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Spec No: 002-04468

Spec Title: AN204468 - FM4 I2S USB MP3 PLAYER APPLICATION 32-BIT MICROCONTROLLER FM4 FAMILY

Replaced by: NONE

AN204468

FM4 I²S USB MP3 Player Application 32-Bit Microcontroller FM4 Family

Target Products: SK-FM4-216-ETHERNET

This application note describes the general structure of the I²S USB MP3Player software example, its single modules in detail and how it is used.

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1 Introduction

1.1 About Document

This application note describes the general structure of the I²S USB MP3Player software example, its single modules in detail and how it is used.

The I²S USB MP3Player software example is an easy extendable audio player application that is able to playback different types of audio files from an attached USB flash drive, while several file information (such as bitrate, MP3 ID3 Tags, etc.) are displayed for the user via LC Display and UART.

The whole project builds on top of a USB template that was generated with aid of the Cypress USB Wizard. This ready-to-use template contains an USB stack and a configured copy of Elm-Chan's FatFs.

The current version can handle all types of mp3 files and wave files with a resolution between 0 and 32 bits.

For mp3 decoding the MPEG Audio Decoder Library (MAD) is used, which is published by Underbit Technologies under GNU General Public License (GPL).

The I²S USB MP3Player is designed to run on the hardware platform of the SK-FM4-216-ETHERNET Starter kit, which includes a SGTL5000 I²S Codec.

This document furthermore will elaborate on:

- An overview about the used hardware
- A general overview of the software and a detailed description of its single components
- ROM and RAM consumption of the presented solution
- How to use the I²S USB MP3Player.

1.2 Supported Tool Chains

The I²S USB MP3Player was successfully tested with the following tool chains:

- winIDEA Open Build 9.12.209 (44770) (gcc version: 4.7.4 20130613)
- Keil µVision V5.10.0.2 (tool chain: 5.10.0.0)
- IAR Embedded Workbench 7.20.5.7624 (tool chain: 7.1.2.3324)

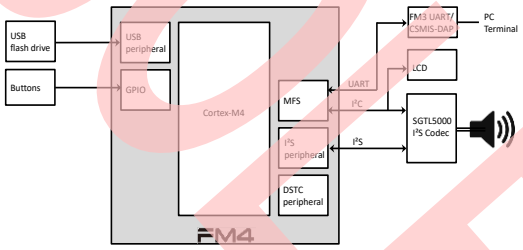
2 Hardware

The I²S USB MP3Player uses the SK-FM4-216-ETHERNET Starter kit. The following hardware components on the board are used in this example:

- One of the two USB host ports (to attach a USB flash drive), connected to the USB peripheral of the FM4
- The buttons on the board for user input, connected as GPIO to the FM4
- The Starter kit's LC display for textual output, connected via I²C to the Multi-function-Serial Interface
- The Freescale SGTL5000 I²S codec, connected via I²C for configuration to the Multi-function-Serial Interface and via I²S for audio data transfer with the I²S peripheral
- The DSTC peripheral to fill the I²S peripheral's TX-FIFO with processed audio data from the memory
- The USB-to-serial converter of the FM3 CMSIS-DAP on board JTAG to send UART log messages to a connected PC.

An overview of the utilized hardware components can be found in Figure 1.

Figure 1. Utilized Hardware Components on the SK-FM4-216-ETHERNET Starter Kit



3 Software

3.1 General Overview

In Table 1 all software components are listed and a brief description is given.

Figure 2 shows a general overview over the interaction of all components of entire software project. In the following section 3.2 the function of all components will be described in detail and how they interact with each other.

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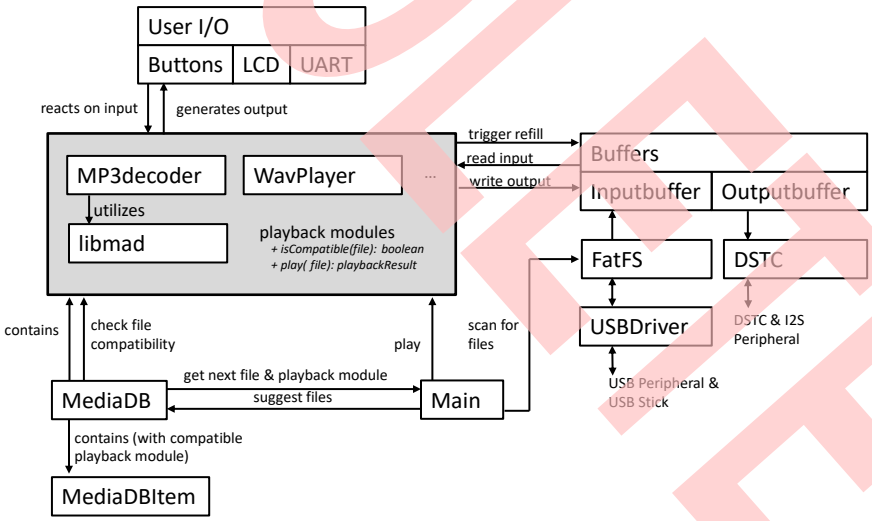
Table 1. Overview of All Software Components and a Brief Description of Them

Software Component	Brief Description
Main	Main program that does all initializations and starts the playback of each audio file.
USB driver	USB stack for accessing the USB flash drive.
FatFS	Elm-Chan's implementation of the FAT file system for accessing the USB flash drive.
Buffers	Holds the input- and output buffers that buffer the data after reading from the FatFS and before decoding respectively after decoding and before sending to the I²S Codec.
Playback Module	One module for each audio file type that is able to decode and play this specific file type.
MP3Decoder	Can play mp3 files by utilizing the MPEG Audio Decoder Library.
WavPlayer	Can play wav files.
User I/O	All interaction with the user is done through this module: display control, pressed buttons, UART logging.
DSTC	Controls the DSTC peripheral, while taking filled output buffers and hand them over to the DSTC.
Media DB	Stores a list of all media files (a reference to a suitable playback module) and the current playback position

Figure 2. General Software Overview



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3.2 Software Components

3.2.1 Main

The Main component contains as the name suggests the main() function. It initializes all other modules and awaits a USB flash drive. As soon as a USB device is found, the Main component mounts the file system, initializes the Media DB (see section 3.2.2) and scans the USB device for files. All found files are suggested to the Media DB, which checks whether a compatible Playback Module (see section 3.2.4) is registered.

When the recursively directory scan is completed, the Main component starts the playback. It fetches the next media file from the Media DB and a pointer to the compatible Playback Module. After playback is finished it fetches the next (or previous, depending on the playback outcome,) media file from the Media DB and starts playback again.

The program flow of the Main component and its interaction with the Media DB is illustrated in Figure 3 and Figure 4.

3.2.2 Media DB

The Media DB holds a list of all Playback Modules and a list of all media files found on the attached USB flash drive. It also associates each media file with a suitable playback module. For a prober functionality the Media DB has to be initialized by calling the `MediaDB_Init()` function. After that all Playback Modules have to be registered by passing a pointer of their `play(…)` and the is `Compatible()` function to the `MediaDB_AddPlaybackModule(…)` function. Now media files can be added. This is done by handing over the path of the media file and its title to the `MediaDB_Add(char_t* pcFileFullPath, char_t* pcFileTitle)` function. The Media DB will check whether an appropriate Playback Module, which can handle the given file, is registered and adds (if this applies) the media file to the database. The number of media files respectively Playback Modules, that can be added, is limited by the constant `MEDIADB_DB_MAX_SIZE` respectively `MEDIADB_PLAYBACKMODULES` and can be adjusted, if necessary.

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Figure 3. Program Flow of the Main Component

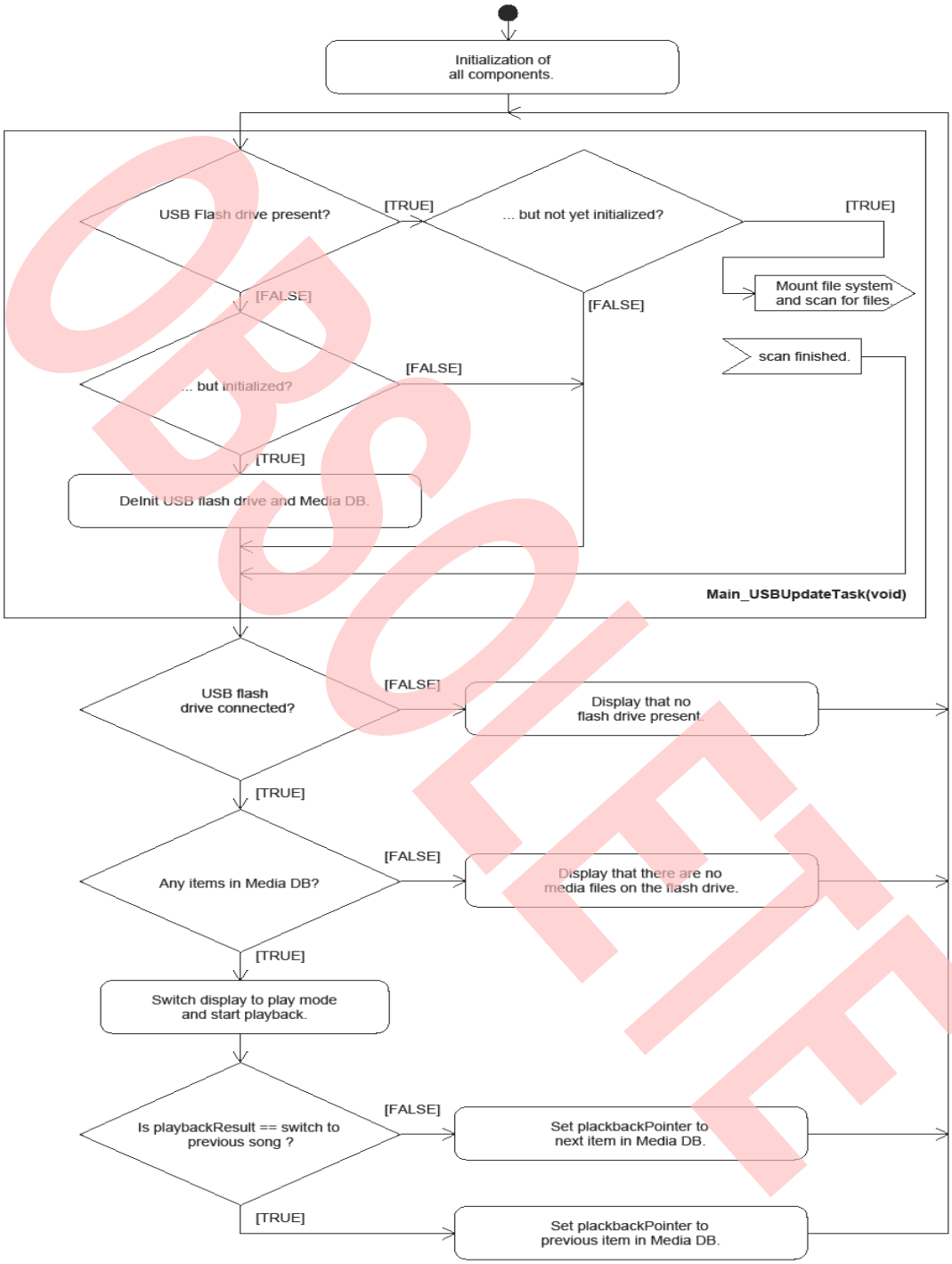

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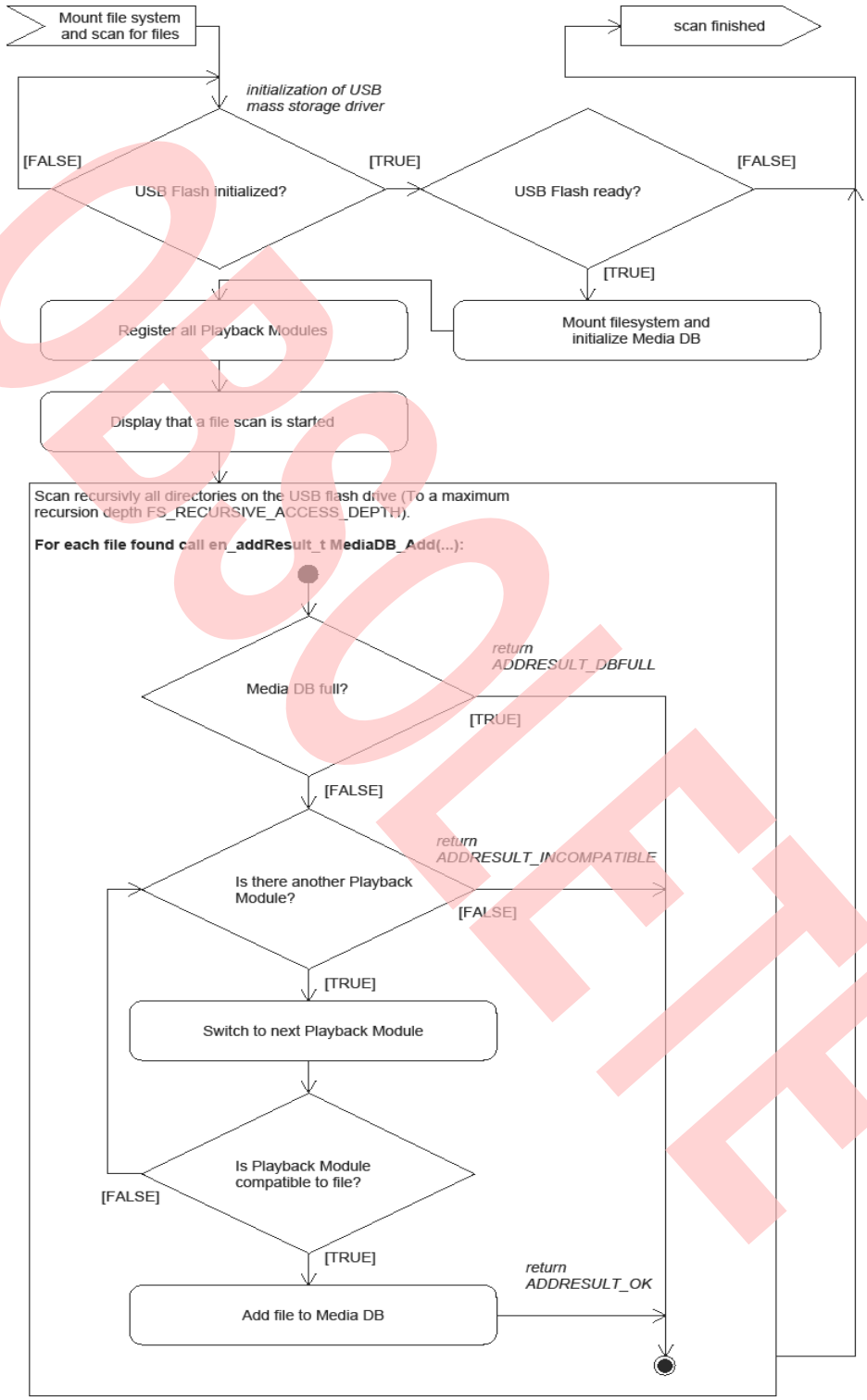
Figure 4. Program Flow of the Main Component While Initializing USB Flash Drive



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3.2.3 Buffers

The buffers component contains the input and output buffer. The input buffer is used to buffer the data read from the USB flash drive. The output buffer holds the data, that is already processed by the Playback Module and waiting to be handed over to the I²S codec.

The input buffer `acInputBuffer[]` is just a single array and its size is determined by the constant `INPUTBUFFER_SIZE`. In order to refill the input buffer the Buffers component provides the `boolean_t Buffers_fillInputBuffer(FIL* file, uint32_t* u32bytesLeftInBuffer, boolean_t* eof)` function, which can be called by the active Playback Module as soon as the input buffer gets empty. The process of refilling the input buffer is presented in Figure 5 and described in the following. As soon as the input buffer is no longer filled sufficiently (e.g. contains no entire audio frame), the `Buffer_fillInputBuffer(…)` function is called. The `Buffer_fillInputBuffer(…)` function moves the remaining bytes from the tail of the buffer to the top and fills the input buffer up until it is completely full again. The active Playback Module can start reading the input data from the top of the buffer again.

Figure 5. Procedure of an Input Buffer Refill

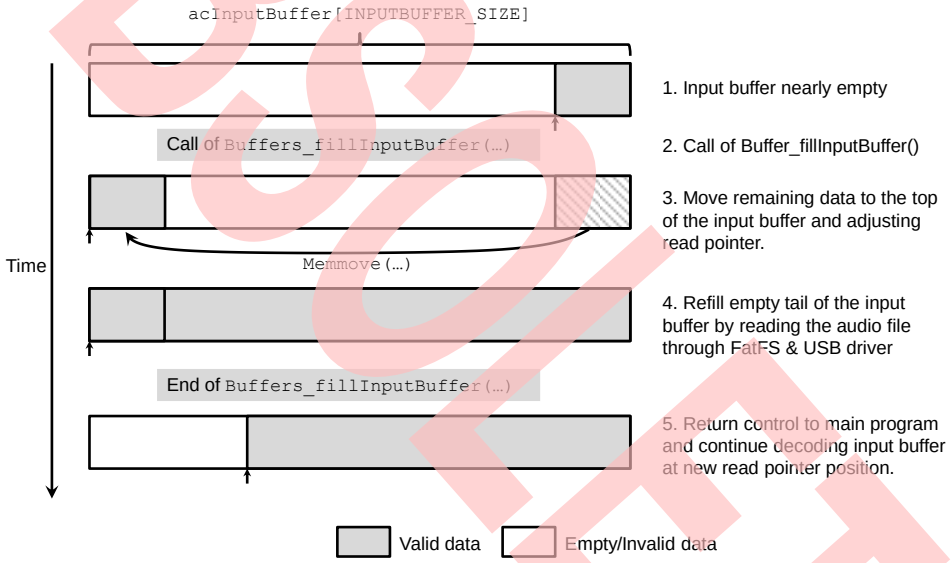

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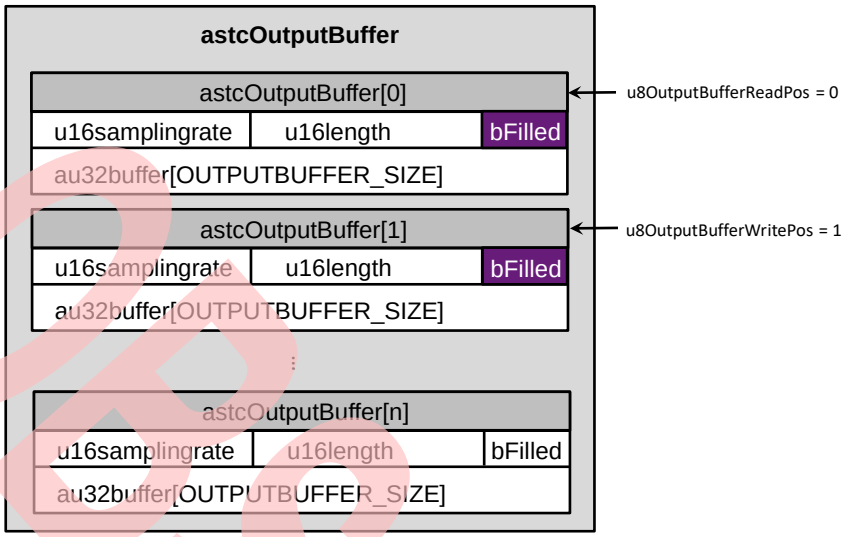
Figure 6. Concept of the Output Buffer



The whole output buffer `astcOutputBuffer[]` consists of several output buffer structures of the type `stc_OutputBuffer_t`. As soon as the active Playback Module has filled one of the output buffer structures, it can be passed to the DSTC peripheral (see section 3.2.6), which handles the transfer to the I²S peripheral TX-FIFO. Figure 6 shows the concept of the output buffer. Besides the actual buffer `au32buffer[]`, an output buffer structure consists of two unsigned integer fields: `u16length` and `u16samplingrate`, which indicates how many valid samples are contained the buffer field au32buffer[] and the sampling rate of these samples. It also has a field `bFilled` to signal whether the buffer field `au32buffer[]` contains any valid data at all. In order to work properly two unsigned integers `u8OutputBufferReadPos` and `u8OutputBufferWritePos` are declared to represent the current reading respectively writing position. As soon as a Playback Module finished filling an output buffer, it marks the structure as filled by setting the field `bFilled` to TRUE and increments the value of `u8OutputBufferWritePos`, vice versa, as soon as the DSTC peripheral has finished transferring the data from an output buffer structure, the DSTC component marks this structure as empty by setting the field `bFilled` to `FALSE` and increments the value of `u8OutputBufferWritePos`.

Please note that each sample in the buffer `au32buffer[]` is 32 bit wide, while the 16 MSBs representing the left audio channel (16bit, signed, PCM) and the 16 LSBs the right audio channel (16bit, signed, PCM).

The size of the buffer `au32buffer[]` contained in an output buffer structure and the overall number of output buffer structures in the output buffer `astcOutputBuffer[]` can be adjusted by changing the constants `OUTPUTBUFFER_SIZE` and `OUTPUTBUFFER_COUNT`. In most cases more than 2 buffers are not necessary. For mp3 playback a size of 1152 is recommended, because an mp3 frame has always 1152 samples.

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3.2.4 Playback Modules

A Playback Module fulfills the task to play media files. It has to implement 2 functions:

- `en_playbackResult_t play(char_t* pcFilePath, char_t* pcFileTitle)`
- `boolean_t isCompatible(char_t* pcFilePath)`

The first function is utilized to play the given media file, whereby `pcFilePath` is the path to the file and `pcFileTitle` is the file's title that should be shown to the user. The second function `isCompatible(…)` is used to determine whether the file with the given path `pcFilePath` can be played by the play(…) function of the Playback Module. The returned enumeration `en_playbackResult_t` indicates the outcome of the playback (e.g. if it was successful, a decoding error occurs or the user just want to skip the audio file). Each Playback Module has to be registered with its two functions at the Media DB component. It also has to report its current status (title of the media file, playback progress …) to the User I/O component and fetch and react on user inputs provided by the User I/O component. The media data, which is processed by the Playback Modules, is read from the input buffer and written into the output buffer after processing. There are 2 Playback Modules implemented in this example: MP3Decoder and WavPlayer.

MP3Decoder

The MP3Decoder playback module is used to play MP3 files. It utilizes the MPEG Audio Decoder (libmad or just MAD) (for more details see http://www.underbit.com/products/mad/) to decode the given media file. The MAD provides, besides a low-level API, a high-level API, which is used by the MP3Decoder playback module. With this API the full control is given to the MAD. The decoding process can only be influenced by a handful of callback functions (input, output, header and error function), which are handed over at the beginning of the decoding process. These callback functions are implemented in the MP3Decoder module. In Table 2 it can be seen, in which cases a callback function is called by the MAD and how they are handled by the MP3Decoder module. The MP3Decoder also contains a tiny ID3Tag Reader, which can read ID3v2.3 Tags and overrides the `pcFileTitle` with the Artist, Album and Title tags, if present.

Table 2. MAD Callback Functions

Callback Function	When Does MAD Call This Function?	How Does MP3Decoder React?
input	The Input function is called by the MAD, if the input buffer is nearly empty.	MP3Decoder fills the buffer as soon as this function is called
output	The Output function is called, if a mp3 frame is decoded and can be played.	MP3Decoder waits until a new output buffer is empty, down samples the mp3 frame, transfers it to the output buffer and notifies the DSTC component. In this function also User I/Os are processed.
header	The Header function is called as soon as a frame header is read.	The MP3Decoder reads the bitrate and sample rate from the mp3 header and configures the I2S codec accordingly.
error	The Error function is called, if an error occurred while encoding.	The MP3Decoder propagates the error to the user via the User I/O UART functionality.

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WavPlayer

The WavPlayer Playback Module can play PCM encoded wave files. It is able process all wave files that have a resolution between 0 and 32 bits per sample and one of the sample rates supported by the SGTL5000 I2S-Codec (8k, 10.025k, 12k, 16k, 22.05k, 24k, 32k, 44.1k, 48k and 96k). Due to performance limitations of the FatFS and USB driver only files with 1 Mbit/s data rate can be played.

After initialization the WavPlayer enters a playback loop, which mainly consists of 3 steps:

- Refill the input buffer.
- Handle new user inputs and wait until at least one output buffer array is empty.
- Process audio data in input buffer (down respectively up sampling) and transfer it to output buffer until input buffer is empty

3.2.5 User I/O

The User I/O module is used to communicate with the user. It recognizes pushed buttons, refreshes the board display and provides some UART functions. It is necessary to initialize the User I/O component by calling the `UserIO_Init()` function. It starts the FRT of the MFT0 for the display refresh interrupt routine and configures the external interrupt to react on the pressed board buttons.

User Input

In order to fetch user inputs the function `en_userIOInputType_t UserIO_getInput(void)` has to be called. The returned enumeration signals, if a new user input has been received since the function was called the last time. It also informs about the type of user input (e.g. which board button was pressed).

LC Display

The content of the board's LCD depends on the current state of the I²S USB MP3Player. This state can passed to the User I/O component by calling the `UserIO_displaySetMode(const en_userIOdisplayMode_t enDisplayNewMode)` function. The most important state is the audio playback (DISPLAYMODE_PLAY). The board's LC Display is divided in 3 areas then as shown in Figure 7. The entire first line is used to show the title of the currently playing song. It can be set with the `UserIO_displaySetScrollingText(const char_t* pcText)` function of the User I/O component. If the given text is longer than 16 characters, the User I/O component will take care of the scrolling.

The right 6 segments of the second display line are used to show the elapsed time. Its value can be modified by the following two functions:

- UserIO_displaySetElapsedSec(const uint16_t u16elapsedSec)
- UserIO_displayIncElapsedSec(void)

The first one sets the elapsed time to the given value in seconds, while the second one increases the current value by one second.

The left 9 segments of the second display line can be set for each Playback Module individually. Up to `USERIO_DISPLAYENTRIES` entries can be added. They will be switched automatically by the User I/O module. To add a new entry the function `uint8_t UserIO_displayAddDisplayEntry(const char_t* pcDisplayEntry)` has to be called. It returns an unique ID, which have to be used to if the entry shall be modified (done by calling `boolean_t UserIO_displayUdateDisplayEntry(const uint8_t u8DisplayEntryID, const char_t* pcDisplayEntry))`. To remove all entries again the `UserIO_displayClearDisplayEntries()` function have to be called.

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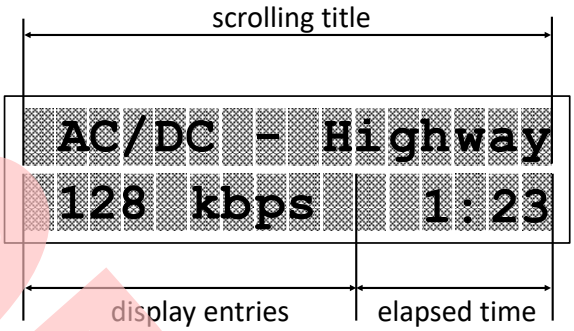
Figure 7. Display Areas



UART Logging

To send more detailed information to the user the User I/O component provides some functionality to send UART log messages. The amount of messages can be controlled by setting a global log level `(UserIO_logSetLvl(const en_logLvl_t enLogLvl))`.

3.2.6 DSTC

The DSTC component is responsible for the communication with the DSTC peripheral. The `Dstc_Init()` function has to be called to initialize the DSTC Peripheral and generate one Descriptor for each output buffer structure in the output buffer array `astcOutputBuffer[]`. It also enables the DSTC interrupt for error logging and the DSTC combined type interrupt, which is triggered every time a Descriptor Job is finished. As soon as the first output buffer in the output buffer array is filled by one of the Playback Modules, the `Dstc_DESx_Setup(uint8_t u8OutputBufferNo)` function has to be called. It will hand over the Descriptor, corresponding to the output buffer structure with the given output buffer number u8OutputBufferNo, to the DSTC peripheral, which will fill the I2S TX-FIFO automatically from the audio data stored in this output buffer structure. From now on the DSTC component will setup the Descriptor for the next output buffer on its own. Unless no filled output buffer can be found. Then the DSTC component will set the global variable `bOutputBufferUnderrun to TRUE` and the active Playback Module have to call the `Dstc_DESx_Setup(uint8_t u8OutputBufferNo)` again as soon as an output buffer is filled with new data.

4 Memory Usage

4.1 ROM

The following Table 3 shows the approximately ROM consumption of the project parts. The data was taken from the GCC linker output with the compiler optimization high (-O3).

Table 3. ROM Usage Overview

Project Part:		Size:
Application		10.0 KB
MAD library		40.2 KB
FatFS file system		17.7 KB
Startup file		1.1 KB
Low level library		32.3 KB
	USB	13.2 KB
	SGTL5000 I²S codec driver	7.2 KB
C libraries		30.2 KB
Total		**~ 132.1 KB**

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4.2 RAM

Table 4 gives an overview of the RAM usage. The data was also taken from the GCC linker output.

Note that the Common section of the Application contains the input and output buffers, which are set to 4,096 Bytes respectively 3x 4,608 Bytes (= 1152 x 32 Bit). Stack and Heap are set to 0x2000 and 0x20000, assuming the Media DB (which is located on the Heap) can contain maximally 256 entries, each with a 256 Byte field for the file path and a 256 Bytes field for the files' title.

Table 4. RAM Usage Overview (All Values in Bytes)

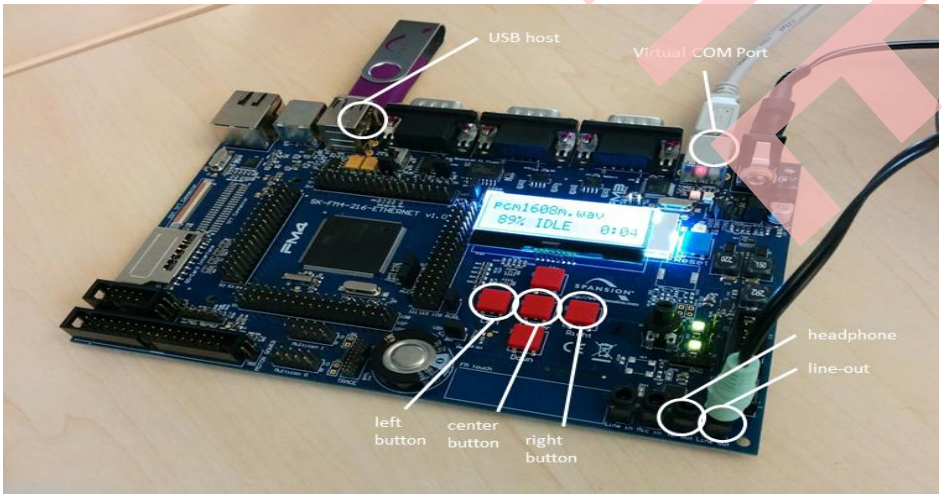
Project Part:	RO Data:	Data:	BSS:	Common:	Total:
Application	844	48	452	18,603	19,947
MAD library	43,127	-	-	-	43,127
FatFS file system	1,363	-	8	-	1,371
Low level library	456	5,208	212	437	6,313
USB	72	5,200	75	136	5,483
SGTL5000 I²S codec driver	-	-	-	-	-
C libraries	456	2,235	68	4	2,763
Heap	-	-	-	-	131,072
Stack	-	-	-	-	8,192
Total	**46,318**	**12,691**	**815**	**19,180**	**218,268**

5 How to Use the I²S USB MP3Player

If you want to use the I²S USB MP3Player software example attach a USB flash drive formatted with a FAT file system and your music on it to one of the USB ports of the SK-FM4-216-ETHERNET board. Also plug in your headphones to the headphone connector or some other playback device to the line-out connector of the SK-FM4-216-ETHERNET. Optionally you can connect the Virtual COM Port with your PC to receive log messages in a UART terminal.

After the board is powered on and the initialization is done, you can use the right and left buttons on the SK-FM4-216-ETHERNET to skip the current file or step back to the previous one. Press the middle button to pause the playback.

Figure 8. Usage of the MP3Player



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Document History

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Document Number: 002-04468

Revision	ECN	Orig. of Change	Submission Date	Description of Change
**	–	YUIS	02/16/2015	Initial Release.
*A	5028554	YUIS	12/01/2015	Updated to Cypress template.
*B	5711419	AESATP12	04/26/2017	Updated logo and copyright.
*C	6350773	WOFR	10/15/2018	Obsolete document. Completing Sunset Review.

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