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Using Speex in NXP's LPC175x/6x MCU family

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Document information

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Abstract	This document describes the use of Speex's Codec in NXP's LPC175x/6x family of microcontrollers.

Revision history

Rev	Date	Description
2	20120305	Second version, to match with updated firmware.
1	20110616	Initial version.

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1. Introduction

1.1 Overview

Once designed to be a free alternative to expensive speech codecs, Speex is an Open Source / Free software patent-free audio compression format designed for speech. Speex is part of the GNU project and this application note provides information regarding the usage of this library on NXP's LPC175x/6x microcontrollers (based on Cortex-M3).

1.1.1 Speex features

The Speex library is based on Code-Excited Linear Prediction (CELP). It is designed to compress voice at bitrates ranging from 2 kb/s to 44 kb/s. Some of Speex's features include:

- Narrowband (8 kHz), wideband (16 kHz), and ultra-wideband (32 kHz) compression in the same bitstream
- Intensity stereo encoding
- Packet loss concealment
- Variable bitrate operation (VBR)
- Voice Activity Detection (VAD)
- Discontinuous Transmission (DTX)
- Fixed-point port
- Acoustic echo canceller
- Noise suppression

Note that Speex has a number of features that are not present in other codecs, such as intensity stereo encoding, integration of multiple sampling rates in the same bitstream (embedded coding), and a VBR mode.

For more information regarding Speex visit http://speex.org/docs/.

1.1.2 Applications

The Speex library can be used in various applications, such as VoIP, internet audio streaming, data archiving (e.g., voice mail), and audio books.

1.1.3 About this document

The purpose of this application note is to describe the Speex library features and interface and provide the source code containing the library and a sample application to be used with a LPC175x/6x microcontroller, compatible with Keil MDK, IAR EWARM and LPCXpresso IDE's.

1.2 LPC175x/6x features

The LPC175x/6x is an ARM Cortex-M3 based microcontroller for embedded applications requiring a high level of integration and low power dissipation. It operates at frequencies up to 100 MHz (120 MHz in LPC1759 and LPC1769 versions). Some details of the peripherals used in this application are listed below:

- 12-bit Analog-to-Digital Converter (ADC) with input multiplexing among eight pins, conversion rates up to 200 kHz, and multiple result registers. The 12-bit ADC can be used with the GPDMA controller.
- 10-bit Digital-to-Analog Converter (DAC) with dedicated conversion timer and DMA support.
- Four general purpose timers/counters, with a total of eight capture inputs and ten compare outputs. Each timer block has an external count input. Specific timer events can be selected to generate DMA requests.
- Three enhanced I^2C-bus interfaces, one with an open-drain output supporting the full I^2C specification and Fast mode plus with data rates of 1 Mbit/s, two with standard port pins. Enhancements include multiple address recognition and monitor mode.
- I^2S (Inter-IC Sound) interface for digital audio input or output, with fractional rate control. The I^2S interface can be used with the GPDMA. The I^2S interface supports 3-wire data transmit and receive or 4-wire combined transmit and receive connections, as well as master clock output.

1.3 About Code Red's RBD1768 development board

Code Red Technologies offers a development board containing an LPC1768 and several hardware options for evaluating and testing the LPC1768 features. This demo uses NXP's UDA1380 I2S Stereo Codec which is integrated on the evaluation board. It also contains an input for the ADC and an output for the DAC pins, allowing the application to integrate various working modes, merging usage of the converters and I2S codec interface.

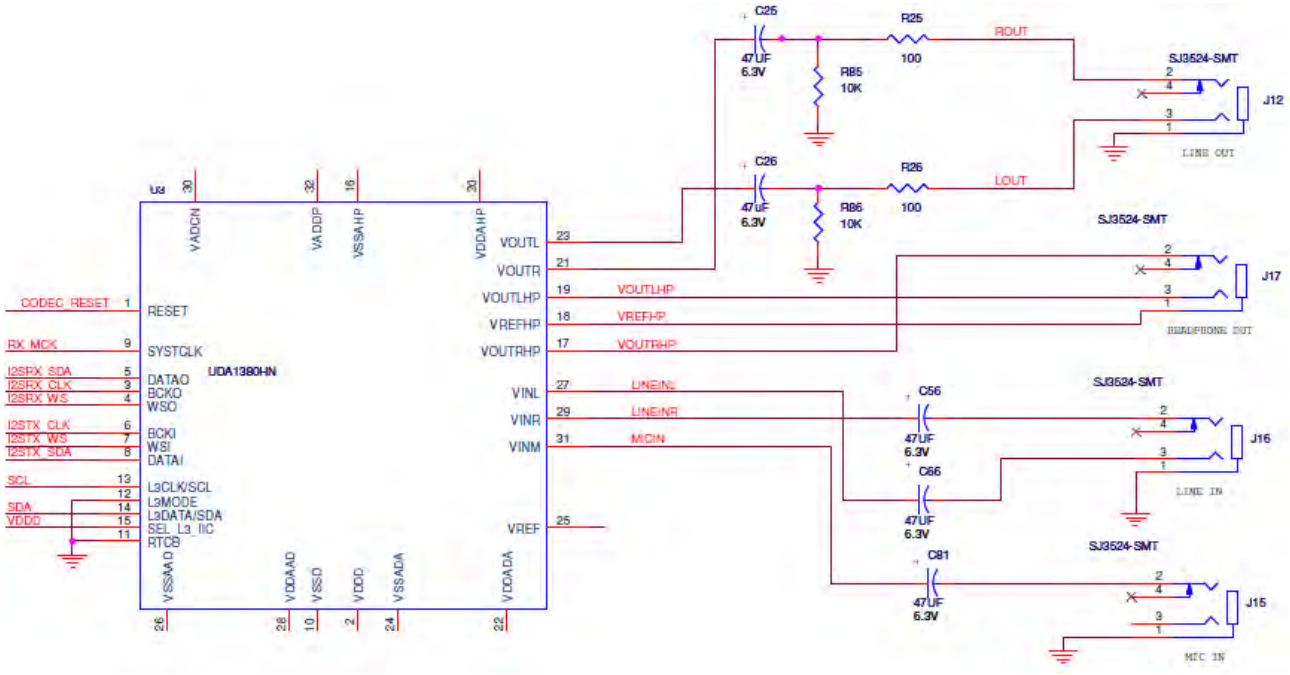


Fig 1. Detail of I2S Codec in RBD1768 development board

2. Application

2.1 Vocoder overview

The application proposed is a Vocoder using LPC1768. Vocoders are analysis and processing systems mostly used for voice applications. It treats the audio signal enhancing the bandpass related to the voice spectrum frequencies, encoding, decoding, filtering and finally amplifying it.

The application software processes Speex data, capturing data either from ADC or I2S and to deliver it either to DAC or I2S. The application allows usage of ADC and DAC converters in case of I2S codec is not available:

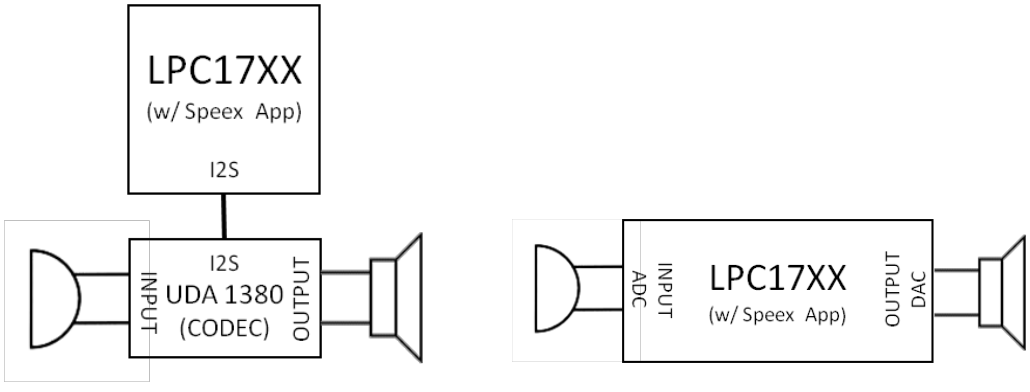


Fig 2. Functional diagram of Speex application in LPC17XX using (a) NXP I2S Codec and (b) using ADC and DAC converters

2.2 Memory requirements

The LPC175x/6x microcontroller has sufficient internal SRAM to meet the memory requirements for Speex. One adjustment is necessary in heap size, in order to enable the data to be processed correctly. Because the Speex CODEC demands a large portion of heap memory for dynamic allocation, a minimum of 8 kB is necessary to allocate all necessary data.

Table 1 shows the amount of memory used by application using the three IDE's (Keil MDK, IAR EWARM, LPCXpresso). Based on these values a suitable member of the LPC175x/6x family can be selected. For these specific examples, LPC1751 and LPC1752 don't match the memory requirements.

Table 1. Memory usage

IDE	Flash usage (bytes)	RAM usage (bytes)
Keil RVMDK	49900	10120
IAR EWARM	36346	18196
LPCXpresso[1]	86676	18272

[1] LPCXpresso code size includes the UDA1380 Library and is also not optimized.

2.3 Speex application implementation

2.3.1 Codec settings

2.3.1.1 Sampling rate

The LPC175x/6x port for the Speex codec works only with narrowband (8 kHz sampling rate);

2.3.1.2 Speex Parameters

Below are some parameters required to configure the Speex codec in this application. The default values are:

- Quality – Encoder quality is set to 4
- VBR – Variable Bit-Rate is disabled
- Complexity – Encoder complexity is set to 1
- Enhancer – Decoder audio enhancer feature is enabled

2.3.2 Environment features and requirements

All code examples were written using CMSIS resources, including the LPC175x/6x CMSIS-Compliant Standard Peripheral Firmware Driver Library (Jan 28, 2011) available here:
http://ics.nxp.com/support/documents/microcontrollers/zip/lpc17xx.cmsis.driver.library.zip

In IAR EWARM and Keil RVMDK the Heap Size was set to 0x2000 in order to allow Speex to allocate the necessary memory.

According to Speex specification, for a sampling rate of 8 kHz, the frame size is 20 ms, corresponding to 160 samples. For the application ported to RDB1768v2, without any optimization, LPC1768 running at 100 MHz takes about 17 ms to encode a single frame,

and up to 4.5 ms for decoding[1]. This makes the LPC175x/6x suitable for real-time encoding or decoding.

2.3.3 Using libSpeex

In order to use libSpeex functions for encoding/decoding speech, a Speex bit-packing struct must be declared, along with a Speex encoder state:

```
SpeexBits bits;
void *enc_state;
```

The struct bits, encoder and decoder are initialized by spx_Init, using a SPX_CODEC_CFG_Type for CODEC configuration, as shown in Fig 3 and Fig 4.

```
  SPX_CODEC_CFG_Type spx_config;

 /* Speex CODEC configuration */
  spx_config.quality    = 4;                    /* Encoder parameter */
  spx_config.complexity = 1;                    /* Encoder parameter */
  spx_config.vbr        = SPX_VBR_DISABLED;     /* Encoder parameter */
  spx_config.enh        = SPX_ENHANCER_ENABLED; /* Decoder parameter */
  spx_Init(&spx_config);
```

Fig 3. Speex configuration struct

1. Only during encoding or decoding, P0_25 is set to a high level providing a simple approach for time measurement.

```
void spx_Init(SPX_CODEC_CFG_Type *SpxCfg)
{
   Speex_bits_init(&bits);
   /* Speex encoding initializations */
   enc_state = Speex_encoder_init(&Speex_nb_mode);
   Speex_encoder_ctl(enc_state, SPEEX_SET_VBR, &SpxCfg->vbr);
   Speex_encoder_ctl(enc_state, SPEEX_SET_QUALITY, &SpxCfg->quality);
   Speex_encoder_ctl(enc_state, SPEEX_SET_COMPLEXITY, &SpxCfg->complexity);
   /* Speex decoding intilalization */
   dec_state = Speex_decoder_init(&Speex_nb_mode);
   Speex_decoder_ctl(dec_state, SPEEX_SET_ENH, &SpxCfg->enh);

}
```

Fig 4. Speex initialization

2.4 Application description

Examples are provided for three LPC175x/6x evaluation boards, Code Red RDB1768v2, Keil MCB1700 and IAR LPC1768-SK.

The Vocoder application examples provide one or two functions, depending on the board used:

1. Recording function: Through a routine call, the application obtains the audio stream from an input (I^2S or ADC), encodes it and then stores it into the RAM. This function is available only in applications for IAR LPC1768-SK and Code_Red RDB1768v2 boards.
2. Playback function: The application loads a voice audio stream previously stored in RAM memory, decodes it and delivers the audio to the appropriate output (I^2S or DAC). This function is available in all three evaluation boards.

2.4.1 Record process

Two buffers are used to store the input frames: IN_Buffer[0] and IN_Buffer[1]. At the beginning of a encoding process, the sampler uses IN_Buffer[0] to store the first 160 samples. As the sampler starts to store the next 160 frames in IN_Buffer[1], the encoder starts encoding IN_Buffer[0]. The sampler and the encoder are always alternating the buffers' accesses. Each encoded frame is composed of 20 bytes, and a buffer called output_bytes uses the Speex encoder to store the encoded frame. Fig 5 shows the encoding scheme and Fig 6 the flowchart.

The application can record 6 seconds (300 frames) of voice by using an array of 6000 bytes. For IAR LPC1768-SK board, the sampler is composed by the ADC and a TIMER. The audio level is converted by the ADC inside the TIMER0 interrupt handler, which is programmed to be called every 125 us (8 kHz).

For the Code Red RDB1768 board, samples are captured from the I2S interface. The I2S frequency is adjusted to allow UDA1380 Audio Codec transfer sample data at a frequency of 8 kHz. This data is saved in IN_Buffer's inside I2S interrupt handler.

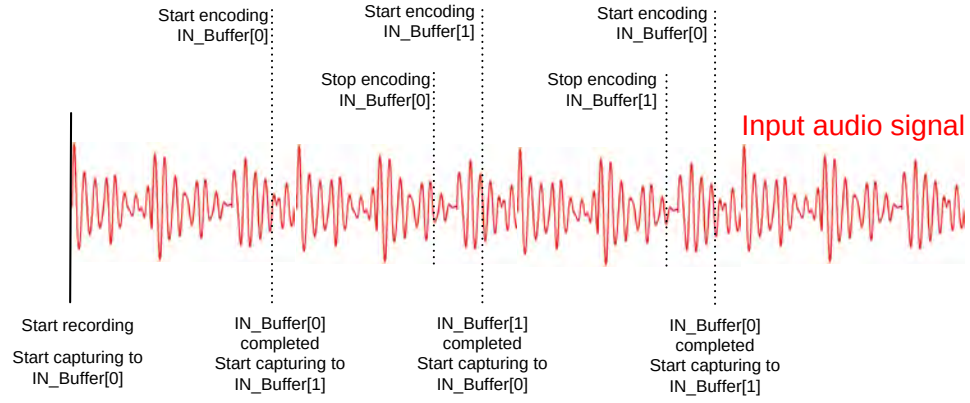
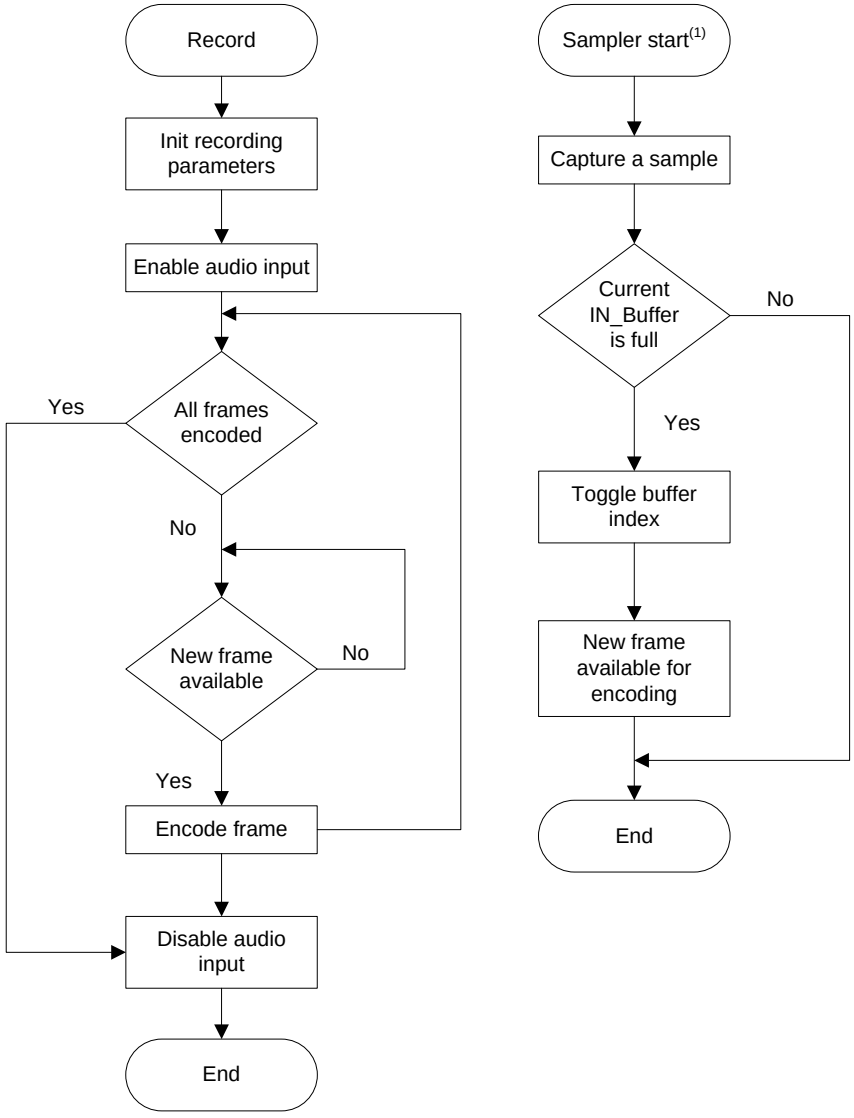


Fig 5. Encoding scheme



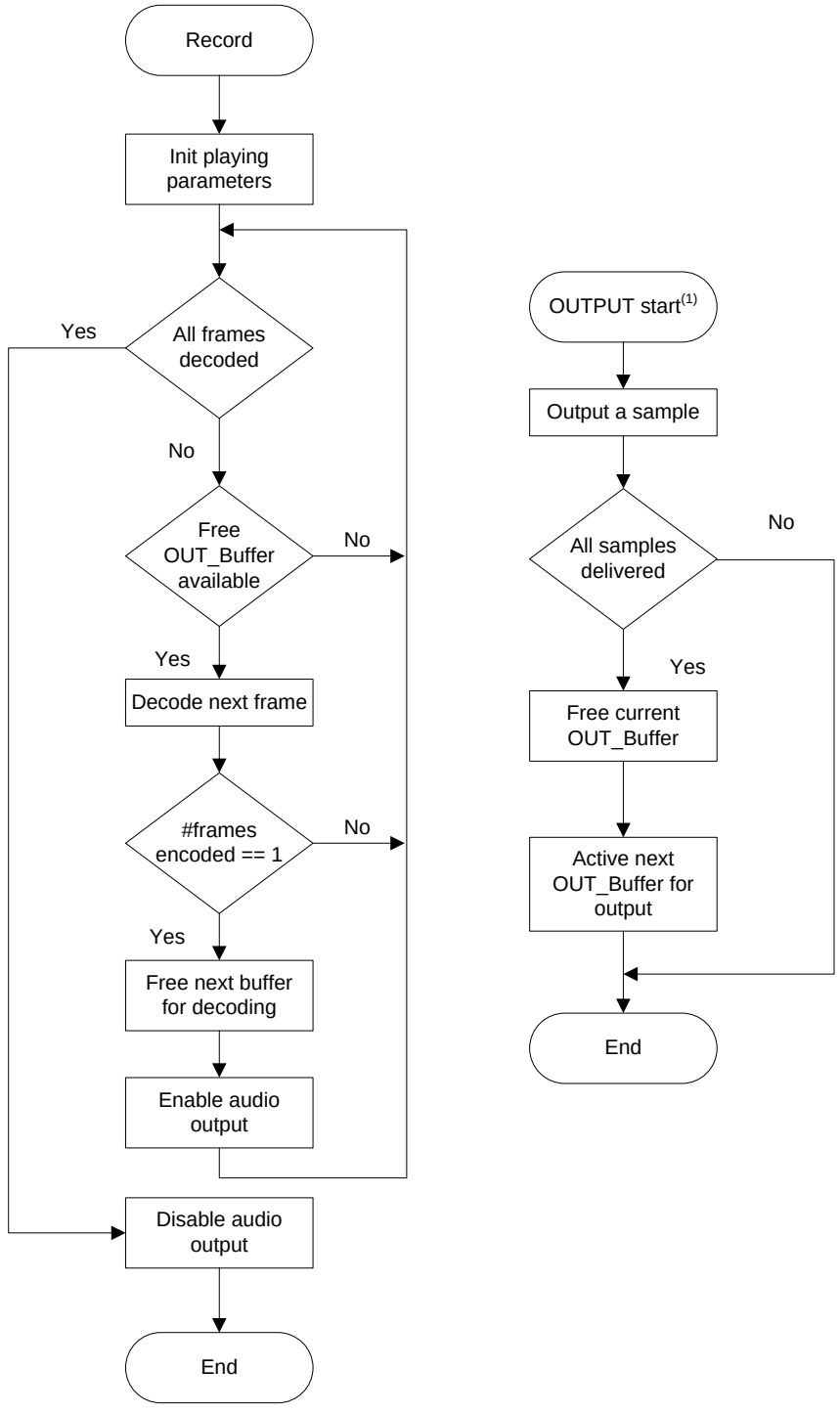
(1) Depending on the board, Sampler can be TIMER0 or I2S Interrupt Handler

Fig 6. Encoding flowchart

2.4.2 Playback process

The playback process is similar to the encoding process. Two buffers are used to deliver frame data to the output.

The first encoded frame (20 bytes) is taken from the 6 kB array, decoded and the resulting frame is stored in OUT_Buffer[0]. The Decoder starts decoding the next Speex frame, storing the result in OUT_Buffer[1] while OUT_Buffer[0] is delivered to the output (DAC for IAR LPC1768-SK, and I2S transmitter for code_red RDB1768). It continues until all Speex frames are decoded. Fig 7 and Fig 8 illustrate the decoding process.



(1) Depending on the board, OUTPUT can be TIMER0 or I2S Interrupt Handler

Fig 7. Decoding flowchart

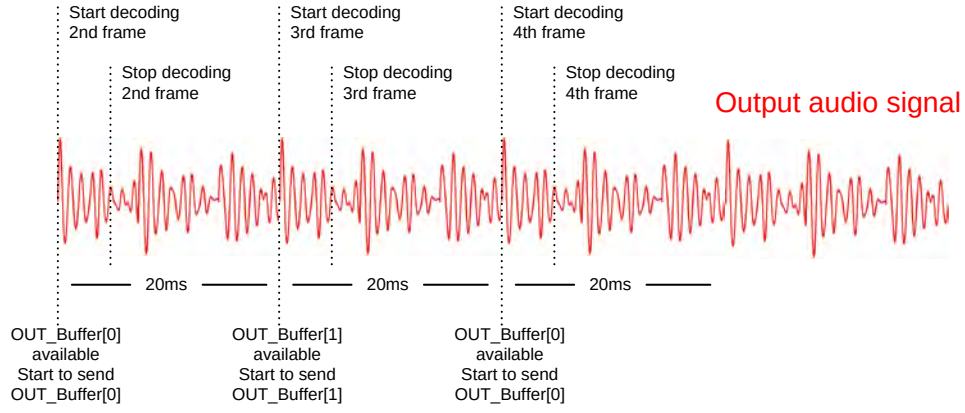


Fig 8. Decoding scheme. 1st frame is decoded previously.

2.4.3 Audio input/output for RDB1768 board

The CodeRed RDB1768 board uses an external Audio Codec (UDA1380) for input/output audio signal. This external coder-decoder is configured to capture audio from the MIC input, which is then sent to the microcontroller using the I2S interface. The LPC175x/6x I2S controller is configured as follows:

- Bit clock = 16 kHz (resulting in 8 k samples per second, as the UDA1380 will always transfer stereo data);
- Transmitter master, Receiver master;
- 16-bit data words, MONO.

The UDA1380 sends data according to WS and BCK signals generated by LPC1768. Because the microphone signal is MONO, the same value is sent as RIGHT and LEFT data.

When configured for 16-bit word, the 32 bits RX FIFO contains two consecutive 16-bit samples after a complete WS cycle. The RX FIFO contents and I2S bus format sent by UDA1380 are shown in Fig 9 and Fig 10. An oscilloscope screen of a transition is shown in Fig 11.

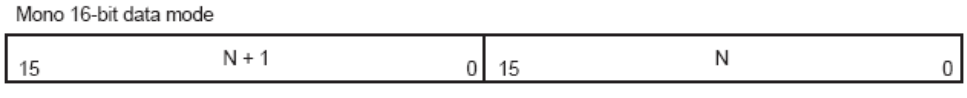


Fig 9. RX FIFO content of LPC175x/6x, 2 mono samples transferred

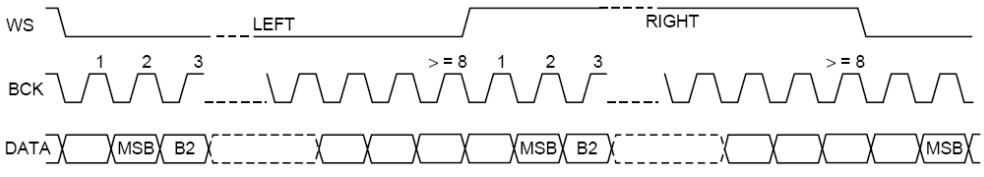


Fig 10. I2S bus format for UDA1380 for transferring 1 mono sample

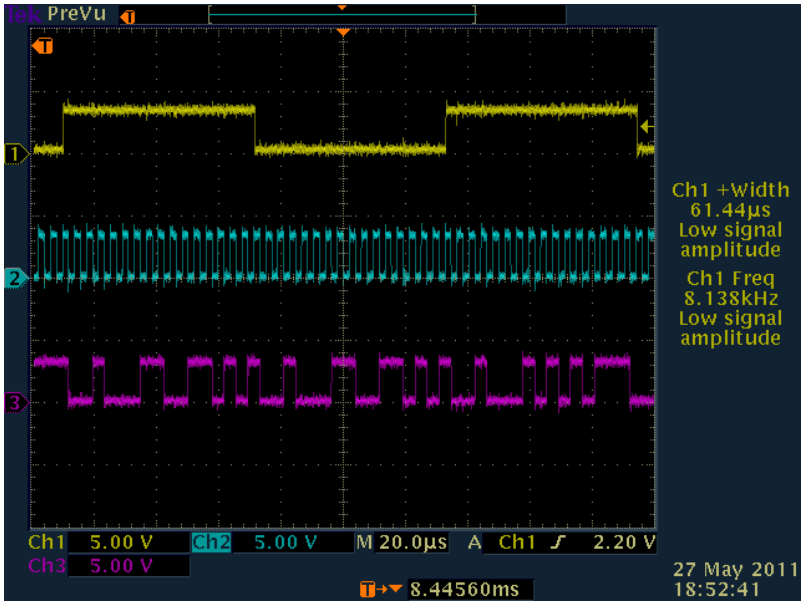


Fig 11. Oscilloscope screen of an I2S signal received by the LPC1768. Yellow (I2SRX_WS), blue (I2SRX_CLK) and magenta (I2SRX_SDA)

Note: On the CodeRed RDB1768 board the microphone is not working properly by default due to a hardware bug, as there is no power supplied to the microphone. This can easily be fixed by connecting a 10 kΩ resistor from the microphone to the analog power supply of the UDA1380. Fig 12 shows the required patch.

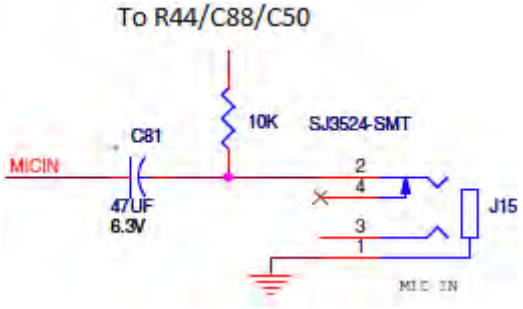


Fig 12. Hardware fix required when connecting an electret microphone to the RDB1768 board

2.4.4 User Interface

The application example for the Code Red RDB1768 board uses an LCD interface to show a menu, where the user can choose “Record” and “Play” functions by using the on-board joystick. It uses only the DOWN direction to toggle the cursor position; by pressing CENTER the current option is selected.

For the IAR LPC1768-SK the application code is simpler. Two buttons are used to start the “Record” and “Play” functions. The user can use BUTTON 1 for recording a new 6 second voice stream and BUTTON 2 for playing back the recorded voice stream.

This software package also includes a project using Keil Real-View MDK for the Keil MCB1700 board. This board doesn’t have a microphone input or a headphone output,

but it contains a speaker that is used by the application to play a sample audio that comes with the software.

3. Conclusion

We can see in this application note that the LPC175x/6x is suitable for Vocoder applications using the Speex Codec. Even using no optimization methods, this microcontroller can perform real-time Speex encoding/decoding satisfactorily. Users also can implement some Preprocessor functions available by the Speex software library, such as Resampler, Echo Cancellation, etc.

4. References

- Speex manual, http://speex.org/docs/
- Speex API Reference Manual, http://speex.org/docs/
- LPC17xx user manual (UM10360), http://www.nxp.com

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