bytes**					**19.8**

Note: Footprints on STM32F7 are measured on boards with stack and heap sections located in DTCM memory and with a 10ms framing.
Scratch RAM is the memory that can be shared with other process running on the same priority level. This memory is not used from one frame to another by Omni2 routines.

2 Module Interfaces

Two files are needed to integrate this module. *OMNI2_MC_xxx_CMy_zzz.a /.lib* library and the *omni2_glo.h* header file which contain all definitions and structures to be exported to the software integration framework.

Note: The audio_fw_glo.h file is a generic header file common to all audio modules; it must be included in the audio framework.

2.1 APIs

Six generic functions have a software interface to the main program:

- omni2_reset
- omni2_setParam
- omni2_getParam
- omni2_setConfig
- omni2_getConfig
- omni2_process

2.1.1 omni2_reset function

This procedure initializes the persistent memory of the module, and initializes static and dynamic parameters with default values.

```
int32_t omni2_reset(void *persistent_mem_ptr, void *scratch_mem_ptr);
```

Table 3. omni2_reset

I/O	Name	Type	Description
Input	persistent_mem_ptr	void *	Pointer to internal persistent memory
Input	scratch_mem_ptr	void *	Pointer to internal scratch memory
Returned value	–	int32_t	Error value

This routine must be called at least once at initialization time, when the real time processing has not started.

2.1.2 omni2_setParam function

This procedure writes module’s static parameters from the main framework to the module's internal memory. It can be called after the reset routine and before the start of the real time processing. It handles the static parameters, i.e. the parameters with the values which cannot be changed during the module processing (frame by frame).

```
int32_t omni2_setParam(omni2_static_param_t *input_static_param_ptr, void
*persistent_mem_ptr);
```

Table 4. omni2_setParam

I/O	Name	Type	Description
Input	input_static_param_ptr	omni2_static_param_t*	Pointer to static parameters structure
Input	persistent_mem_ptr	void *	Pointer to internal persistent memory
Returned value	–	int32_t	Error value

2.1.3 omni2_getParam function

This procedure gets the module's static parameters from the module's internal memory to the main framework. It can be called after the reset routine and before the start of the real time processing. It handles the static parameters, i.e. the parameters with values which cannot be changed during the module processing (frame by frame).

```
int32_t omni2_getParam(omni2_static_param_t *input_static_param_ptr, void
*persistent_mem_ptr);
```

Table 5. omni2_getParam

I/O	Name	Type	Description
Input	input_static_param_ptr	omni2_static_param_t *	Pointer to static parameters structure
Input	persistent_mem_ptr	void *	Pointer to internal persistent memory
Returned value	–	int32_t	Error value

2.1.4 omni2_setConfig function

This procedure sets the module's dynamic parameters from the main framework to the module's internal memory. It can be called at any time during the module processing (after the reset and setParam routines).

```
int32_t omni2_setConfig(omni2_dynamic_param_t *input_dynamic_param_ptr,
void *persistent_mem_ptr);
```

Table 6. omni2_setConfig

I/O	Name	Type	Description
Input	input_dynamic_param_ptr	omni2_dynamic_param_t *	Pointer to dynamic parameters structure
Input	persistent_mem_ptr	void *	Pointer to internal persistent memory
Returned value	–	int32_t	Error value

2.1.5 omni2_getConfig function

This procedure gets the module’s dynamic parameters from the internal persistent memory to the main framework. It can be called at any time during processing (after the reset and setParam routines).

```
int32_t omni2_getConfig(omni2_dynamic_param_t *input_dynamic_param_ptr,
void *persistent_mem_ptr);
```

Table 7. omni2_getConfig

I/O	Name	Type	Description
Input	input_dynamic_param_ptr	omni2_dynamic_param_t *	Pointer to dynamic parameters structure
Input	persistent_mem_ptr	void *	Pointer to internal persistent memory
Returned value	–	int32_t	Error value

2.1.6 omni2_process function

This procedure is the module's main processing routine. It should be called at any time, to process each frame.

```
int32_t omni2_process(buffer_t *input_buffer, buffer_t *output_buffer, void
*persistent_mem_ptr);
```

Table 8. omni2_process

I/O	Name	Type	Description
Input	input_buffer	buffer_t *	Pointer to input buffer structure
Output	output_buffer	buffer_t *	Pointer to output buffer structure
Input	persistent_mem_ptr	void *	Pointer to internal persistent memory
Returned value	–	int32_t	Error value

This process routine can run in place only in case of w.x to y.z with $(w+x) \geq (y+z)$. For instance, processing such as the stereo widening effect (2.0 to 2.0) or 5.1 virtualization effect (5.1 to 2.0) can run in place.

2.2 External definitions and types

In order to facilitate the integration in the main frameworks, some types and definitions have been defined.

2.2.1 Input and output buffers

The library is using extended I/O buffers which contain, in addition to the samples, some useful information on the stream such as the number of channels, the number of bytes per sample, and the interleaving mode.

An I/O buffer structure type, as described below, must be followed and filled in by the main framework before each call to the processing routine:

```
typedef struct {
    int32_t       nb_channels;
    int32_t       nb_bytes_per_Sample;
    void          *data_ptr;
    int32_t       buffer_size;
    int32_t       mode;
} buffer_t;
```

Table 9. Input and output buffers

Name	Type	Description
nb_channels	int32_t	Number of channels in data: 1 for mono, 2 for stereo, 6 for 5.1, 8 for 7.1
nb_bytes_per_Sample	int32_t	Dynamic data in number of bytes (2 for 16-bit data, …)
data_ptr	void *	Pointer to data buffer (must be allocated by the main framework)
buffer_size	int32_t	Number of samples per channel in the data buffer
mode	int32_t	Buffer mode: 0 = not interleaved, 1 = interleaved

2.2.2 Returned error values

Possible returned error values are described below:

Table 10. Returned error values

Definition	Value	Description
OMNI2_ERROR_NONE	0	OK - No error detected
OMNI2_ERROR	-1	Could be a bad sampling frequency, or a bad dynamic memory allocation
OMNI2_ERROR_PARSE_COMMAND	-2	Internal error - covers bad internal settings
OMNI2_BAD_HW	-3	May happen if the library is not used with the right hardware

2.3 Static parameters structure

Some static parameters must be set before calling the processing routine.

```
struct omni2_static_param {
    int32_t   Omni2CentreOutput;
    int32_t   AudioMode;
    int32_t   SamplingFreq;
};
typedef struct omni2_static_param omni2_static_param_t;
```

Table 11. Static parameters structure

Name	Type	Description
Omni2CentreOutput	int32_t	0 to disable the center output (for 3.0), 1 to enable the center output (3.0)
AudioMode	int32_t	Can be one field of the OMNI2_AcMode_Supported_e enumeration described below; it is used to describe the input data format
SamplingFreq	int32_t	I/O sampling frequency in Hz

The possible audio modes are described below, but only the ones in red are supported in this module version:

```
enum OMNI2_AcMode_Supported_e
{
    AMODE20t = 0x0,/*  Stereo channels for dolby pro logic */
    AMODE10  = 0x1,/*  Mono channel (1.0) */
    AMODE20  = 0x2, /*  Stereo channels (2.0) */
    AMODE30  = 0x3, /*  Stereo + Center channel (3.0) */
    AMODE32  = 0x7, /*  Stereo + Center channel + Surround Channels (5.0) */
    AMODE34  = 0xB,/*  Stereo + Center channel + Surround Channels + Center
Surround Channels (7.0) */
    AMODE20t_LFE = 0x80,/*  Stereo channels for dolby pro logic + LFE
channel */
    AMODE20_LFE = 0x82,/*  Stereo + LFE channel (2.1) */
    AMODE30_LFE = 0x83,/*  Stereo + Center channel + LFE channel (3.1) */
    AMODE32_LFE = 0x87,/*  Stereo + Center channel + LFE channel + Surround
Channels (5.1) */
    AMODE34_LFE = 0x8B,/*  Stereo + Center channel + LFE channel + Surround
Channels + Center Surround Channels  (7.1) */
    AMODE_ID   = 0xFF/*  End of supported configurations */
};
```

2.4 Dynamic parameters structure

Three dynamic parameters can be used.

```
struct omni2_dynamic_param {
    int32_t   Omni2Enable;
    int32_t   Omni2Strength;
    int32_t   Omni2ListeningAngle;
};
typedef struct omni2_dynamic_param omni2_dynamic_param_t;
```

Table 12. Dynamic parameters structure

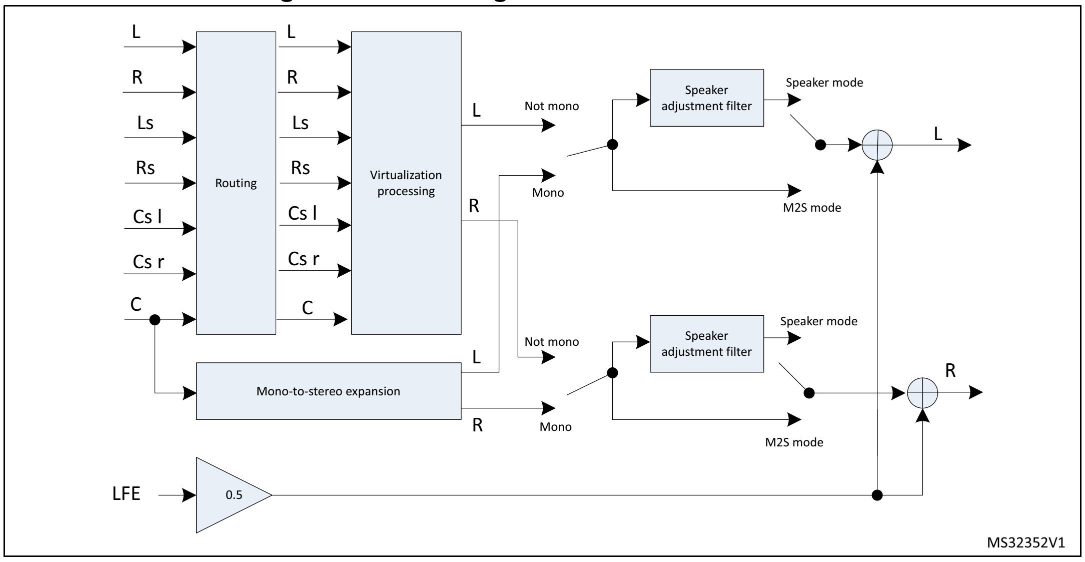
Name	Type	Description
Omni2Enable	int32_t	1 to enable the effect, 0 to disable the effect
Omni2Strength	int32_t	Used to widen front signals from multichannel and stereo inputs. The value is from 0% (no widening perception) to 100% (maximum widening perception)
Omni2ListeningAngle	int32_t	Can be OMNI2_LISTENING_ANGLE_10 to have optimal effect with 10 degrees listening angle, OMNI2_LISTENING_ANGLE_20 to have optimal effect with 20 degrees listening angle and OMNI2_LISTENING_ANGLE_30 to have optimal effect with 30 degrees listening angle

3 Algorithm description

3.1 Processing steps

The block diagram of the Omni2 module is described in *Figure 4*.

Figure 4. Block diagram of the Omni2 module



Routing block: Carries out a premixing of the channels so that it can be processed with a single virtualization structure.

Virtualization block: Applies the HRTF and Crosstalk cancellation function.

Speaker adjustment filter: Processes the audio signal after virtualization processing for speaker rendering and spectrum preservation.

Mono-to-stereo block: Carries out a mono-to-stereo expansion and bypasses the speaker rendering block.

3.2 Data formats

The module supports fixed point data in Q15 or Q31 format, with a mono or a multichannel up to 7.1 interleaved pattern at 48kHz input sampling frequency.

3.3 Performance assessment

There is no objective measurement available for this module; performances are only based on a subjective assessment.

Below a list of subjective indicators that could be used to evaluate the effect quality:

- **Balance between Left Front and Right Front:** capacity not to change energy on one front channel as compared to the other.
- **Balance between Left Surround and Right Surround:** capacity not to change energy on one surround channel as compared to the other.
- **Stereo Widening:** ability to increase the audio perception angle to widen the stereo signal.
- Distinction between front and side surround channels
- **Center image stability:** ability to keep the center image at the center loudspeaker, or between the left and right front loudspeakers.
- **Sensitivity to sweet spot:** ability to feel a widening or surround effect moving away from the sweet spot described in *Section 4.1* and *Section 4.2*.
- **Spectrum preservation:** ability to keep the original spectrum perception, wherever the virtual sound comes from.

Note: For more information on the performance, refer to Section 4: System requirements and hardware setup and Section 5: How to run and tune the application.

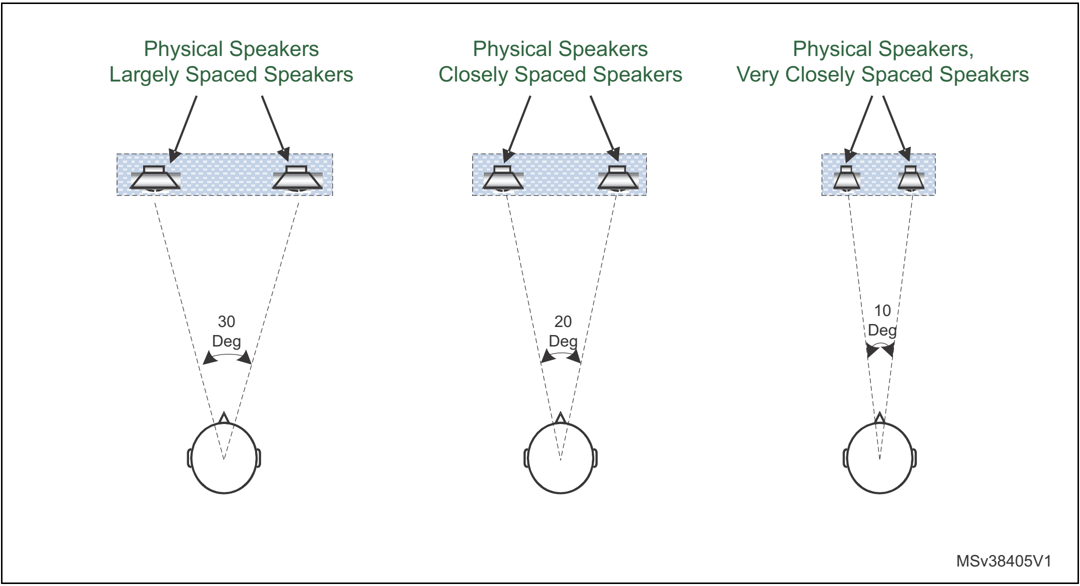
4 System requirements and hardware setup

Omni2 multichannel libraries are built to run either on a Cortex M4 or on a Cortex M7 core, without FPU usage. They can be integrated and run on corresponding STM32F4/STM32L4 or STM32F7 family devices.

4.1 Recommended setup for stereo widening effect

The stereo widening effect is designed for 10, 20 and 30 degrees typical listening angles.

Figure 5. Setup for stereo widening effect



Find in *Table 13* some setup examples and direct impacts on speaker distance to get a typical listening angle and an optimal stereo widening perception.

Table 13. Setup examples

Inter Speaker Distance	Speaker/Listener Distance	Corresponding Listening Angle	Recommended mode to use
0.3 m	2.5 m	7	OMNI2_LISTENING_ANGLE_10
0.3 m	1.8 m	10	OMNI2_LISTENING_ANGLE_10
0.3 m	1.2 m	14	OMNI2_LISTENING_ANGLE_10
0.3 m	0.6 m	28	OMNI2_LISTENING_ANGLE_30
0.4 m	2.5 m	9	OMNI2_LISTENING_ANGLE_10
0.4 m	1.8 m	13	OMNI2_LISTENING_ANGLE_10
0.4 m	1.2 m	19	OMNI2_LISTENING_ANGLE_20
0.4 m	0.6 m	37	OMNI2_LISTENING_ANGLE_30
0.6 m	2.5 m	14	OMNI2_LISTENING_ANGLE_10

Table 13. Setup examples (continued)

Inter Speaker Distance	Speaker/Listener Distance	Corresponding Listening Angle	Recommended mode to use
0.6 m	1.8 m	19	OMNI2_LISTENING_ANGLE_20
0.6 m	1.2 m	28	OMNI2_LISTENING_ANGLE_30
0.8 m	2.5 m	18	OMNI2_LISTENING_ANGLE_20
0.8 m	1.8 m	25	OMNI2_LISTENING_ANGLE_20 or OMNI2_LISTENING_ANGLE_30
0.8 m	1.2 m	37	OMNI2_LISTENING_ANGLE_30
1.0 m	2.5 m	23	OMNI2_LISTENING_ANGLE_20
1.0 m	1.8 m	31	OMNI2_LISTENING_ANGLE_30
1.2 m	2.5 m	27	OMNI2_LISTENING_ANGLE_30
1.2 m	1.8 m	37	OMNI2_LISTENING_ANGLE_30

It must be noted that the listener must be well centered between the two loudspeakers in order to benefit from the stereo widening effect because this effect is very sensitive to lateral sweet spot.

Listening angle below 20 degrees could correspond to a typical TV watching with down firing speakers, small sound bars or docking stations usage.

Positions of the virtual front channels should vary from ±15˚ to ±50˚.

4.2 Recommended setup for multichannel virtualizer effect

Like the Stereo Widening effect, the multichannel virtualizer effect has been designed for 10, 20 and 30 degrees listening angles.

Figure 6. Setup for multichannel virtualizer effect

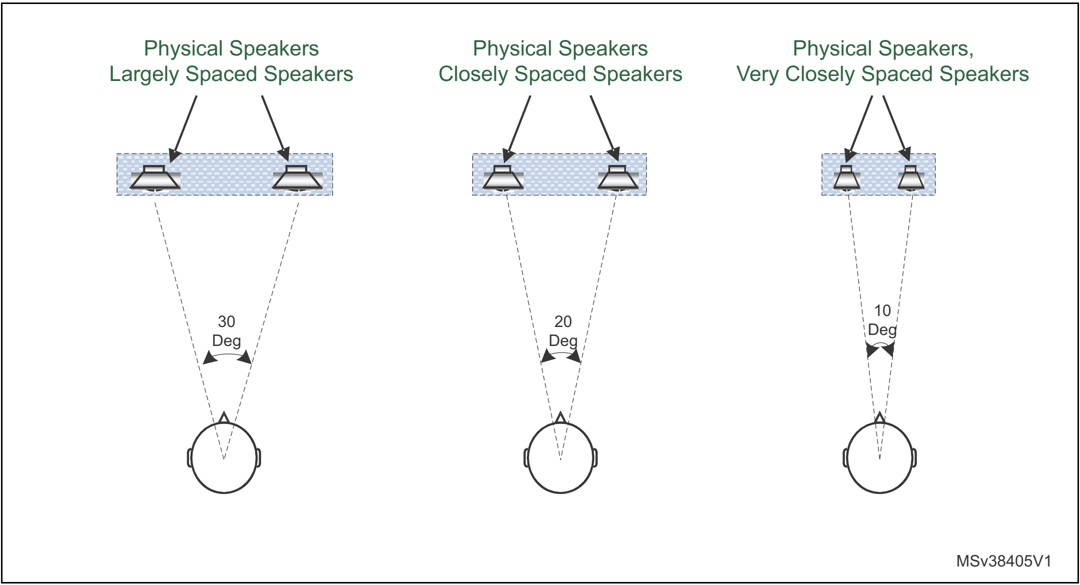
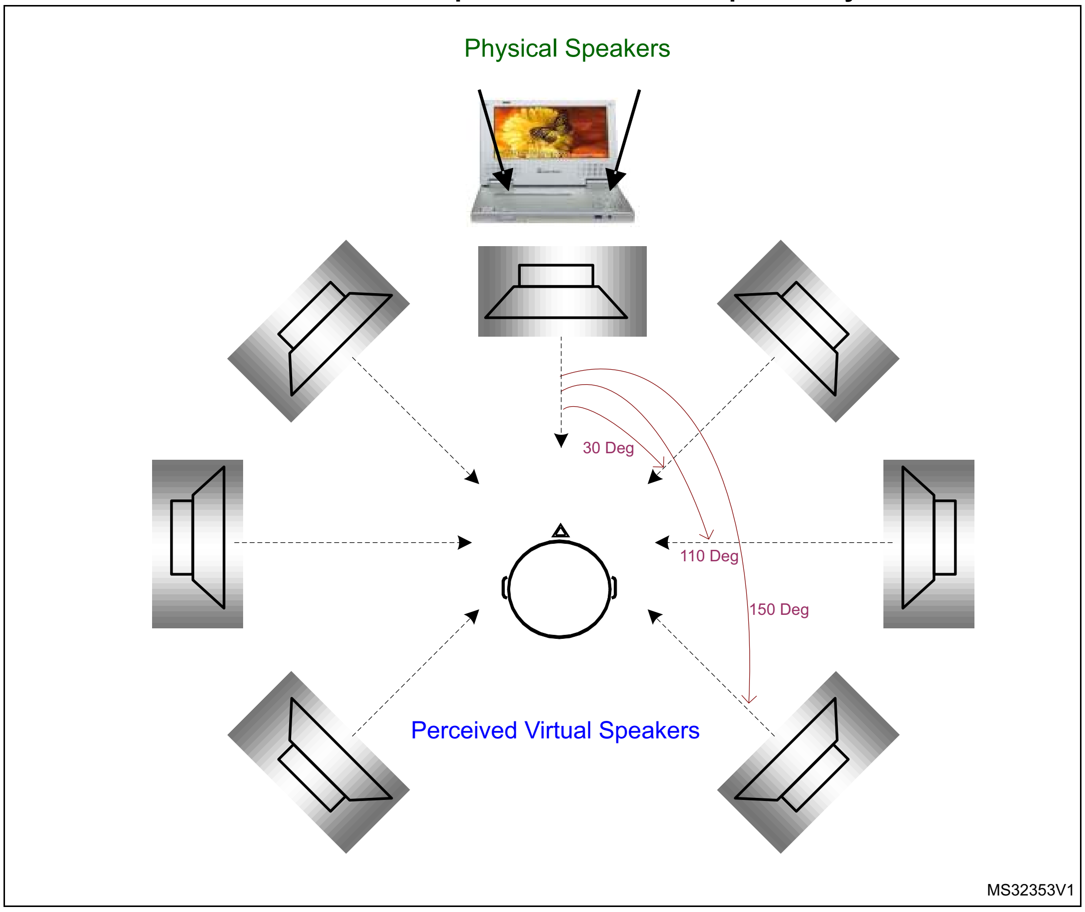


Table 14. Virtualized sound compliant with ITU-T 7.1 speaker layout standards



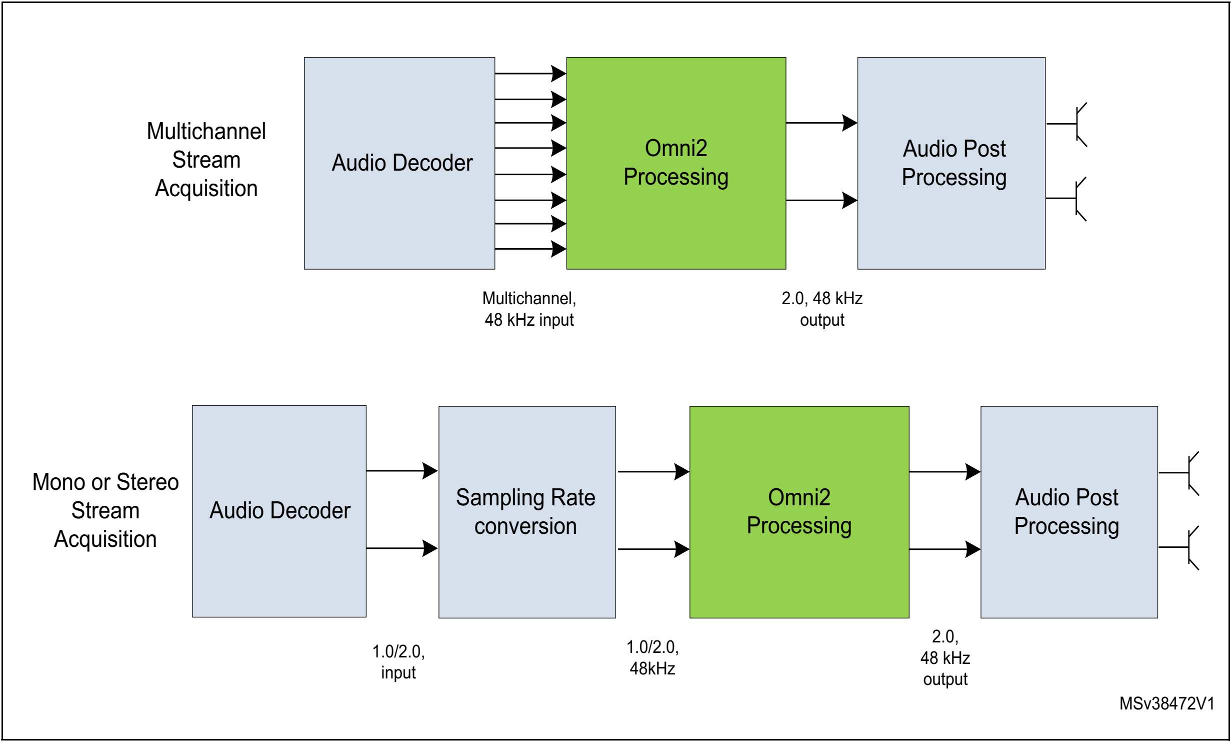
i.e. Front channels are at ± 30°, Side channels are at ± 110° and Rear channels are at ± 150°.

4.3 Recommendations for an optimal setup

The library processing should be placed just after the multichannel decoder for the multichannel streams at 48kHz, or after the sampling rate conversion for stereo streams at any sampling frequencies. Note that only 48kHz sampling frequency is supported in this SW version.

There is no need for this module to be close to the audio DAC, and some graphical equalizer and volume management modules can be placed after it without affecting the widening or virtualization perception.

Figure 7. Omnisurround placement in the audio chain

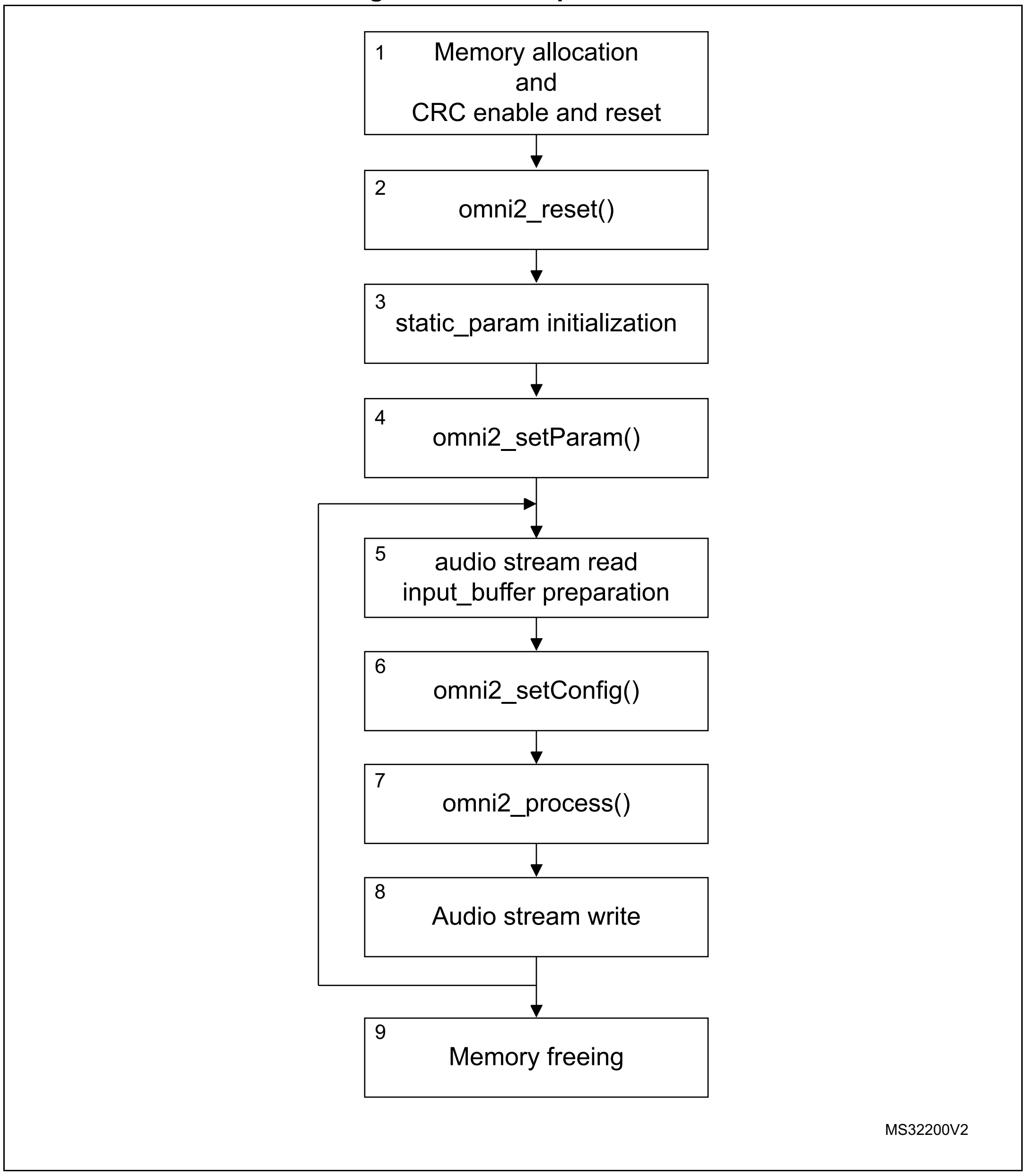


4.3.1 Module integration example

Cube expansion OMNI2_MC integration examples are provided on STM32746G-Discovery and STM32469I-Discovery boards. Please refer to provided integration code for more details.

4.3.2 Module integration summary

Figure 8. API call procedure


1 Memory allocation and CRC enable and reset
2 omni2_reset()
3 static_param initialization
4 omni2_setParam()
5 audio stream read input_buffer preparation
6 omni2_setConfig()
7 omni2_process()
8 Audio stream write
9 Memory freeing
MS32200V2

1. As explained above, the scratch and persistent memories containing dynamic and static parameters have to be allocated, as well as the input and output buffer, according to the structures defined in *Section 2.2.1: Input and output buffers*. Furthermore, as Omni2 library run on STM32 devices, CRC HW block must be enable and reset.
2. Once the memory has been allocated, the call to omni2_reset() function initializes the internal variables.
3. The module's static configuration can now be set by initializing the static_param structure, once the input sampling frequency and the audio mode are known.
4. Call the omni2_setParam() routine to send the static parameters from the audio framework to the module.
5. The audio stream is read from the proper interface and the input_buffer structure has to be filled in according to the stream characteristics (number of channels, sample rate, interleaving and data pointer). The output buffer structure has to be set as well.
6. Get the dynamic parameters when they are updated and call the omni2_setConfig() routine to send the

dynamic parameters from the audio framework to the module.

7. Call the main processing routine to apply the effect.
8. The output audio stream can now be written in the proper interface.
9. Once the processing loop is over, the allocated memory has to be freed.

5 How to run and tune the application

Once the module has been integrated into an audio framework to play stereo samples at 48kHz, user launches a player and the output file will be decoded and played with a stereo widening or a multichannel virtualization effect on loudspeakers without returning any error message.

The Omni2Enable from the module's dynamic parameters is used to enable and disable the effect.

The Omni2Strength field is used to change the virtual listening angle. 0% means that virtual speakers are close to physical speakers, while 100% leads to the widest virtual angle (typically 100 degrees).

Omni2ListeningAngle field from the module's dynamic parameters should be set depending on the End User configuration (largely, closely or very closely spaced speakers).

6 Revision history

Table 15. Document revision history

Date	Revision	Changes
26-Aug-2013	1	Initial release.
28-Nov-2014	2	Updated RPN on cover page
10-Dec-2014	3	Updated *Section 5*.
22-Jul-2015	4	Updated: – *Section 1.1*, *Section 1.3*, *Section 2.4*, *Section 4.1*, *Section 4.3*, *Section 4.2.2* – *Table 2*, *Table 3*, *Table 12* – *Figure 5*, Added: – *Table 13* Removed: – section: “Recommended setup for stereo widening effect for closely spaced speakers (Omni2DownFiringSpeakers set)”
25-Jan-2016	5	Updated: – *Introduction* and document title. – *Section 1.2*, *Section 1.3*, *Section 2.1*, *Section 2.3*, *Section 3.2*, *Section 4*, *Section 4.3*, *Section 5* – *Table 1*, *Table 2*, *Table 3*, *Table 12* – *Figure 3*, *Figure 8*, Added: *Section 4.3.1*, *Figure 7*
31-Mar-2015	6	Updated: – *Table 1: Supported multichannel formats*, *Table 2: Resources summary*, *Table 3: omni2_reset*, *Table 4: omni2_setParam*, *Table 5: omni2_getParam*, *Table 6: omni2_setConfig*, *Table 7: omni2_getConfig*, *Table 8: omni2_process*, *Table 9: Input and output buffers*, *Table 11: Static parameters structure*. – *Section 1.2: Module configuration*, *Section 1.3: Resources summary*, *Section 2: Module Interfaces*, *Section 2.1.1: omni2_reset function*, *Section 2.1.2: omni2_setParam function*, *Section 2.1.3: omni2_getParam function*, *Section 2.1.4: omni2_setConfig function*, *Section 2.1.5: omni2_getConfig function*, *Section 2.1.6: omni2_process functionSection 2.3: Static parameters structure*, *Section 4.3.1: Module integration example*, *Section 5: How to run and tune the application*.
08-Jan-2018	7	Replace X-CUBE-AUDIO-F4, X-CUBE-AUDIO-F7 and X-CUBE-AUDIO-L4 with X-CUBE-AUDIO.