



AN00162: Implementing an I2S loopback using the lib_i2s library

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1 Introduction

The XMOS I²S library provides software defined, industry-standard, I²S (Integrated Inter-chip Sound) components that allows you to stream audio between devices using xCORE GPIO ports.

I²S is a specific type of PCM digital audio communication using a serial clock (sometimes referred as bit clock) line, word clock line and at least one multiplexed data line.

The library includes features such as I²S master (newly termed controller), I²S slave (newly termed target), and TDM master components. This application note uses the library to create an I²S master digital loopback.

2 Block diagram

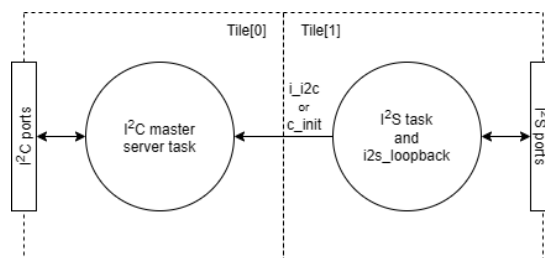


Fig. 1: Application block diagram

The main application fits within one thread with a remote I²C task to configure the audio hardware remotely from the other tile. The **lib_board_support** library, which includes I²C, takes care of the audio hardware setup.

The I²S task calls back to the **i2s_loopback** task, and the processing in the **i2s_loopback** task occurs in-between the I/O operations of I²S.



3 I²S loopback demo

3.1 The CMakeLists.txt file

XMOS applications use the [xcommon-cmake](#) build and dependency management system. This is bundled with the XMOS XTC tools.

To start using the I²S, include **lib_i2s** as a dependent module in the application's CMakeLists.txt file:

Listing 1: Identifying I²S as a dependent module

```
set(APP_DEPENDENT_MODULES "lib_i2s")
```

This demo also uses the I²C library (**lib_i2c**) which **lib_board_support** includes as a dependent module. The application uses I²C to configure the audio CODECs. Consequently, the application's CMakeLists.txt includes both **lib_i2s** and **lib_board_support** as dependent modules.

Listing 2: APP_DEPENDENT_MODULES definition

```
set(APP_DEPENDENT_MODULES "lib_board_support(1.3.0)"
    "lib_i2s(6.0.1)")
```

3.2 Includes

All xC files which declare the application **main()** function need to include **platform.h**. XMOS xcore specific defines for declaring and initialising hardware appear in **xs1.h**.

Listing 3: Critical headers to include

```
#include <platform.h>
#include <xs1.h>
```

The **i2s.h** file defines the I²S library functions. This header must be included to use the library.

Listing 4: The I²S header

```
#include "i2s.h"
```

Another include gives access to the the board setup code. It varies depending on the board in use.

Listing 5: Setup header for the XK-AUDIO-316-MC board

```
#include "xk_audio_316_mc_ab/board.h"
```

Listing 6: Setup header for the XK-EVK-XU316 board

```
#include "xk_evk_xu316/board.h"
```

3.3 Allocating hardware resources

An I²S interface requires both clock and data pins in order to communicate with the audio CODEC device. On an xcore the pins are controlled by **ports**.

The ports used by the I²S library are declared on the tile on which they reside. Their declaration includes each port's direction and buffered nature. Three 1-bit ports are used for the I²S clock signals.



Listing 7: Defining I²S clock ports

```
on tile[1]: in port p_mclk =          PORT_MCLK_IN;
on tile[1]: buffered out port:32 p_lrclk =  PORT_I2S_LRCLK;
on tile[1]: out port p_bclk =          PORT_I2S_BCLK;
```

This loopback application uses 1-bit ports for input and output. The number of input and output ports, i.e., the value of **NUM_I2S_LINES** depends on the board in use.

Listing 8: Port definition for the XK-AUDIO-316-MC board

```
on tile[1]: buffered out port:32 p_dac[NUM_I2S_LINES] = {PORT_I2S_DAC0, PORT_I2S_DAC1, PORT_I2S_DAC2, PORT_
↪ I2S_DAC3};
on tile[1]: buffered in port:32 p_adc[NUM_I2S_LINES] = {PORT_I2S_ADC0 ,PORT_I2S_ADC1, PORT_I2S_ADC2, PORT_
↪ I2S_ADC3};
```

Listing 9: Port definition for the XK-EVK-XU316 board

```
on tile[1]: buffered out port:32 p_dac[NUM_I2S_LINES] = {PORT_I2S_DAC_DATA};
on tile[1]: buffered in port:32 p_adc[NUM_I2S_LINES] = {PORT_I2S_ADC_DATA};
```

The xcore also provides **clock block** hardware to efficiently generate a clock signal that can either be driven out of a port or used to control a port. This application uses one clock block.

Listing 10: Clock block definition

```
on tile[1]: clock bclk =          XS1_CLKBLK_1;
```



3.4 The application `main()` function

The `main()` function in the program sets up the tasks in the application.

Firstly, it declares **interfaces** and **channels**. XC interface and channel provides a means for concurrent tasks to communicate with each other. This application includes an interface for the I²S master and an interface/channel for the I²C master.

Listing 11: I²S Interface definition

```
interface i2s_frame_callback_if i_i2s;
```

An interface or channel is used in different board for the I²C master.

When running on an **XK-AUDIO-316-MC** board, it includes an interface for the I²C master also.

Listing 12: I²C Interface definition for the XK-AUDIO-316-MC board

```
interface i2c_master_if i_i2c[1]; // Cross tile interface
```

On the **XK-EVK-XU316** board, the application uses a channel instead.

Listing 13: I²C Channel definition for the XK-EVK-XU316 board

```
chan c_init; // Cross tile channel
```

The rest of the `main()` function starts all the tasks in parallel using the `XC par` construct:

Listing 14: Tasks for the XK-AUDIO-316-MC board

```
par {
  on tile[0]: {
    xk_audio_316_mc_ab_board_setup(hw_config); // Setup must be done on tile[0]
    xk_audio_316_mc_ab_i2c_master(i_i2c);      // Run I2C master server task to allow control from tile[1]
  }
  on tile[1]: {
    interface i2s_frame_callback_if i_i2s;

    par {
      // The application - loopback the I2S samples - note callbacks are inlined so does not take a thread
      [[distribute]] i2s_loopback(i_i2s, i_i2c[0]);
      i2s_frame_master(i_i2s, p_dac, NUM_I2S_LINES, p_adc, NUM_I2S_LINES, DATA_BITS, p_bclk, p_lrcclk, p_
      ↪mclk, bclk);
    }
  }
}
```

Listing 15: Tasks for the XK-EVK-XU316 board

```
par {
  on tile[0]: {
    xk_evk_xu316_AudioHwRemote(c_init); // Run I2C master task to allow control from tile[1]
  }
  on tile[1]: {
    interface i2s_frame_callback_if i_i2s;
    xk_evk_xu316_AudioHwChanInit(c_init);

    par {
      // The application - loopback the I2S samples - note callbacks are inlined so does not take a thread
      [[distribute]] i2s_loopback(i_i2s);
      i2s_frame_master(i_i2s, p_dac, NUM_I2S_LINES, p_adc, NUM_I2S_LINES, DATA_BITS, p_bclk, p_lrcclk, p_
      ↪mclk, bclk);
    }
  }
}
```

This code starts the I²S master, the I²C master, the board setup logic, and the loopback application.

The call to the `i2s_loopback` task in the `par` is marked with the `[[distribute]]` attribute, and the corresponding `i2s_loopback()` function is marked with the



`[[distributable]]` attribute. These attributes mean that the `i2s_loopback` task will run on an existing logical core if possible rather than creating a new one. In this case it will share the logical core used by the I²S master.

3.5 Configuring audio CODECs

All of the audio hardware is setup using functions in `lib_board_support`. The previous inclusion of `board.h` from the `xk_audio_316_mc_ab` directory targets the hardware setup to the XU316 Multichannel Audio board(XK-AUDIO-316-MC) and the `xk_audio_316_mc_ab` directory targets the XCORE.AI Evaluation Kit(XK-EVK-XU316). These lines perform some board-specific initialisation and start the I²C task.

Listing 16: Board initialisation for the XK-AUDIO-316-MC board

```
xk_audio_316_mc_ab_board_setup(hw_config); // Setup must be done on tile[0]
```

Note

The XK-EVK-XU316 board does not need board-specific initialisation.

The `hw_config` struct specifies the hardware configuration. In this case, it sets up the xcore to be an I²S master with the following settings:

Listing 17: I2S master settings for the XK-AUDIO-316-MC board

```
#define SAMPLE_FREQUENCY      48000
#define MASTER_CLOCK_FREQUENCY 24576000
#define DATA_BITS             32
#define CHANS_PER_FRAME       2
#define NUM_I2S_LINES          4
```

Listing 18: I2S master settings for the XK-EVK-XU316 board

```
#define SAMPLE_FREQUENCY      48000
#define MASTER_CLOCK_FREQUENCY 24576000
#define DATA_BITS             32
#define CHANS_PER_FRAME       2
#define NUM_I2S_LINES          1
```

Note

`lib_board_support` only support changing master clock frequency in XK-EVK-XU316 Board

The following functions, called from the `i2s_loopback` task, complete the initialisation and configuration of the ADCs and DACs:

Listing 19: ADCs and DACs initialisation and configuration for the XK-AUDIO-316-MC board

```
xk_audio_316_mc_ab_AudioHwInit(i_i2c, hw_config);
xk_audio_316_mc_ab_AudioHwConfig(i_i2c, hw_config, SAMPLE_FREQUENCY, MASTER_CLOCK_FREQUENCY, 0, DATA_BITS, DATA_
↳BITS);
```



Listing 20: ADCs and DACs initialisation and configuration for the XK-EVK-XU316 board

```
xk_evk_xu316_AudioHwInit(hw_config);  
xk_evk_xu316_AudioHwConfig(SAMPLE_FREQUENCY, MASTER_CLOCK_FREQUENCY, 0, DATA_BITS, DATA_BITS);
```

For full documentation of the **lib_board_support** API, please refer to the following link: [lib_board_support](#).



3.6 The i2s_loopback application

The I²S loopback task provides the function of a digital loopback so that all I²S samples received by the device will be forwarded on.

The task itself is declared as a `[[distributable]]` function allowing it to share a logical core with other tasks. This xC feature can be enabled for any task with the form:

Listing 21: Distributable task pattern

```
// Task initialization code here
while(1) {
    select {
        // Event cases here
    }
}
```

The function takes a number of arguments:

Listing 22: i2s_loopback function for the XK-AUDIO-316-MC board

```
[[distributable]]
void i2s_loopback(server i2s_frame_callback_if i_i2s, client i2c_master_if i_i2c)
```

Listing 23: i2s_loopback function for the XK-EVK-XU316 board

```
[[distributable]]
void i2s_loopback(server i2s_frame_callback_if i_i2s)
```

The interface to the I²S master, `server i2s_frame_callback_if i_i2s`, provides a set of callback functions. The I²S master will call these functions as needed.

The `i2s_loopback` task uses the I²C master interface, `client i2c_master_if i_i2c`, to configure the CODECs (ADCs and DACs) remotely.

The main loop in the `i2s_loopback` task handles the I²S interface calls.

Listing 24: I²S task main loop

```
while (1) {
    select {
        case i_i2s.init(i2s_config_t &i2s_config, tdm_config_t &tdm_config):
            i2s_config.mode = I2S_MODE_I2S;
            i2s_config.mclk_bclk_ratio = (MASTER_CLOCK_FREQUENCY / (SAMPLE_FREQUENCY * CHANS_PER_FRAME * DATA_BITS));
            ... // Audio HW Config for the board
            break;

        case i_i2s.receive(size_t n_chans, int32_t in_samps[n_chans]):
            for (int i = 0; i < n_chans; i++){
                samples[i] = in_samps[i]; // copy samples
            }
            break;

        case i_i2s.send(size_t n_chans, int32_t out_samps[n_chans]):
            for (int i = 0; i < n_chans; i++){
                out_samps[i] = samples[i]; // copy samples
            }
            break;

        case i_i2s.restart_check() -> i2s_restart_t restart:
            restart = I2S_NO_RESTART; // Keep on looping
            break;
    } // End select
} // End while (1)
```

The I²S master library calls the `init()` method before it starts any data streaming. This call allows the application to reset and configure the audio CODECs, for example when the sample rate changes.

The `receive()` interface method is called when the master has received a frame of audio samples (all channels in one sample period). The `receive()` method stores the samples in the `samples` array.



The I²S master calls the **send()** interface method when it needs a new frame of samples to send. In this case the application simply returns the frame of samples previously received.

Finally, the **restart_check()** method is called by the I²S master once per frame. It allows the application to control restart or shutdown of the I²S master. In this case the application continues to run forever and so always returns **I2S_NO_RESTART**.



4 Building the application

The following section assumes you have downloaded and installed the [Xilinx XTC tools](#). See the *README* file for required version. Installation instructions can be found [here](#). Be sure to pay attention to the section [Installation of required third-party tools](#).

The application uses the [xcommon-cmake](#) build system as bundled with the XTC tools.

The `AN00162_i2s_loopback_demo` software zip-file should be downloaded and unzipped to a chosen directory.

To configure the build, run the following from an XTC command prompt:

```
cd an00162
cd app_an00162
cmake -G "Unix Makefiles" -B build
```

All required dependencies are included in the software download. However, if any are missing, they will be downloaded by the build system.

Finally, the application binaries can be built using `xmake`:

```
xmake -j -C build
```

The application uses approximately 3 kiB on Tile[0] and 7 kiB on Tile[1] (each tile has 512 kiB available).

5 Demo hardware setup

Please refer to the [XU316 Multichannel Audio board](#) and [XCORE.AI Evaluation Kit](#) hardware platform documentation.

The demo is designed to run on the XU316 Multichannel Audio board and XCORE.AI Evaluation Kit. To run the demo:

- ▶ Connect a USB cable from your host to the DEBUG connector.
- ▶ Connect a USB cable from your host to the USB DEVICE connector.
- ▶ Connect a sound source to the 3.5mm line in. Channels 1-2, 3-4, 5-6 or 7-8 can be used.
- ▶ Connect headphones or speakers to the corresponding line out.

6 Running the demo application

To run the application return to the `app_an00162` directory and run the following command:

Listing 25: For the XK-AUDIO-316-MC board

```
xrun app_an00162_xk_audio_316_mc/bin/app_an00162_xk_audio_316_mc.xe
```

Listing 26: For the XK-EVK-XU316 board

```
xrun app_an00162_xk_evk_xu316/bin/app_an00162_xk_evk_xu316.xe
```

You should hear the audio connected to the analog input jacks looped back to the output jacks.

7 References

- ▶ Xilinx Tools User Guide
<https://www.xilinx.com/documentation/XM-014363-PC-9/html/>



- ▶ XMOS xcore Programming Guide
<https://www.xmos.com/published/xmos-programming-guide>
- ▶ XMOS Libraries
<https://www.xmos.com/libraries/>
- ▶ I²S Protocol
<https://en.wikipedia.org/wiki/I2S>



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