

Project 03 - DSP/BIOS based FIR

Introduction to Embedded Systems - University of Nebraska

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Contents

1	Introduction	3
2	Project Description	3
2.1	Filter Design	3
2.2	Program Description	3
2.3	HWI_I2S_Rx	4
2.4	HWI_I2S_Tx	5
2.5	SWI_PingFunc and SWI_PongFunc	5
2.6	montiorSW1	5
2.7	monitorSW2	6
3	Results	7
3.1	CPU Usage	7
3.2	Execution Graph	8
3.3	Demonstration	8
4	Summary	9
5	Appendix	10

1 Introduction

The purpose of this project was to introduce the Texas Instruments (TI) real-time operating system BIOS using the TI ezDSP5535 development board (ezDSP). The project required the use of hardware interrupt (HWI) threads, software interrupt (SWI) threads, and idle (IDL) threads. The goal of the project was to receive, filter and retransmit audio samples using HWIs and SWIs. Additional components to change between a low-pass (bass) and high-pass (treble) filter and to transmit a one kHz tone were included to employ the IDL threads. The project built on previous projects by requiring the use of myNCO and myFIR functions designed in Projects 1 and 2, respectively.

2 Project Description

2.1 Filter Design

Two filters were implemented for this project, a low- and high-pass filter, with the intent of isolating bass tones with the low-pass filter and isolating treble tones with the high-pass filter. The design process was trial-and-error until filters were achieved that produced the distinct bass and treble sounds that were desired.

The low-pass filter was designed with the following specifications:

- Passband frequency: **350 Hz**
- Stopband frequency: **1310 Hz**
- Passband ripple: **0.2 dB**
- Stopband attenuation: **60 dB**
- Order: **125**

The high-pass filter was designed with the following specifications:

- Passband frequency: **2100 Hz**
- Stopband frequency: **1400 Hz**
- Passband ripple: **0.2 dB**
- Stopband attenuation: **60 dB**
- Order: **124**

The frequency response of both filters is shown in Figure 1.

2.2 Program Description

TI provides an easy-to-use GCONF tool to configure the BIOS scheduler, which was used to establish the threads that were used for this project. To progress through the project incrementally the HWIs were setup and tested, the SWI was incorporated and finally the IDL threads were included. HWI 14 and 15 were used for I2S transmit (tx) and I2S receive (rx) with function handles `_HWI_I2S_Tx` and `_HWI_I2S_Rx`, respectively. Two SWI threads

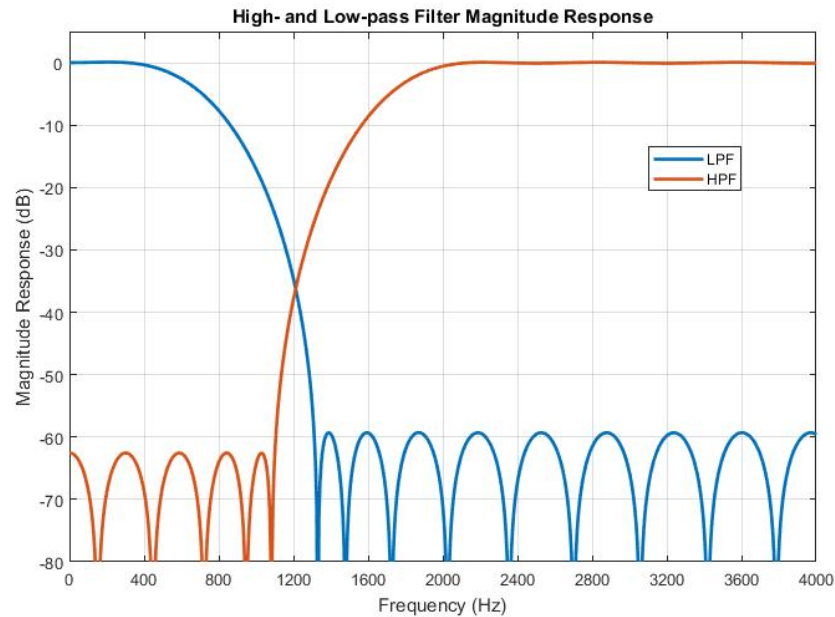


Figure 1: Magnitude response of low- and high-pass filters

with function handles `_SWIPingFunc` and `_SWIPongFunc` and equal priority were defined using `GCONF`. Lastly, the `GCONF` tool was used establish two IDL threads with function handles `_monitorSW1` and `_monitorSW2`.

After establishing the threads using `GCONF`, the HWI threads were enabled in main and once the program exited main it launched the DSP/BIOS scheduler, which managed all the threads. The scheduler ensures that threads run in the correct order based on priority. In general, the priority level of thread types is HWI, SWI, IDL, in descending order.

2.3 HWI_I2S_Rx

Listing 1 shows the code for the HWI thread that handled I2S reception. It was assumed that the right and left samples were the same; therefore, the right sample was read and disregarded and the left sample was stored into a double buffer. The double buffer was 96 elements and was broken into two 48 element buffers, ping and pong. The purpose of the double buffer was that once ping was full its elements could be filtered while new data was loaded into pong. Otherwise, if a single buffer was used, then data may be lost during the process of filtering. The double buffer is reflected in the code. New data is stored in the double buffer `rxPingPong` until 48 samples have been received; then, the HWI posts the software interrupt `SWIPing` which handles filtering of the ping buffer. While `SWIPingFunc` filters the samples the HWI continues to place new samples into pong, i.e. the latter half of `rxPingPong`. Samples are stored until 48 more have been received, and the HWI posts a second SWI to filter the pong samples.

```

1 void HWI_I2S_Rx(void)
2 {
3     volatile int16_t temp;
4     temp = hI2s->hwRegs->I2SRXRT1;
5     rxPingPong[rxIndex++] = hI2s->hwRegs->I2SRXLT1;
6
7     if (rxIndex == 48)           //Have 48 samples been collected
8     {

```

```

9      /* Ping is full */
10     SWI_post(&SWIPing);
11 }
12 if (rxIndex == 96)
13 {
14     /* Pong is full */
15     SWI_post(&SWIPong);
16     rxIndex = 0;
17 }
18 }

```

Listing 1: I2S receive HWI thread

2.4 HWI_I2S_Tx

Listing 2 shows the code for the HWI thread that handled I2S transmission. This thread simply writes the filtered samples to the I2S, checks to see if the end of the array has been reached and resets back to the beginning of the transmit array if it has.

```

1 void HWI_I2S_Tx(void)
2 {
3     hI2s->hwRegs->I2STXLT1 = txPingPong[txIndex];
4     hI2s->hwRegs->I2STXRT1 = txPingPong[txIndex++];
5
6     if (txIndex == 96)           //Have 96 samples been transmitted?
7     {
8         txIndex = 0;
9     }
10 }

```

Listing 2: I2S transmit HWI thread

2.5 SWI_PingFunc and SWI_PongFunc

Listing 3 shows the code for the SWI thread that filtered samples in the ping array. The SWI thread for the filtering pong was not included because it was very similar. The SWI calls the myfir function designed in project 2, which used a delayline approach for implementing a FIR filter. The function took the ping array (i.e. samples 0-47 of rxPingPong), sampled all 48 samples and stored in txPingPong. To be able to switch between filters, a pointer was used to point to either the array of low-pass or high-pass coefficients and another pointer pointed to the filters' corresponding delayline array.

The ping and pong threads only ran when they had been posted by the rx HWI thread.

```

1 void SWIPingFunc(void)
2 {
3     myfir(&rxPingPong[0], filterPtr, &txPingPong[0], delayLinePtr, NX, myNH);
4 }

```

Listing 3: Ping filter SWI thread

2.6 montiorSW1

Listing 4 shows the code for the IDL thread that monitored for switch one strokes. When the thread detected a switch stroke, it disabled all SWIs and HWI ensure that a one kHz tone was played for one second without being interrupted and to prevent other samples from being transmitted with tone. The tone was generated using myNCO from project 1. Once the tone

played, both delaylines were cleared and the double buffer indexes were reset before enabling SWIs and restoring the HWIs to their previous state.

This thread would run when the HWIs and SWIs were not running and occurred sequentially with the other IDL thread.

```

1 void monitorSW1(void)
2 {
3     /* Check SW1 */
4     if(EZDSP5535_SAR_getKey( ) == SW1) // Is SW1 pressed?
5     {
6         if(sw1State) // Was previous state not pressed?
7         {
8             int16_t msec, sample;
9
10            /* Disable SWIs and HWIs — store HWI state */
11            SWI_disable( );
12            Uns oldState1 = HWI_disable( );
13
14            /* nested for loop to play 1 kHz tone for 1 sec */
15            for ( msec = 0 ; msec < 1000 ; msec++ )
16            {
17                for ( sample = 0 ; sample < 48 ; sample++ )
18                {
19                    /* call myNCO to get 1 kHz tone sample */
20                    int16_t temp = (myNCO( 1000 ) >> 5);
21
22                    /* Write 16-bit left channel Data */
23                    EZDSP5535_I2S_writeLeft( temp );
24
25                    /* Write 16-bit right channel Data */
26                    EZDSP5535_I2S_writeRight( temp );
27                }
28            }
29            /* clear phase accumulator */
30            clearPA( );
31
32            /* clear both delayLines and reset rx and tx indices */
33            memset(delayLineLPF, 0, sizeof(delayLineLPF));
34            memset(delayLineHPF, 0, sizeof(delayLineHPF));
35            rxIndex = 0;
36            txIndex = 0;
37
38            /* restore HWIs to previous state and enable SWIs */
39            HWI_restore( oldState1 );
40            SWI_enable( );
41
42            sw1State = 0; // Set state to 0 to allow only single press
43        }
44    } else // SW1 not pressed
45    {
46        sw1State = 1; // Set state to 1 to allow timer change
47    }
48 }

```

Listing 4: IDL thread for monitoring switch one strokes and playing a tone

2.7 monitorSW2

Listing 5 shows the code for the IDL thread that monitored for switch two strokes. When the thread detected a switch stroke, it checked to see if the low-pass or high-pass filter was being used and proceeded to implement the alternate filter. As mentioned, two delaylines were used because the filters differed in length, which required different length delaylines. When switching filters the new filter's delay line was cleared. This generated a brief disturbance in

the audio that was noticed if focused on trying to hear the sound. It was determined that the minor disturbance was a lower cost than the noise generated by having a single delayline or the cycles required to dump one delayline into another. Additionally, it provided an easier means of implementation. To make switching between filter and delayline arrays easier, pointer variables were used to simply point to the desired arrays.

```

1 void monitorSW2(void)
2 {
3     /* Check SW2 */
4     if(EZDSP5535_SAR_getKey( ) == SW2) // Is SW2 pressed?
5     {
6         if(sw2State) // Was previous state not pressed?
7         {
8             if(filtState) //Was previous state High-pass?
9             {
10                /* Clear Low-pass delayLine */
11                memset(delayLineLPF, 0, sizeof(delayLineLPF));
12
13                /* Point filter pointer to myLPF */
14                filterPtr = &myLPF[0];
15
16                /* Point delay line pointer to delayLineLPF */
17                delayLinePtr = &delayLineLPF[0];
18
19                /* Set myNH to number of low-pass coefficients */
20                myNH = LPF_NH;
21
22                /* Set filtState to low-pass */
23                filtState = 0;
24            } else //Was previous state low-pass
25            {
26                /* Clear high-pass delay line */
27                memset(delayLineHPF, 0, sizeof(delayLineHPF));
28
29                /* Point filter pointer to myHPF */
30                filterPtr = &myHPF[0];
31
32                /* Point delayline pointer to delayLineHPF */
33                delayLinePtr = &delayLineHPF[0];
34
35                /* Set my NH to number of high-pass coefficients */
36                myNH = HPF_NH;
37
38                /* Set filtState to high-pass */
39                filtState = 1;
40            }
41            sw2State = 0; // Set state to 0 to allow only single press
42        }
43    } else // SW2 not pressed
44    {
45        sw2State = 1; // Set state to 1 to allow tone change
46    }

```

Listing 5: IDL thread for monitoring switch two strokes and changing filters

3 Results

3.1 CPU Usage

Both the rx and the tx HWIs required 16 cycles per sample. With a 100 MHz CPU and 48 kHz codec, 2,083 cycles per sample were available; hence, each HWI used 0.77 percent of the CPU time.

The SWIs required approximately 20,000 cycles per frame of samples. At 48 samples per frame, each sample required 417 cycles and the CPU load for the SWIs was 20 percent.

3.2 Execution Graph

To implement an execution graph, a LED was turned off when the BIOS scheduler entered a thread and was turned back on when it returned from the thread. Therefore, on a logic analyzer the line was pulled high when entering a thread and pushed low when exiting. The red LED was not used because the hardware pulled the line low enough to turn off the LED but did not pull it low enough to register as low on the logic analyzer. As a result, on three threads were monitored at a time.

Figure 2 shows an execution graph of the I2S rx HWI (top), both ping and pong SWIs (middle), and both IDL threads (bottom). The HWI and the SWI graphs were similar to what was expected. As the measurement shows, every 48 times the HWI occurred another SWI was posted and the HWI continued to occur while the SWI was running. In reality, each time the tx or rx HWI occurred the SWI graph would go low since the HWIs would have higher priority. Such a graph was generated, but it was difficult to decipher the graph and the graph provided was generated instead. It was interesting to observe the amount of time that it took each IDL thread to run. As the lowest priority thread type, the IDL was continually interrupted and took longer to execut as a result. It became obvious that if too many higher priority threads were running then the IDL thread may never be reached.

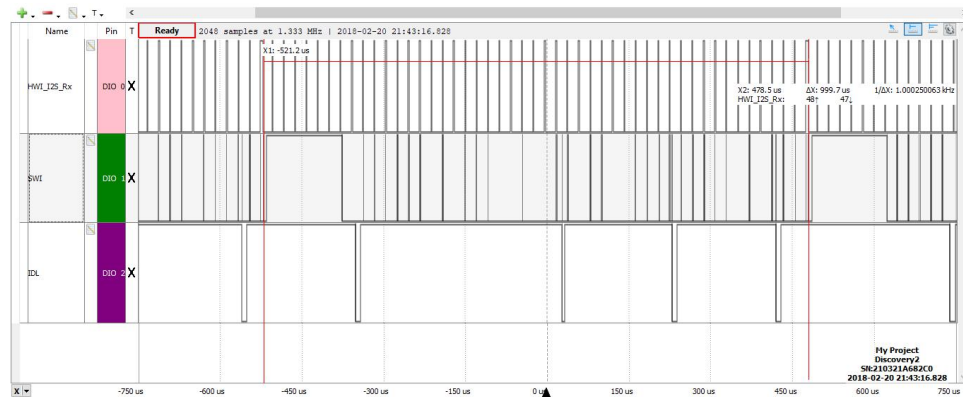


Figure 2: Execution of I2S rx HWI, ping and pong SWI, and both IDL threads

Figure 3 shows another execution graph with the I2S tx HWI (bottom) instead of the IDL threads. Note the measurement, which indicates that the HWI is clocked at the codec sampling frequency of 48 kHz as expected.

Additionally, the time between the SWI thread going high and going low was measured to 168.7 microseconds. This time corresponds to a CPU load of 16.87 percent, which varied slightly from the aforementioned CPU load.

3.3 Demonstration

The project demonstrated as expected, except for the function of the buttons. When pressing switch two, especially when pressing rapidly, the board would register the press as switch one and perform the wrong operation. After investigating the issue, it was discovered that the design of the switches is less than desirable. Switch one is connected by a 20 k Ω resistor to an

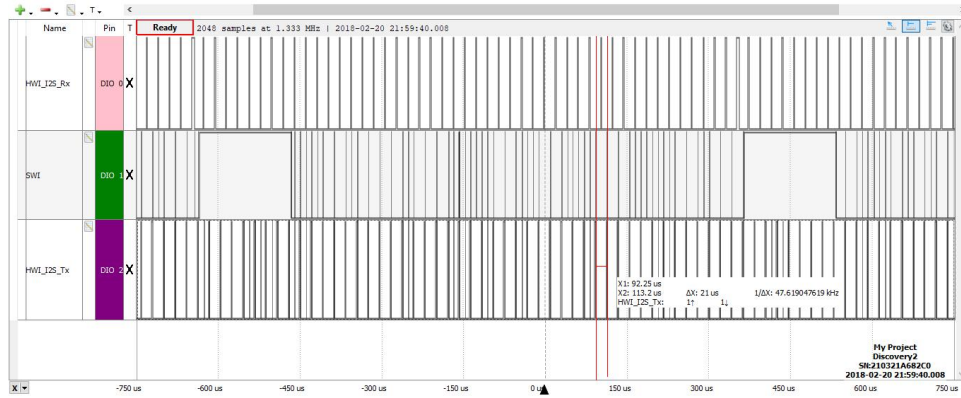


Figure 3: Execution of I2S rx HWI, ping and pong SWI, and I2S tx HWI threads

ADC and switch two is connected by a 10 k Ω resistor to the same ADC. The ADC values for switch one and two are close enough that switch two will occasionally generate a value higher than the switch one value. Therefore, the problem could not be fixed by changing the threshold values and the issue pursued no further.

4 Summary

This project introduced and showed the significance of using real-time operating systems. After completing the project, I have ideas of trying to implement RTOSs in other projects where I believe the scheduling nature may be useful and appropriate.

5 Appendix

```

1  #include <std.h>
2
3  #include <log.h>
4
5  #include "hellocfg.h"
6  #include "ezdsp5535.h"
7  #include "ezdsp5535_led.h"
8  #include "ezdsp5535_sar.h"
9  #include "ezdsp5535_i2s.h"
10 #include "csl_i2s.h"
11 #include "stdint.h"
12 #include "aic3204.h"
13
14 extern CSL_I2sHandle  hI2s;
15 extern void audioProcessingInit(void);
16
17
18 void main(void)
19 {
20     LOG_printf(&trace, "hello_world!");
21
22     /* Initialize BSL */
23     EZDSP5535_init( );
24
25     /* init LEDs and set to off*/
26     EZDSP5535_LED_init( );
27     EZDSP5535_LED_setall(0x0F);
28
29     /* init dip switches */
30     EZDSP5535_SAR_init( );
31
32     // configure the Codec chip
33     ConfigureAic3204();
34
35     /* Initialize I2S */
36     EZDSP5535_I2S_init();
37
38     /* enable the interrupt with BIOS call */
39     C55_enableInt(14); // reference technical manual, I2S2 tx interrupt
40     C55_enableInt(15); // reference technical manual, I2S2 rx interrupt
41
42     audioProcessingInit();
43
44     // after main() exits the DSP/BIOS scheduler starts
45 }

```

Listing 6: main.c

```

1  /*
2  *   Copyright 2010 by Texas Instruments Incorporated.
3  *   All rights reserved. Property of Texas Instruments Incorporated.
4  *   Restricted rights to use, duplicate or disclose this code are
5  *   granted through contract.
6  *
7  */
8  /*****
9  */
10 /*      H E L L O . C                               */
11 /*                                           */
12 /*      Basic LOG event operation from main.      */
13 /*                                           */
14 /*****
15
16 #include <std.h>
17
18 #include <log.h>
19
20 #include "stdint.h"
21 #include "string.h"
22 #include "hellocfg.h"
23 #include "ezdsp5535.h"
24 #include "ezdsp5535_gpio.h"
25 #include "ezdsp5535_led.h"
26 #include "ezdsp5535_sar.h"
27 #include "ezdsp5535_i2s.h"
28 #include "csl_i2s.h"
29 #include "csl_gpio.h"
30 #include "aic3204.h"
31 #include "filters.h"
32
33 #define NX                      48
34 #define BL_ONLY                 0x0E
35 #define YL_ONLY                 0x0D
36 #define RD_ONLY                 0x0B
37 #define GR_ONLY                 0x07
38 #define MIN(a,b) ( ((a) < (b)) ? (a) : (b) )
39
40 extern CSL_I2sHandle    hi2s;
41 extern void myfir(const int16_t* input, const int16_t* filterCoeffs,
42                  int16_t* output, int16_t* delayLine, uint16_t nx, uint16_t nh);
43 extern int16_t myNCO(uint16_t f_tone);
44 extern void clearPA(void);
45
46 int16_t rxPingPong[96];
47 int16_t txPingPong[96];
48
49 int16_t delayLineLPF[NX + LPF_NH - 1];
50 int16_t delayLineHPF[NX + HPF_NH - 1];
51
52 int16_t rxIndex;
53 int16_t txIndex;
54
55 uint16_t sw1State = 0;           // SW1 state
56 uint16_t sw2State = 0;           // SW2 state
57 uint16_t filtState = 0;          // filter state
58
59 int16_t * filterPtr;
60 int16_t * delayLinePtr;
61 uint16_t myNH;
62
63 Uint16 id1 = 0, swi = 0;
64
65 /*
66 *   audioProcessingInit
67 */

```

```

68  * @brief:      Initialize arrays used for filtering and transmitting
69  *              and initialize array indices to 0.
70  */
71  void audioProcessingInit(void)
72  {
73      /* Initialize arrays as empty*/
74      memset(txPingPong, 0, sizeof(txPingPong));
75      memset(delayLineLPF, 0, sizeof(delayLineLPF));
76      memset(delayLineHPF, 0, sizeof(delayLineHPF));
77
78      /* Initially select low-pass filter */
79      filterPtr = &myLPF[0];
80      delayLinePtr = &delayLineLPF[0];
81      myNH = LPF_NH;
82
83      /* Initialize rx and tx indices to 0 */
84      rxIndex = 0;
85      txIndex = 0;
86  }
87
88  /******
89  ***** HWIs
90  *****
91  *****/
92  /*
93  * HWI_I2S_Rx
94  *
95  * @brief:      Function handle for HWI 15. Stores received samples into a
96  *              double buffer and post SWIs to perform filtering.
97  */
98  void HWI_I2S_Rx(void)
99  {
100     /* Blue LED off */
101     EZDSP5535_GPIO_setOutput( 14, 1 );
102
103     /* Turn on yellow (SWI) and green (IDL) LED */
104     EZDSP5535_GPIO_setOutput( 15, 0 );
105     EZDSP5535_GPIO_setOutput( 17, 0 );
106
107     /* Read right sample and disregard. Read left sample and store
108     * in rxPingPong.
109     * Ping -> first 48 samples in array (0 - 47)
110     * Pong -> second 48 samples in array (48 - 97)
111     */
112     volatile int16_t temp;
113     temp = hI2s->hwRegs->I2SRXRT1;
114     rxPingPong[rxIndex++] = hI2s->hwRegs->I2SRXLT1;
115
116     if (rxIndex == 48)                //Have 48 samples been collected
117     {
118         /* Ping is full -> Post SWIPing to run SWI that will
119         * filter the ping samples.
120         */
121         SWI_post(&SWIPing);
122     }
123     if (rxIndex == 96)
124     {
125         /* Pong is full -> Post SWIPong to run SWI that will
126         * filter the pong samples. Clear rxIndex so rxPingPong
127         * will begin filling ping again.
128         */
129         SWI_post(&SWIPong);
130         rxIndex = 0;
131     }
132
133     /* Blue LED on */
134     EZDSP5535_GPIO_setOutput( 14, 1 );

```

```

135
136     /* Return yellow (SWI) and green (IDL) LED to previous state */
137     EZDSP5535_GPIO_setOutput( 15, swi );
138     EZDSP5535_GPIO_setOutput( 17, idl );
139 }
140
141 /*
142  * HWI_I2S_Tx
143  *
144  * @brief:      Function handle for HWI 14. Transmits filtered samples
145  *              from a double buffer.
146  */
147 void HWI_I2S_Tx(void)
148 {
149     //EZDSP5535_GPIO_setOutput( 17, 1 );
150
151     /* Transmit filtered samples */
152     hI2s->hwRegs->I2STXLT1 = txPingPong[txIndex];
153     hI2s->hwRegs->I2STXRT1 = txPingPong[txIndex++];
154
155     if (txIndex == 96)                //Have 96 samples been transmitted?
156     {
157         /* Set index to beginning of tx array */
158         txIndex = 0;
159     }
160
161     //EZDSP5535_GPIO_setOutput( 17, 0 );
162 }
163
164 /*****
165  *****/
166  *****/
167  *****/
168 void SWIPingFunc(void)
169 {
170     /* swi = 1 -> SWI thread is running -> turn yellow LED off */
171     swi = 1;
172     EZDSP5535_GPIO_setOutput( 15, swi );
173
174     /* Turn green (IDL) LED on */
175     EZDSP5535_GPIO_setOutput( 17, 1 );
176
177     /* Filter a frame of 48 received samples and store output in tx buffer
178      * using my fir. Variables filterPtr and delayLinePtr point to the desired
179      * filter (LPF or HPF) and it's corresponding delayline (selected in second IDL
180      * thread).
181      */
182     myfir(&rxPingPong[0], filterPtr, &txPingPong[0], delayLinePtr, NX, myNH);
183
184     //
185     swi = 0;
186     EZDSP5535_GPIO_setOutput( 15, 0 );
187     EZDSP5535_GPIO_setOutput( 17, idl );
188 }
189
190 void SWIPongFunc(void)
191 {
192     //
193     swi = 1;
194     EZDSP5535_GPIO_setOutput( 15, 1 );
195     EZDSP5535_GPIO_setOutput( 17, 0 );
196
197     /* Filter a frame of 48 received samples and store output in tx buffer
198      * using my fir. Variables filterPtr and delayLinePtr point to the desired
199      * filter (LPF or HPF) and it's corresponding delayline (selected in second IDL
200      * thread).
201      */
202     myfir(&rxPingPong[48], filterPtr, &txPingPong[48], delayLinePtr, NX, myNH);

```

```

202     /* swi = 0 -> SWI thread finished -> turn yellow LED on */
203     swi = 0;
204     EZDSP5535_GPIO_setOutput( 15, 0 );
205
206     /* return green (IDL) LED to previous state */
207     EZDSP5535_GPIO_setOutput( 17, idl );
208 }
209
210 /*****
211     IDLs
212     *****/
213
214 void monitorSW1(void)
215 {
216     /* idl = 1 -> IDL thread running -> turn green LED off */
217     idl = 1;
218     EZDSP5535_GPIO_setOutput( 17, 1 );
219
220     /* Check SW1 */
221     if(EZDSP5535_SAR_getKey( ) == SW1) // Is SW1 pressed?
222     {
223         if(swiState) // Was previous state not pressed?
224         {
225             int16_t msec, sample;
226
227             /* Disable SWIs and HWIs — store HWI state */
228             SWI_disable( );
229             Uns oldState1 = HWI_disable( );
230
231             /* nested for loop to play 1 kHz tone for 1 sec */
232             for ( msec = 0 ; msec < 1000 ; msec++ )
233             {
234                 for ( sample = 0 ; sample < 48 ; sample++ )
235                 {
236                     /* call myNCO to get 1 kHz tone sample */
237                     int16_t temp = (myNCO( 1000 ) >> 5);
238
239                     /* Write 16-bit left channel Data */
240                     EZDSP5535_I2S_writeLeft( temp );
241
242                     /* Write 16-bit right channel Data */
243                     EZDSP5535_I2S_writeRight( temp );
244                 }
245             }
246             /* clear phase accumulator */
247             clearPA( );
248
249             /* clear both delayLines and reset rx and tx indices */
250             memset(delayLineLPF, 0, sizeof(delayLineLPF));
251             memset(delayLineHPF, 0, sizeof(delayLineHPF));
252             rxIndex = 0;
253             txIndex = 0;
254
255             /* restore HWIs to previous state and enable SWIs */
256             HWI_restore( oldState1 );
257             SWI_enable( );
258
259             swiState = 0; // Set state to 0 to allow only single press
260         }
261     } else // SW1 not pressed
262     {
263         swiState = 1; // Set state to 1 to allow timer change
264     }
265
266     /* idl = 0 -> IDL thread finished -> turn green LED on */
267     idl = 0;
268     EZDSP5535_GPIO_setOutput( 17, 0 );

```

```

269 }
270
271 void monitorSW2(void)
272 {
273     /* idl = 1 -> IDL thread running -> turn green LED off */
274     idl = 1;
275     EZDSP5535_GPIO_setOutput( 17, 1 );
276
277     /* Check SW2 */
278     if(EZDSP5535_SAR_getKey( ) == SW2) // Is SW2 pressed?
279     {
280         if(sw2State) // Was previous state not pressed?
281         {
282             if(filtState) //Was previous state High-pass?
283             {
284                 /* Clear Low-pass delayLine */
285                 memset(delayLineLPF, 0, sizeof(delayLineLPF));
286
287                 /* Point filter pointer to myLPF */
288                 filterPtr = &myLPF[0];
289
290                 /* Point delay line pointer to delayLineLPF */
291                 delayLinePtr = &delayLineLPF[0];
292
293                 /* Set myNH to number of low-pass coefficients */
294                 myNH = LPF_NH;
295
296                 /* Set filtState to low-pass */
297                 filtState = 0;
298             } else //Was previous state low-pass
299             {
300                 /* Clear high-pass delay line */
301                 memset(delayLineHPF, 0, sizeof(delayLineHPF));
302
303                 /* Point filter pointer to myHPF */
304                 filterPtr = &myHPF[0];
305
306                 /* Point delayline pointer to delayLineHPF */
307                 delayLinePtr = &delayLineHPF[0];
308
309                 /* Set my NH to number of high-pass coefficients */
310                 myNH = HPF_NH;
311
312                 /* Set filtState to high-pass */
313                 filtState = 1;
314             }
315             sw2State = 0; // Set state to 0 to allow only single press
316         }
317     } else // SW2 not pressed
318     {
319         sw2State = 1; // Set state to 1 to allow tone change
320     }
321
322     /* idl = 0 -> IDL thread finished -> turn green LED on */
323     idl = 0;
324     EZDSP5535_GPIO_setOutput( 17, 1 );
325 }
326
327 /*****
328 *****/
329 /*****

```

Listing 7: audioProcessing.c

```

1  /*****
2  ****                                I N C L U D E S
3  ****                                ****/
4
5  /*****
6  ****                                D E F I N I T I O N S
7  ****                                ****/
8  #define LPF_NH          126
9  #define HPF_NH          125
10 /*****
11 ****                                G L O B A L   V A R I A B L E S
12 ****                                ****/
13
14 int16_t myLPF[] =
15 {
16     -23,    -13,    -16,    -20,    -24,    -28,    -33,    -38,    -43,    -49,
17     -55,    -60,    -66,    -72,    -77,    -82,    -86,    -90,    -93,    -95,
18     -96,    -99,    -103, -106, -109, -112, -115, -118, -121, -124,
19     -126, -129, -132, -135, -138, -141, -144, -147, -150, -153,
20     -156, -159, -162, -165, -168, -171, -174, -177, -180, -183,
21     -186, -189, -192, -195, -198, -201, -204, -207, -210, -213,
22     -216, -219, -222, -225, -228, -231, -234, -237, -240, -243,
23     -246, -249, -252, -255, -258, -261, -264, -267, -270, -273,
24     -276, -279, -282, -285, -288, -291, -294, -297, -300, -303,
25     -306, -309, -312, -315, -318, -321, -324, -327, -330, -333,
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27     -366, -369, -372, -375, -378, -381, -384, -387, -390, -393,
28     -396, -399, -402, -405, -408, -411, -414, -417, -420, -423,
29     -426, -429, -432, -435, -438, -441, -444, -447, -450, -453,
30     -456, -459, -462, -465, -468, -471, -474, -477, -480, -483,
31     -486, -489, -492, -495, -498, -501, -504, -507, -510, -513,
32     -516, -519, -522, -525, -528, -531, -534, -537, -540, -543,
33     -546, -549, -552, -555, -558, -561, -564, -567, -570, -573,
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35     -606, -609, -612, -615, -618, -621, -624, -627, -630, -633,
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37     -666, -669, -672, -675, -678, -681, -684, -687, -690, -693,
38     -696, -699, -702, -705, -708, -711, -714, -717, -720, -723,
39     -726, -729, -732, -735, -738, -741, -744, -747, -750, -753,
40     -756, -759, -762, -765, -768, -771, -774, -777, -780, -783,
41     -786, -789, -792, -795, -798, -801, -804, -807, -810, -813,
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44     -876, -879, -882, -885, -888, -891, -894, -897, -900, -903,
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196    -5436, -5439, -5442, -5445, -5448, -5451, -5454, -5457, -5460, -5463,
197    -5466, -5469, -5472, -5475, -5478, -5481, -5484, -5487, -5490, -5493,
198    -5496, -5499, -5502, -5505, -5508, -5511, -5514, -5517, -5520, -5523,
199    -5526, -5529, -5532, -5535, -5538, -5541, -5544, -5547, -5550, -5553,
200    -5556, -5559, -5562, -5565, -5568, -5571, -5574, -5577, -5580, -5583,
201    -5586, -5589, -5592, -5595, -5598, -5601, -5604, -5607, -5610, -5613,
202    -5616, -5619, -5622, -5625, -5628, -5631, -5634, -5637, -5640, -5643,
203    -5646, -5649, -5652, -5655, -5658, -5661, -5664, -5667, -5670, -5673,
204    -5676, -5679, -5682, -5685, -5688, -5691, -5694, -5697, -5700, -5703,
205    -5706, -5709, -5712, -5715, -5718, -5721, -5724, -5727, -5730, -5733,
206    -5736, -5739, -5742, -5745, -5748, -5751, -5754, -5757, -5760, -5763,
207    -5766, -5769, -5772, -5775, -5778, -5781, -5784, -5787, -5790, -5793,
208    -5796, -5799, -5802, -5805, -5808, -5811, -5814, -5817, -5820, -5823,
209    -5826, -
```



```

1  /*
2  // *****
3  // *****
4  // **
5  // ** File Name: myfir.c
6  // **
7  // ** Author: David McCreight
8  // **
9  // ** Description:
10 // **
11 // **
12 // *****
13 // *****
14 */
15
16 /*****
17 ****                                I N C L U D E S
18 ****                                ****/
19
20 #include "stdint.h"
21 #include "stdio.h"
22
23 /*****
24 ****                                D E F I N I T I O N S
25 ****                                ****/
26
27 /*****
28 ****                                S T A T I C   V A R I A B L E S
29 ****                                ****/
30
31 /*****
32 ****                                G L O B A L   V A R I A B L E S
33 ****                                ****/
34
35 /*****
36 ****                                F U N C T I O N   D E F I N I T I O N S
37 ****                                ****/
38 void myfir(const int16_t* input,
39           const int16_t* filterCoeffs,
40             int16_t* output,
41             int16_t* delayLine,
42             uint16_t nx,
43             uint16_t nh)
44 {
45
46     uint16_t i;
47     uint16_t j;
48     long sum = 0;
49
50     /*
51     * Assumes delayLine length is nh - 1 + nx
52     */
53
54     // copy input samples to the delay line
55     for (i = 0; i < nx; i++)
56     {
57         delayLine[i + nh - 1] = input[i];
58     }
59
60     for (i = 0; i < nx; i++)
61     {
62         for (j = 0; j < nh; j++)
63         {
64             sum = _smacr(sum, filterCoeffs[j], delayLine[i + nh - 1 - j]);
65         }
66
67         output[i] = (int16_t)(sum >> 15);

```

```
68         sum = 0;
69     }
70
71     // Update delay line for next function call
72     for (i = 0; i < (nh - 1); i++)
73     {
74         delayLine[i] = delayLine[nx + i];
75     }
76 }
77
78 /*****
79      E N D   O F   F I L E
80 *****/
```

Listing 9: myfir.c

```

1  /*
2  // *****
3  // *****
4  // **
5  // ** File Name: myfir.c
6  // **
7  // ** Author: David McCreight
8  // **
9  // ** Description:
10 // **
11 // **
12 // *****
13 // *****
14 */
15
16 /*****
17 ****                                I N C L U D E S
18 ****                                ****/
19
20 #include "stdint.h"
21 #include "stdio.h"
22
23 /*****
24 ****                                D E F I N I T I O N S
25 ****                                ****/
26
27 /*****
28 ****                                S T A T I C   V A R I A B L E S
29 ****                                ****/
30
31 /*****
32 ****                                G L O B A L   V A R I A B L E S
33 ****                                ****/
34
35 /*****
36 ****                                F U N C T I O N   D E F I N I T I O N S
37 ****                                ****/
38 void myfir(const int16_t* input,
39           const int16_t* filterCoeffs,
40             int16_t* output,
41             int16_t* delayLine,
42             uint16_t nx,
43             uint16_t nh)
44 {
45
46     uint16_t i;
47     uint16_t j;
48     long sum = 0;
49
50     /*
51     * Assumes delayLine length is nh - 1 + nx
52     */
53
54     // copy input samples to the delay line
55     for (i = 0; i < nx; i++)
56     {
57         delayLine[i + nh - 1] = input[i];
58     }
59
60     for (i = 0; i < nx; i++)
61     {
62         for (j = 0; j < nh; j++)
63         {
64             sum = _smacr(sum, filterCoeffs[j], delayLine[i + nh - 1 - j]);
65         }
66
67         output[i] = (int16_t)(sum >> 15);

```

```
68         sum = 0;
69     }
70
71     // Update delay line for next function call
72     for (i = 0; i < (nh - 1); i++)
73     {
74         delayLine[i] = delayLine[nx + i];
75     }
76 }
77
78 /*****
79      E N D   O F   F I L E
80 *****/
```

Listing 10: myNCO.c