

# Octave Keyboard with AutoPlay

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The goal of this project was to create a simple one octave keyboard mapped to buttons with the additional capability to autoplay “Kids” by MGMT when a switch is turned on. When the buttons corresponding to notes are pressed, the appropriate notes are played through the speaker, and LEDs which correspond to the keys light up. The LEDs can be disabled using a switch.

This project was created by Vivian Hu and Daniel Chen in Summer 2014 at Dartmouth College for the Digital Electronics (ENGS031/COSC056) course. This report goes over the implementation, design, and usage of the final product, which implements all of these features.

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# 1 Introduction: The Problem

The problem that this project solves is the creation of a one-octave keyboard, and the ability to produce certain sounds through circuit logic. An additional issue is representing the song that will be autoplayed.

## 2 Design Solution

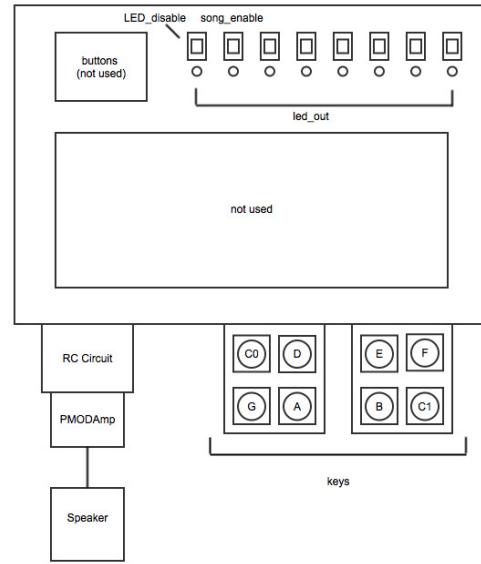
### 2.1 Specifications

The inputs to this circuit are:

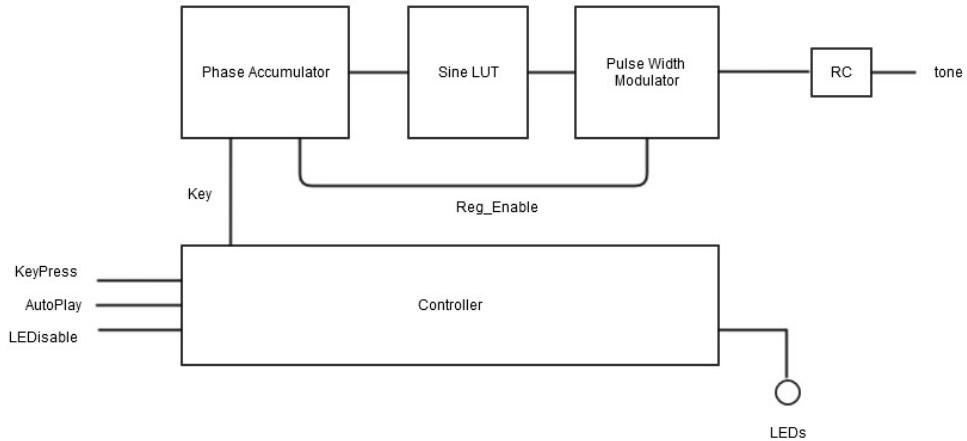
- 8 Buttons that map to the notes to play (bottom right of image to the right).
- An LED disable switch which disables LED output.
- An AutoPlay switch which enables the playing of “Kids” by MGMT.

The outputs to the circuit are:

- 8 LEDs which correspond to the notes being played.
- A speaker which outputs the notes appropriate to the song or specified by the keys.



The picture shown below displays the datapath and control of the circuit. The controller (a finite state machine) takes in all of the inputs and outputs the LEDs. It emits a signal corresponding to the note that needs to be output (a copy of the LED output) which is the Phase Accumulator receives. The data from the Phase Accumulator transfers to the Sine LUT, which goes to the Pulse Width Modulator...



## 2.2 Operating Instructions

### Set up Circuit

To set up the one-octave keyboard circuit, you will need:

- Xilinx ISE Design Suite 14.4
- Digilent Adept
- The source code or the programming file
- 1 x Digilent NEXYS 3 Spartan 6 FPGA
- 2 x 4 button Digilent Button Module
- 1 x Digilent PmodBB
- 1 x Digilent PmodAMP2
- 1 x Speaker

Here are the steps to get the circuit running:

1. (If no bit file) Open the project in Xilinx, generate the programming file.
2. Plug in FPGA (NEXYS 3 Spartan 6) into computer.
3. Insert Digilent Button Modules in the top of JA1 and the top of JB1 on the NEXYS 3.
4. Insert the Digilent PmodBB into JD1.
5. Insert the PmodAMP2 into the top of J4 on the PmodBB.
6. Connect the speaker to J2 on PmodAMP2.
7. Set up the RC circuit on the PmodBB.
8. Open Digilent Adept, select bit file to program the FPGA.

### Playing notes

To play notes, press the buttons on the FPGA corresponding to the notes that you want to play. There are two rows of four buttons. The top four buttons represent low c, d, e and f, while the bottom four buttons are g, a, b and high c.

Only one note can be played at a time (first note pressed takes priority), and user-inputted notes only play when the auto-play switch is off.

### **Auto-play “Kids” by MGMT**

To play “Kids” by MGMT, simply flip the AutoPlay switch on. You cannot create additional notes at this time using the buttons.

### **Disable LEDs**

To disable the LEDs that light up corresponding to the notes that are pressed, simply turn on the LED disable switch.

## **2.3 Theory of Operation**

The key component of our keyboard project is the generation of sine waves of varying frequencies using a technique called direct digital synthesis (DDS). To implement this, we use a combination of a phase accumulator and a sine wave lookup table (LUT) to produce wave samples of specific frequencies. In the place of a digital-to-analog converter, we use a pulse width modulator (PWM) to convert these sine wave samples to audio.

The controller of our program is a finite state machine. The controller takes in the user’s input and turns it into a single-note output for the Phase Accumulator and the LEDs. It uses the note that was input first. If two notes are both initially pressed at the same exact time, the lower note is used. When the autoplay switch gets turned on, the state machine moves into hard-coded states that play MGMT’s “Kids.” The song only starts if the user is not currently pressing a key. The song consists of a large number of states that output a time that corresponds to the length of the note or the rest, and waits for either the switch to be turned off (at which point it goes to idle) or for the beat counter to reach its max (at which point it moves to the next note or rest).

The song itself consists of 3 snippets, which repeat in a particular fashion. Given that the three parts are A, B, and C, the song is a repetition of ACACBCBC. To keep track of this, an additional counter is used to determine whether to go to A or B at the end of C. See the appendix for detailed state diagrams related to the controller.

8 different buttons (button module extensions on the FPGA), or “key” serve as the main “playable” interface of the keyboard. In VHDL, the keys are represented as an 8-bit bus input to the controller, where each bit represents a different note. Because our keyboard is monophonic, the controller checks each bit in succession from low to high C and outputs the first note it detects to the FreqLUT. As a result, only one bit in the 8-bit key\_out vector received by ToneFreq-LUT should be high at a time; otherwise, when no button is being pressed, all bits are ‘0’. This prevents conflicts when multiple buttons are pressed at once. The

controller also takes in an LED\_disable input that disables the LEDs and a song\_enable that automatically plays back a pre-programmed song (here “Kids” by MGMT).

Key\_out is then used as an index of sorts into the ToneFreq-LUT, which contains the pre-calculated phase increment values for each note, which is related to the desired frequency in the following way where N represents the bit size of the accumulator and fclk is the frequency of the clock. We use N=13 here. This increment value is then passed on to the phase accumulator.

The phase accumulator is essentially an incrementer composed of an adder and a register which increases by the increment value every clock cycle. However, although the system is running at a frequency of about 50MHz in order to reduce noise, in actuality the phase accumulator is updating at a frequency of around 10kHz, at the clk10 signal given by the PWMCounter. As a result, clk10 here serves as an enable. The phase produced by the accumulator is then passed as an input address to the SineLUT. However, because our SineLUT only takes an 8-bit phase, only the 8 most significant bits are used.

To obtain wave samples, this value is then used as an index into a SineLUT supplied by the Xilinx Core Generator. Rather than having to generate all the samples of a waveform everytime, the values of a  $2^M$  (where M is the bit size of our phase) sample wave are simply stored in block memory (BRAM) for easy access. The SineLUT generates a 10-bit sample for conversion by the PWM.

The PWM maps the amplitude of the signal to a square wave pulse by comparing the sample value (which needs to be first converted from two’s complement to unsigned offset binary) to a counter value. When the count is less than the sample, the comparator output is a ‘1’; otherwise the output is a ‘0’. In order to send the clk10 enable to the phase accumulator at a 10kHz frequency, the PWM counter also generates a terminal count signal every 5,000 clock cycles.

The signal then passes through an off-board low-pass RC filter that reduces higher frequency signal noise before passing the tone through to the speaker. One importnat thing to note is that the Pmod we used had a ‘shutdown’ signal that had to be tied high in order to output sound.

Our circuit also features the additional functionality of automatically playing a pre-programed song when given the song\_enable signal. Most of this work is done by the controller state-machine (ie which note or sequence to go to next). However, in order to get the song to play at an appropriate speed, we implemented an additional BeatCounter that counts at a rate of about 240 beats per minute. When the signal to autoplay the song is given, the controller sends a count\_en signal and a number count\_to to the beat counter letting it know how long to “hold” the note before sending the terminal tc\_tick back to the controller to move on to the next note/state.

## 2.4 Construction and Debugging

To build the circuit, we began by building and testing the VHDL modules for the PWM. We designed the counter and the comparator and simulated the generation of wave “samples” with a separate counter in the place of our DDS module. In our testbench, we were able to observe the square wave pulses getting wider as the “sample” increased as expected. From there, we implemented the phase accumulator. Testing was simply a matter of assigning an arbitrary number to the increment signal and confirming the values were adding up correctly. The next step was designing a lookup table with phase increment information for each note frequency and mapping it via the top module to the phase accumulator. We did run into a slight problem here with integer arithmetic. When trying to calculate the increment (as in equation above), dividing the desired frequency by the clock frequency first would always yield 0. To account for this, we simply multiplied the desired frequency by the phase constant ( $2^N$ ) before dividing that product by the clock frequency.

Once the main components were built and mapped together, we implemented the FSM controller, which handled the key and led outputs. From there, using a PmodBB (breadboard), we built a small low-pass RC filter; we ran into a little bit of wiring trouble because we weren’t properly wired to ground, but it was pretty easily fixed. We then passed our tone through the RC filter and were able to display our sine waveforms on the oscilloscope. Our signal was definitely a sine wave, but we discovered that our desired frequencies were a power of 10 too large. It turned out this was because we had been testbenching our programs on a 10MHz clock, even though the FPGA was running at 100MHz. Adding a clock divider and clock buffer fixed this issue. After this, we were able to generate tones at the desired frequency, but we were getting a lot of residual high frequency noise. To counter this, we upped our system clock to 50MHz from 10MHz for a higher carrier frequency. This way, even though our PWMCounter was still only sending enable signals to the phase accumulator at 10kHz, the counter itself was running at 50MHz. Adding a larger capacitor helped to significantly reduce the noise, but also the volume of the keyboard itself. Although the noise is barely perceptible now, you can still hear it slightly.

We also ran into a bug where the keyboard would be playing normally and then suddenly everything would stop. We figured some kind of metastability was occurring because we were using switches as “keys”. We noticed that the keyboard would usually stop when we held a switch between ‘0’ and ‘1’. After switching over to buttons, the problem was still occurring, but we remembered that we had forgotten to add debouncers to our buttons. This resolved our issue.

At the very end, once our keyboard was completely playable, we decided to go back in and implement

the autoplay functionality. Most of that was done by simply adding more states to the controller. The only extra component we needed was a “metronome” of sorts in the form of our BeatCounter, which counted at a rate of 4 beats per second, or 240 beats per minute. Testbenching the counter was difficult because it took the simulator so long to generate a couple standard seconds as opposed to the usual nano- or micro- seconds, but we were able to observe terminal count ticks occurring at the right time. The major issue we ran into was that the first note of the song would sometimes be cut short or get dragged out. We resolved this by adding another “idle”-like state that only occurred when the song enable went from low to high.

### 3 Evaluation of Design

Our solution is

### 4 Conclusions and Recommendations

The original goal of our project was to simply make a one-octave keyboard that plays all the notes in C major. LEDs would light up when notes were played, unless an “LED disable” switch was turned on.

At the end, we were not only able to accomplish our original goal of the simple keyboard but also to add an additional autoplay feature that played “Kids” by MGMT.

For future groups looking to create this project, we would recommend that they really take the time to understand the operation of the circuit before jumping into the project. Another important consideration is to remember to synchronize the inputs and debounce the buttons throughout the project’s creation.

## 5 Acknowledgments

We would like to thank Eric Hansen and Dave Picard for their support and mentorship throughout not only this project but also the course. We would also like to thank the other students of Digital Electronics as well as the TAs. We'd also like to thank MGMT for an awesome song that conveniently contains itself to a single octave.

5.1 and 5.2 list the contributions for each partner. Although both partners had their hands in most aspects of the project, some components generally had one partner who was more involved in its creation.

### 5.1 Vivian's Contributions

- Circuit Design
- DDS, PWM, FreqLUT, PlayCount
- RC Circuit
- Block Diagrams

### 5.2 Daniel's Contributions

- Majority of the controller, including auto-play
- Design and creation of song auto-play, state diagram
- Top level
- Diagrams
- LaTeX for report
- Git creation/management

## 6 References

- [1] Cordesses, Lionel. "Direct Digital Synthesis: A Tool for Periodic Wave Generation." *IEEE Signal Processing Magazine*. IEEE, July 2004. Web.
- [2] Hansen, Eric. *Lab Assignment 1*. N.p.: ENGS128 - Advanced Digital System Design, Spring 2011. PDF.
- [3] *Introduction to Direct Digital Synthesis*. San Jose: Intel Corporation, June 1991. PDF.
- [4] Palacheria, Amar. *Using PWM to Generate Analog Output*. N.p.: Microchip Technology Inc., 1997. PDF.

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## 7.1 System level diagrams

### 7.1.1 Front Panel

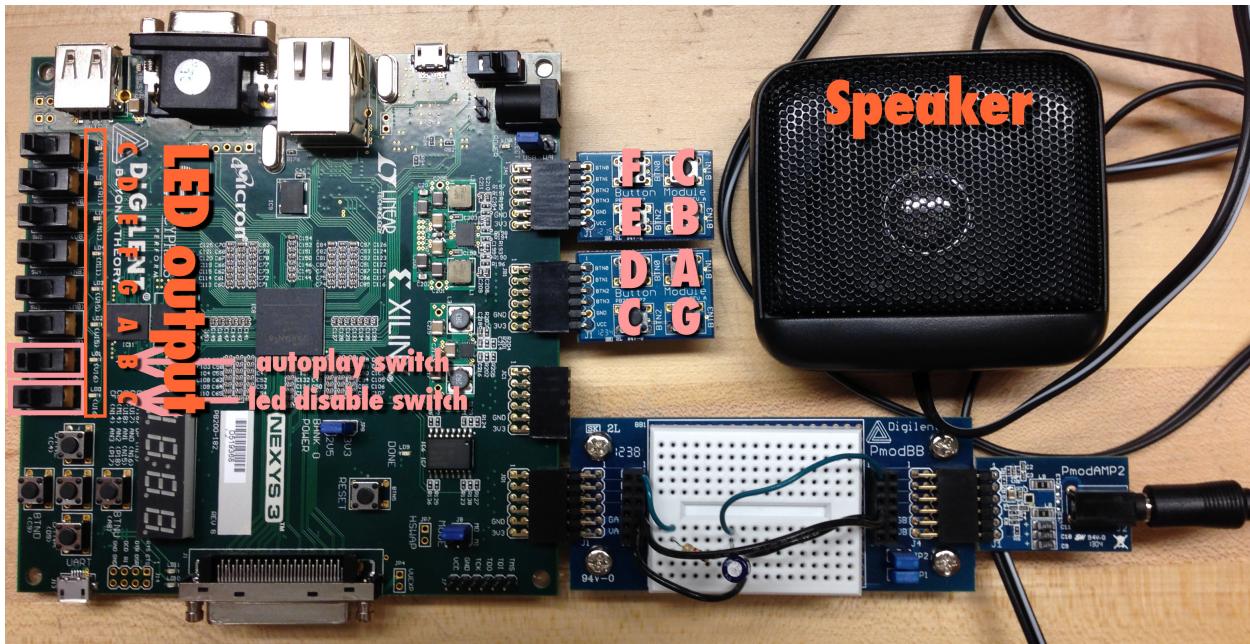


Figure 1: Annotated Digital Photo of Project

### 7.1.2 Block Diagram

### 7.1.3 Schematic Diagram

#### 7.1.4 Package Map

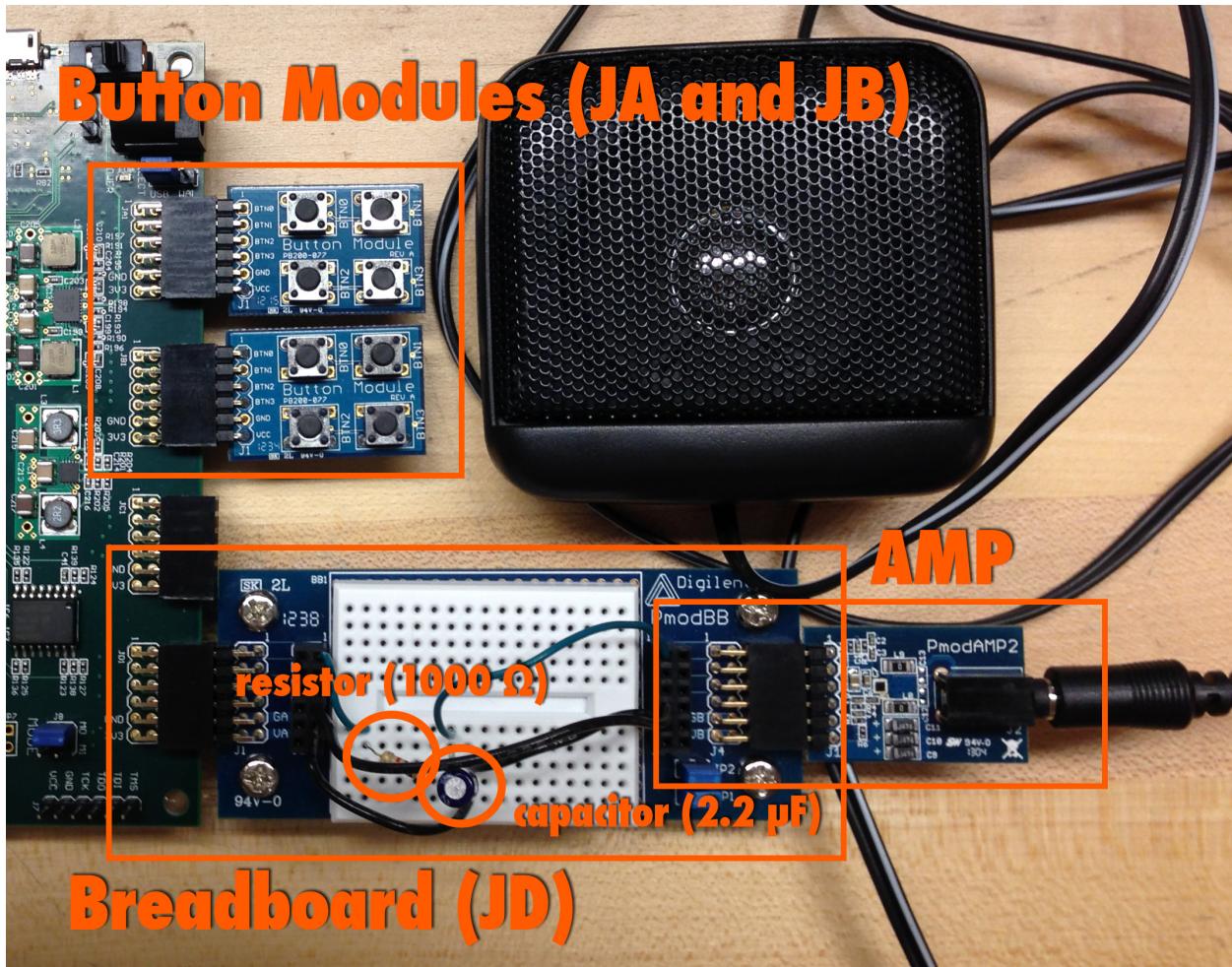


Figure 2: Package Map

#### 7.1.5 External Components

Table 1: Parts List

Reference	Quantity	Description
Nexys3	1	Digilent Nexys3 board
PmodBTN	2	Digilent PmodBTN Push Button. 4 buttons
PmodAMP2	1	Digilent Amplifier for monophonic output
PmodBB	1	Digilent Bread board
Speaker	1	Any generic speaker with standard input

## 7.2 Programmed Logic

### 7.2.1 State Diagrams

For simplicity, the state machine for this program is represented in two state diagrams. The first, “User Play State Diagram,” represents the state machine for when the user is given input through the buttons. The second, “Autoplay State Diagram,” represents the state machine when the autoplay mode is on. Both state diagrams share an idle state. If the song enable switch is off, the “User Play State Diagram” should be used. If it is turned on, the “Autoplay State Diagram” should be used.

The program starts at the idle state in the “User Play State Diagram.” If the song enable switch is turned on, the state jumps to autoidle in the “Autoplay State Diagram.” Otherwise, the state changes depending on the user’s input.

**Default Values if unspecified:**

```
next_state <= curr_state;
out <= (others => '0');
key_out <= output;
count_out <= "0001";
repeat_tick <= '0';
beat_en <= '0';
```

Figure 3: State Diagram Defaults

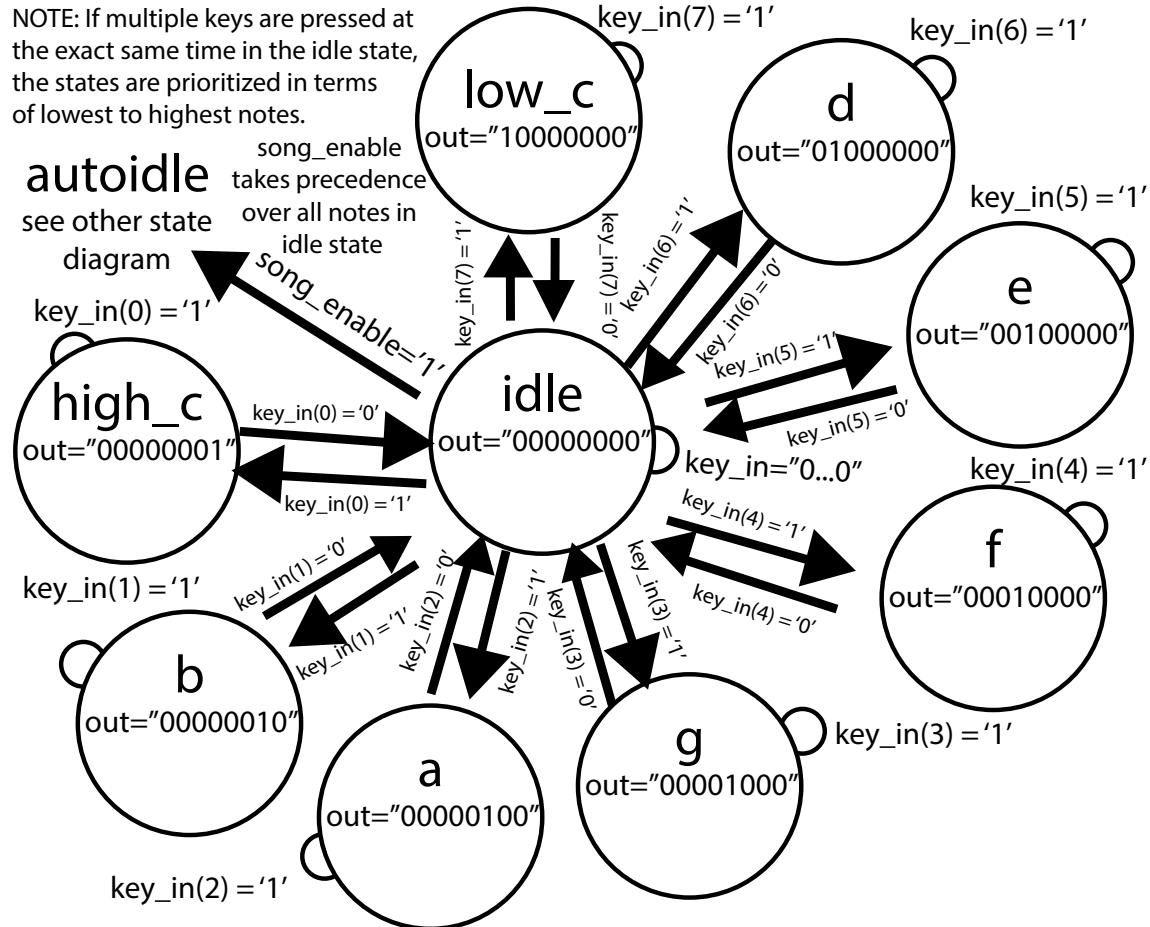


Figure 4: User Play State Diagram

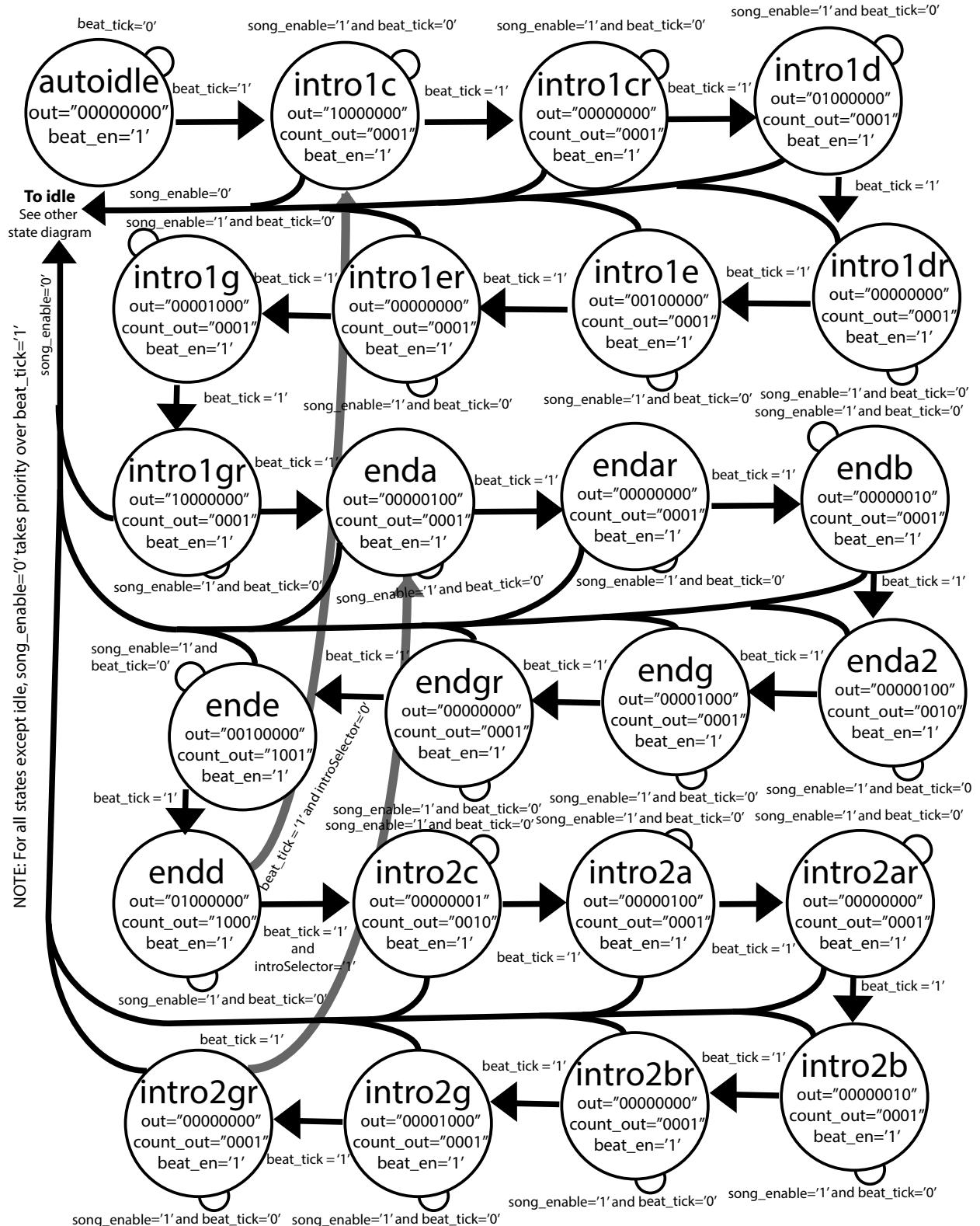


Figure 5: Autoplay State Diagram

### 7.2.2 VHDL Code

Figure 6: OctaveKeyboardTop.vhd

```
1  -----
2  -- Company: ENGS 31
3  -- Engineer: Vivian Hu, Daniel Chen
4  --
5  -- Create Date: 19:58:26 08/12/2014
6  -- Design Name:
7  -- Module Name: OctaveKeyboardTop - Behavioral
8  -- Project Name: OctaveKeyboard
9  -- Target Devices:
10 -- Tool versions:
11 -- Description: Top level VHDL module for keyboard
12 --
13 -- Dependencies:
14 --
15 -- Revision:
16 -- Revision 0.01 - File Created
17 -- Additional Comments:
18 --
19 -----
20 library IEEE;
21 use IEEE.STD_LOGIC_1164.ALL;
22 use IEEE.NUMERIC_STD.ALL;
23
24 library UNISIM;
25 use UNISIM.VComponents.all;
26
27 entity OctaveKeyboardTop is
28     Generic (    ACCUMSIZE      : integer := 13;      -- phase accumulator bitsize
29                 INDEXSIZE      : integer := 8;       -- SineLUT index bitsize
30                 LUTOUT        : integer := 10);     -- SineLUT out bitsize
31
32     Port (    clk          : in  STD_LOGIC;
33               keys         : in  STD_LOGIC_VECTOR (7 downto 0);
34               led_disable   : in  STD_LOGIC;
35               song_enable   : in  STD_LOGIC;
36               tone          : out STD_LOGIC;
37               shutdown      : out STD_LOGIC;
38               led_out       : out STD_LOGIC_VECTOR (7 downto 0));
39 end OctaveKeyboardTop;
40
41 architecture Behavioral of OctaveKeyboardTop is
42
43     -- signals for 100MHz to 50Mhz clk divider
44     signal clk_en        : std_logic := '0';
45     signal slowclk       : std_logic;
```

```

47 signal led_disable_sync : std_logic := '0';
48 signal song_enable_sync : std_logic := '0';
49
50 -- mapping signals
51 signal step : std_logic_vector(ACCUMSIZE-1 downto 0) := (others => '0');
52 signal controllerKeys : std_logic_vector(7 downto 0) := (others => '0');
53 signal phase : std_logic_vector(INDEXSIZE-1 downto 0) := (others => '0');
54 signal lutfreq : std_logic_vector(15 downto 0) := (others => '0');
55 signal reg_en : std_logic := '0';
56 signal tempo_en : std_logic := '0';
57 signal keyDB : std_logic_vector(7 downto 0) := (others => '0');
58 signal countDone : std_logic := '0';
59 signal count : std_logic_vector(3 downto 0) := (others => '0');
60
61 -- BEGIN component declarations
62 COMPONENT Controller
63     PORT ( clk : in STD_LOGIC;
64             key_in : in STD_LOGIC_VECTOR (7 downto 0);
65             led_disable : in STD_LOGIC;
66             song_enable : in STD_LOGIC;
67             beat_tick : in STD_LOGIC;
68             beat_en : out STD_LOGIC;
69             count_out : out STD_LOGIC_VECTOR(3 downto 0);
70             key_out : out STD_LOGIC_VECTOR (7 downto 0);
71             led_out : out STD_LOGIC_VECTOR (7 downto 0));
72 END COMPONENT;
73
74 COMPONENT FreqLUT
75     PORT ( clk : in STD_LOGIC;
76             key_in : in STD_LOGIC_VECTOR (7 downto 0);
77             increment : out STD_LOGIC_VECTOR (ACCUMSIZE-1 downto 0));
78 END COMPONENT;
79
80 COMPONENT DDS
81     PORT ( clk : in STD_LOGIC;
82             clk10 : in STD_LOGIC;
83             step : in STD_LOGIC_VECTOR(ACCUMSIZE-1 downto 0);
84             phase : out STD_LOGIC_VECTOR(INDEXSIZE-1 downto 0));
85 END COMPONENT;
86
87 COMPONENT PWM
88     PORT ( clk : in STD_LOGIC;
89             sample : in STD_LOGIC_VECTOR(LUTOUT-1 downto 0);
90             slowclk : out STD_LOGIC;
91             pulse : out STD_LOGIC);
92 END COMPONENT;
93
94 COMPONENT SinLUT
95     PORT ( aclk : in STD_LOGIC;
96             s_axis_phase_tvalid : in STD_LOGIC;
97             s_axis_phase_tdata : in STD_LOGIC_VECTOR(7 DOWNTO 0);
98             m_axis_data_tvalid : out STD_LOGIC;

```

```

99          m_axis_data_tdata    : out STD_LOGIC_VECTOR(15 DOWNTO 0));
100 END COMPONENT;
101
102 COMPONENT debounce
103     PORT ( clk      : in      STD_LOGIC;
104             switch   : in      STD_LOGIC;
105             dbswitch : out      STD_LOGIC);
106 END COMPONENT;
107
108 COMPONENT PlayCount is
109     PORT ( clk           : in      STD_LOGIC;
110             count_en     : in      STD_LOGIC;
111             count_to     : in      STD_LOGIC_VECTOR (3 downto 0);
112             tc_tick      : out      STD_LOGIC);
113 END COMPONENT;
114 -- END component declarations
115
116 begin
117
118 -- synchronizer for auto-play-song switch input
119 SynchronizeSwitches: process(clk)
120 begin
121     if rising_edge(clk) then
122         led_disable_sync <= led_disable;
123         song_enable_sync <= song_enable;
124     end if;
125 end process SynchronizeSwitches;
126
127 -- slow main clock down by half (here: 100Mhz to 50Mhz)
128 clkDivider: process(clk)
129 begin
130     if rising_edge(clk) then
131         clk_en <= NOT(clk_en);
132     end if;
133 end process clkDivider;
134
135 -- map signals
136 shutdown <= '1';                      -- tie shutdown signal high for speaker pmod
137
138 slowclk_buf: BUFG
139     Port map ( I => clk_en,
140                 0 => slowclk );
141
142
143 debouncer0: debounce
144     Port map ( clk => slowclk,
145                 switch => keys(0),
146                 dbswitch => keyDB(0) );
147
148 debouncer1: debounce
149     Port map ( clk => slowclk,

```

```

150         switch => keys(1),
151         dbswitch => keyDB(1) );
152
153 debouncer2: debounce
154     Port map ( clk => slowclk,
155                 switch => keys(2),
156                 dbswitch => keyDB(2) );
157
158 debouncer3: debounce
159     Port map ( clk => slowclk,
160                 switch => keys(3),
161                 dbswitch => keyDB(3) );
162
163 debouncer4: debounce
164     Port map ( clk => slowclk,
165                 switch => keys(4),
166                 dbswitch => keyDB(4) );
167
168 debouncer5: debounce
169     Port map ( clk => slowclk,
170                 switch => keys(5),
171                 dbswitch => keyDB(5) );
172
173 debouncer6: debounce
174     Port map ( clk => slowclk,
175                 switch => keys(6),
176                 dbswitch => keyDB(6) );
177
178 debouncer7: debounce
179     Port map ( clk => slowclk,
180                 switch => keys(7),
181                 dbswitch => keyDB(7) );
182
183 KeyControl: Controller
184     PORT MAP ( clk          => slowclk,
185                 key_in       => keys, -- change to keys if simulating
186                 led_disable  => led_disable_sync,
187                 song_enable  => song_enable_sync,
188                 beat_tick    => countdone,
189                 beat_en      => tempo_en,
190                 count_out    => count,
191                 key_out      => controllerKeys,
192                 led_out      => led_out);
193
194 KeyFrequencies: FreqLUT
195     PORT MAP ( clk          => slowclk,
196                 key_in       => controllerKeys,
197                 increment   => step);
198
199 PhaseAccum: DDS
200     PORT MAP ( clk          => slowclk,

```

```

201          clk10      => reg_en,
202          step       => step,
203          phase      => phase);

204
205 PulseWM: PWM
206     PORT MAP ( clk           => slowclk,
207                 sample        => lutfreq(9 downto 0),
208                 slowclk      => reg_en,
209                 pulse         => tone);

210
211 SinFreqs: SinLUT
212     PORT MAP ( aclk          => slowclk,
213                 s_axis_phase_tvalid => '1',
214                 s_axis_phase_tdata   => phase,
215                 m_axis_data_tvalid  => open,
216                 m_axis_data_tdata   => lutfreq);

217
218 kidsCounter: PlayCount
219     PORT MAP ( clk => slowclk,
220                 count_en => tempo_en,
221                 count_to => count,
222                 tc_tick => countDone);

223
224 end Behavioral;

```

---

Figure 7: Controller.vhd

```
1  -----
2  -- Company: ENGS041 14X
3  -- Engineer: Vivian Hu and Daniel Chen
4  --
5  -- Create Date: 14:49:26 08/11/2014
6  -- Design Name: Controller FSM
7  -- Module Name: Controller - Behavioral
8  -- Project Name: Octave Keyboard
9  -- Target Devices: Spartan 6
10 -- Tool versions:
11 -- Description: Basic controller which converts to monotone.
12 --
13 -- Dependencies:
14 --
15 -- Revision:
16 -- Revision 0.01 - File Created
17 -- Additional Comments:
18 --
19 -----
20 library IEEE;
21 use IEEE.STD_LOGIC_1164.ALL;
22 use IEEE.NUMERIC_STD.ALL;
23
24 entity Controller is
25     Port ( clk         : in  STD_LOGIC;
26             key_in      : in  STD_LOGIC_VECTOR(7 downto 0);
27             led_disable : in  STD_LOGIC;
28             song_enable : in  STD_LOGIC;
29             beat_tick   : in  STD_LOGIC;
30             beat_en     : out STD_LOGIC;
31             count_out   : out STD_LOGIC_VECTOR(3 downto 0);
32             key_out     : out STD_LOGIC_VECTOR(7 downto 0);
33             led_out     : out STD_LOGIC_VECTOR(7 downto 0));
34 end Controller;
35
36 architecture Behavioral of Controller is
37     type statetype is (idle, low_c, d, e, f, g, a, b, high_c, autoidle,
38                         intro1c, intro1cr, intro1d, intro1dr, intro1e, intro1er, intro1g, intro1gr,
39                         enda, endar, endb, enda2, endg, endgr, ende, endd,
40                         intro2c, intro2a, intro2ar, intro2b, intro2br, intro2g, intro2gr
41                     );
42     signal curr_state, next_state : statetype := idle;
43     signal output : STD_LOGIC_VECTOR (7 downto 0) := (others => '0');
44     signal reps : STD_LOGIC := '1';
45     signal introSelector : STD_LOGIC := '0';
46     signal repeat_tick : STD_LOGIC := '0';
47 begin
48     StateUpdate: process(clk)
49
```

```

50      begin
51          if rising_edge(clk) then
52              curr_state <= next_state;
53          end if;
54      end process StateUpdate;
55
56  CombLogic: process(curr_state, next_state, key_in, led_disable, output,
57                      beat_tick, song_enable, introSelector)
58  begin
59      -- defaults
60      next_state <= curr_state;
61      output <= (others => '0');
62      key_out <= output;
63      count_out <= "0001";
64      repeat_tick <= '0';
65      beat_en <= '0';
66
67      if (led_disable = '1') then
68          led_out <= (others => '0');
69      else
70          led_out <= output;
71      end if;
72
73      case curr_state is
74
75          when idle =>
76
77              if song_enable = '1' then
78                  next_state <= autoidle;
79              elsif key_in(7) = '1' then
80                  next_state <= low_c;
81              elsif key_in(6) = '1' then
82                  next_state <= d;
83              elsif key_in(5) = '1' then
84                  next_state <= e;
85              elsif key_in(4) = '1' then
86                  next_state <= f;
87              elsif key_in(3) = '1' then
88                  next_state <= g;
89              elsif key_in(2) = '1' then
90                  next_state <= a;
91              elsif key_in(1) = '1' then
92                  next_state <= b;
93              elsif key_in(0) = '1' then
94                  next_state <= high_c;
95              else
96                  next_state <= idle;
97              end if;
98
99          when low_c =>
100             output <= "10000000";
101             if key_in(7) = '0' then

```

```

102          next_state <= idle;
103      end if;
104
105      when d =>
106          output <= "01000000";
107          if key_in(6) = '0' then
108              next_state <= idle;
109          end if;
110
111      when e =>
112          output <= "00100000";
113          if key_in(5) = '0' then
114              next_state <= idle;
115          end if;
116
117      when f =>
118          output <= "00010000";
119          if key_in(4) = '0' then
120              next_state <= idle;
121          end if;
122
123      when g =>
124          output <= "00001000";
125          if key_in(3) = '0' then
126              next_state <= idle;
127          end if;
128
129      when a =>
130          output <= "00000100";
131          if key_in(2) = '0' then
132              next_state <= idle;
133          end if;
134
135      when b =>
136          output <= "00000010";
137          if key_in(1) = '0' then
138              next_state <= idle;
139          end if;
140
141      when high_c =>
142          output <= "00000001";
143          if key_in(0) = '0' then
144              next_state <= idle;
145          end if;
146
147      when autoidle =>
148          beat_en <= '1';
149          output <= (others => '0');
150          if (beat_tick = '1') then
151              next_state <= intro1c;
152          end if;
153

```

```

154     when intro1c =>
155         beat_en <= '1';
156         output <= "10000000";
157         count_out <= "0001";
158         if (song_enable = '0') then
159             next_state <= idle;
160         elsif(beat_tick = '1') then
161             next_state <= intro1cr;
162         end if;
163
164
165     when intro1cr =>
166         beat_en <= '1';
167         output <= "00000000";
168         count_out <= "0001";
169         if (song_enable = '0') then
170             next_state <= idle;
171         elsif(beat_tick = '1') then
172             next_state <= intro1d;
173         end if;
174
175
176     when intro1d =>
177         beat_en <= '1';
178         output <= "01000000";
179         count_out <= "0001";
180         if (song_enable = '0') then
181             next_state <= idle;
182         elsif(beat_tick = '1') then
183             next_state <= intro1dr;
184         end if;
185
186
187     when intro1dr =>
188         beat_en <= '1';
189         output <= "00000000";
190         count_out <= "0001";
191         if (song_enable = '0') then
192             next_state <= idle;
193         elsif(beat_tick = '1') then
194             next_state <= intro1e;
195         end if;
196
197
198     when intro1e =>
199         beat_en <= '1';
200         output <= "00100000";
201         count_out <= "0001";
202         if (song_enable = '0') then
203             next_state <= idle;
204         elsif(beat_tick = '1') then
205             next_state <= intro1er;

```

```

206     end if;
207
208
209     when intro1er =>
210         beat_en <= '1';
211         output <= "00000000";
212         count_out <= "0001";
213         if (song_enable = '0') then
214             next_state <= idle;
215         elsif(beat_tick = '1') then
216             next_state <= intro1g;
217         end if;
218
219
220     when intro1g =>
221         beat_en <= '1';
222         output <= "00001000";
223         count_out <= "0001";
224         if (song_enable = '0') then
225             next_state <= idle;
226         elsif(beat_tick = '1') then
227             next_state <= intro1gr;
228         end if;
229
230
231     when intro1gr =>
232         beat_en <= '1';
233         output <= "00000000";
234         count_out <= "0001";
235         if (song_enable = '0') then
236             next_state <= idle;
237         elsif(beat_tick = '1') then
238             next_state <= enda;
239         end if;
240
241
242     when enda =>
243         beat_en <= '1';
244         output <= "00000100";
245         count_out <= "0001";
246         if (song_enable = '0') then
247             next_state <= idle;
248         elsif(beat_tick = '1') then
249             next_state <= endar;
250         end if;
251
252
253     when endar =>
254         beat_en <= '1';
255         output <= "00000000";
256         count_out <= "0001";
257         if (song_enable = '0') then

```

```

258         next_state <= idle;
259     elsif(beat_tick = '1') then
260         next_state <= endb;
261     end if;
262
263
264     when endb =>
265         beat_en <= '1';
266         output <= "00000010";
267         count_out <= "0001";
268         if (song_enable = '0') then
269             next_state <= idle;
270         elsif(beat_tick = '1') then
271             next_state <= enda2;
272         end if;
273
274
275     when enda2 =>
276         beat_en <= '1';
277         output <= "00000100";
278         count_out <= "0010";
279         if (song_enable = '0') then
280             next_state <= idle;
281         elsif(beat_tick = '1') then
282             next_state <= endg;
283         end if;
284
285
286     when endg =>
287         beat_en <= '1';
288         output <= "00001000";
289         count_out <= "0001";
290         if (song_enable = '0') then
291             next_state <= idle;
292         elsif(beat_tick = '1') then
293             next_state <= endgr;
294         end if;
295
296
297     when endgr =>
298         beat_en <= '1';
299         output <= "00000000";
300         count_out <= "0001";
301         if (song_enable = '0') then
302             next_state <= idle;
303         elsif(beat_tick = '1') then
304             next_state <= ende;
305         end if;
306
307
308     when ende =>
309         beat_en <= '1';

```

```

310         output <= "00100000";
311         count_out <= "1001";
312         if (song_enable = '0') then
313             next_state <= idle;
314         elsif(beat_tick = '1') then
315             next_state <= endd;
316         end if;
317
318
319     when endd =>
320         beat_en <= '1';
321         output <= "01000000";
322         count_out <= "1000";
323
324         if (beat_tick = '1') then
325             repeat_tick <= '1';
326
327             if (introSelector = '0') then
328                 next_state <= intro1c;
329             else
330                 next_state <= intro2c;
331             end if;
332
333         elsif (song_enable = '0') then
334             next_state <= idle;
335
336         end if;
337
338     when intro2c =>
339         beat_en <= '1';
340         output <= "00000001";
341         count_out <= "0010";
342         if (song_enable = '0') then
343             next_state <= idle;
344         elsif(beat_tick = '1') then
345             next_state <= intro2a;
346         end if;
347
348
349     when intro2a =>
350         beat_en <= '1';
351         output <= "00000100";
352         count_out <= "0001";
353         if (song_enable = '0') then
354             next_state <= idle;
355         elsif(beat_tick = '1') then
356             next_state <= intro2ar;
357         end if;
358
359
360     when intro2ar =>
361         beat_en <= '1';

```

```

362         output <= "00000000";
363         count_out <= "0001";
364         if (song_enable = '0') then
365             next_state <= idle;
366         elsif(beat_tick = '1') then
367             next_state <= intro2b;
368         end if;
369
370
371     when intro2b =>
372         beat_en <= '1';
373         output <= "00000010";
374         count_out <= "0001";
375         if (song_enable = '0') then
376             next_state <= idle;
377         elsif(beat_tick = '1') then
378             next_state <= intro2br;
379         end if;
380
381
382     when intro2br =>
383         beat_en <= '1';
384         output <= "00000000";
385         count_out <= "0001";
386         if (song_enable = '0') then
387             next_state <= idle;
388         elsif(beat_tick = '1') then
389             next_state <= intro2g;
390         end if;
391
392
393     when intro2g =>
394         beat_en <= '1';
395         output <= "00001000";
396         count_out <= "0001";
397         if (song_enable = '0') then
398             next_state <= idle;
399         elsif(beat_tick = '1') then
400             next_state <= intro2gr;
401         end if;
402
403
404     when intro2gr =>
405         beat_en <= '1';
406         output <= "00000000";
407         count_out <= "0001";
408         if (song_enable = '0') then
409             next_state <= idle;
410         elsif(beat_tick = '1') then
411             next_state <= enda;
412         end if;
413

```

```

414     when others =>
415         next_state <= idle;
416
417     end case;
418
419 end process CombLogic;
420
421 RepeatCounter: process(clk, repeat_tick, reps, introselector)
422 begin
423     if (rising_edge(clk)) then
424         if (repeat_tick = '1') then
425             if (reps = '1') then
426                 introSelector <= not introSelector;
427                 reps <= '0';
428             else
429                 reps <= not reps;
430                 end if;
431             end if;
432         end if;
433     end process RepeatCounter;
434
435 end Behavioral;

```

---

Figure 8: DDS.vhd

```
1 -----  
2 -- Company: ENGS031 14X  
3 -- Engineer: Vivian Hu and Daniel Chen  
4 --  
5 -- Create Date: 14:29:30 08/11/2014  
6 -- Design Name: Octave Keyboard  
7 -- Module Name: DDS - Behavioral  
8 -- Project Name: Octave Keyboard  
9 -- Target Devices: Spartan 6  
10 -- Tool versions:  
11 -- Description: Direct Digital Synthesis  
12 --  
13 -- Dependencies:  
14 --  
15 -- Revision:  
16 -- Revision 0.01 - File Created  
17 -- Additional Comments:  
18 --  
19 -----  
20 library IEEE;  
21 use IEEE.STD_LOGIC_1164.ALL;  
22 use IEEE.NUMERIC_STD.ALL;  
23  
24 entity DDS is  
25     Generic ( ACCUMSIZE : integer := 13;  
26                 INDEXSIZE : integer := 8;  
27                 CLKFREQ : integer := 100000000);  
28  
29     Port ( clk : in STD_LOGIC;  
30             step : in STD_LOGIC_VECTOR(ACCUMSIZE-1 downto 0);  
31             clk10 : in STD_LOGIC;  
32             phase : out STD_LOGIC_VECTOR(INDEXSIZE-1 downto 0));  
33 end DDS;  
34  
35 architecture Behavioral of DDS is  
36     signal curr_phase : unsigned(ACCUMSIZE-1 downto 0) := (others => '0');  
37 begin  
38     AccumPhase: process(clk, clk10)  
39     begin  
40         if (rising_edge(clk)) then  
41             if (clk10 = '1') then  
42                 curr_phase <= curr_phase + unsigned(step);  
43             end if;  
44         end if;  
45     end process AccumPhase;  
46  
47     phase <= std_logic_vector(curr_phase(ACCUMSIZE-1 downto ACCUMSIZE-INDEXSIZE));  
48 end Behavioral;
```

Figure 9: PWM.vhd

```
1 -----  
2 -- Company:  
3 -- Engineer:  
4 --  
5 -- Create Date: 10:13:11 08/13/2014  
6 -- Design Name:  
7 -- Module Name: PWM - Behavioral  
8 -- Project Name:  
9 -- Target Devices:  
10 -- Tool versions:  
11 -- Description:  
12 --  
13 -- Dependencies:  
14 --  
15 -- Revision:  
16 -- Revision 0.01 - File Created  
17 -- Additional Comments:  
18 --  
19 -----  
20 library IEEE;  
21 use IEEE.STD_LOGIC_1164.ALL;  
22 use IEEE.NUMERIC_STD.ALL;  
23  
24 entity PWM is  
25     Generic ( LUTOUT      : integer := 10;  
26                 CLKFREQ      : integer := 100000000);  
27  
28     Port ( clk : in STD_LOGIC;  
29             sample : in STD_LOGIC_VECTOR(LUTOUT-1 downto 0);  
30             slowclk : out STD_LOGIC;  
31             pulse : out STD_LOGIC);  
32 end PWM;  
33  
34 architecture Behavioral of PWM is  
35     signal count : unsigned(13 downto 0) := (others => '0');  
36     signal offset : unsigned(LUTOUT-1 downto 0) := (others => '0');  
37     constant max : unsigned(13 downto 0) := "01001110001000";  
38 begin  
39  
40     PWM: process(clk, sample)  
41     begin  
42         -- SinLUT output from two's complement to unsigned offset binary  
43         offset <= unsigned(not sample(LUTOUT-1) & sample(LUTOUT-2 downto 0));  
44  
45         if (rising_edge(clk)) then  
46  
47             -- counter running at 50Mhz, but register updating at 10khz  
48             count <= count + 1;  
49
```

```
50      if (count(9 downto 0) < offset) then
51          pulse <= '1';
52      else
53          pulse <= '0';
54      end if;
55
56      if (count = max) then
57          slowclk <= '1';
58          count <= (others => '0');
59      else
60          slowclk <= '0';
61      end if;
62      end if;
63  end process PWM;
64 end Behavioral;
```

---

Figure 10: PlayCount.vhd

```
1  -----
2  -- Company:
3  -- Engineer:
4  --
5  -- Create Date: 11:40:24 08/16/2014
6  -- Design Name:
7  -- Module Name: PlayCount - Behavioral
8  -- Project Name:
9  -- Target Devices:
10 -- Tool versions:
11 -- Description:
12 --
13 -- Dependencies:
14 --
15 -- Revision:
16 -- Revision 0.01 - File Created
17 -- Additional Comments:
18 --
19 -----
20 library IEEE;
21 use IEEE.STD_LOGIC_1164.ALL;
22 use IEEE.NUMERIC_STD.ALL;
23
24 entity PlayCount is
25     Port ( clk : in STD_LOGIC;
26             count_en : in STD_LOGIC;
27             count_to : in STD_LOGIC_VECTOR (3 downto 0);
28             tc_tick : out STD_LOGIC);
29 end PlayCount;
30
31 architecture Behavioral of PlayCount is
32     constant QRTR_CLK_DIV : integer := 12500000;
33     signal clkcount : integer := 0;
34     signal count : unsigned(3 downto 0) := "0001";
35 begin
36
37     Qrtr_Sec_Count: process(clk)
38     begin
39         if (rising_edge(clk)) then
40
41             if (count_en = '1') then
42                 tc_tick <= '0';
43
44                 if (clkcount = QRTR_CLK_DIV - 1) then
45                     if (count = unsigned(count_to)) then
46                         tc_tick <= '1';
47                         count <= "0001";
48                     else
49                         count <= count + 1;
```

```
50         end if;
51
52         clkcount <= 0;
53     else
54         clkcount <= clkcount + 1;
55     end if;
56 else
57     tc_tick <= '0';
58 end if;
59 end if;
60 end process Qrtr_Sec_Count;
61 end Behavioral;
```

---

Figure 11: FreqLUT.vhd

```
1 -----  
2 -- Company:  
3 -- Engineer:  
4 --  
5 -- Create Date: 15:30:42 08/11/2014  
6 -- Design Name:  
7 -- Module Name: FreqLUT - Behavioral  
8 -- Project Name:  
9 -- Target Devices:  
10 -- Tool versions:  
11 -- Description:  
12 --  
13 -- Dependencies:  
14 --  
15 -- Revision:  
16 -- Revision 0.01 - File Created  
17 -- Additional Comments:  
18 --  
19 -----  
20 library IEEE;  
21 use IEEE.STD_LOGIC_1164.ALL;  
22 use IEEE.NUMERIC_STD.ALL;  
23  
24 entity FreqLUT is  
25     Generic ( ACCUMSIZE : integer := 13;  
26                 CLKFREQ    : integer := 10000);  
27  
28     Port ( clk : in STD_LOGIC;  
29             key_in : in STD_LOGIC_VECTOR (7 downto 0);  
30             increment : out STD_LOGIC_VECTOR (ACCUMSIZE-1 downto 0));  
31 end FreqLUT;  
32  
33 architecture Behavioral of FreqLUT is  
34     constant PHASECONSTANT : integer := 2**ACCUMSIZE;  
35     constant LOWC : integer := 262;  
36     constant D : integer := 294;  
37     constant E : integer := 330;  
38     constant F : integer := 349;  
39     constant G : integer := 392;  
40     constant A : integer := 440;  
41     constant B : integer := 494;  
42     constant HIGHC : integer := 523;  
43 begin  
44  
45     getIncrement: process(key_in)  
46     begin  
47  
48         if (key_in(7) = '1') then  
49             increment <= std_logic_vector(to_unsigned(LOWC * PHASECONSTANT / CLKFREQ, ACCUMSIZE));
```

```

50      elsif (key_in(6) = '1') then
51          increment <= std_logic_vector(to_unsigned(D * PHASECONSTANT / CLKFREQ, ACCUMSIZE));
52      elsif (key_in(5) = '1') then
53          increment <= std_logic_vector(to_unsigned(E * PHASECONSTANT / CLKFREQ, ACCUMSIZE));
54      elsif (key_in(4) = '1') then
55          increment <= std_logic_vector(to_unsigned(F * PHASECONSTANT / CLKFREQ, ACCUMSIZE));
56      elsif (key_in(3) = '1') then
57          increment <= std_logic_vector(to_unsigned(G * PHASECONSTANT / CLKFREQ, ACCUMSIZE));
58      elsif (key_in(2) = '1') then
59          increment <= std_logic_vector(to_unsigned(A * PHASECONSTANT / CLKFREQ, ACCUMSIZE));
60      elsif (key_in(1) = '1') then
61          increment <= std_logic_vector(to_unsigned(B * PHASECONSTANT / CLKFREQ, ACCUMSIZE));
62      elsif (key_in(0) = '1') then
63          increment <= std_logic_vector(to_unsigned(HIGHC * PHASECONSTANT / CLKFREQ, ACCUMSIZE));
64      else
65          increment <= (others => '0');
66      end if;
67
68  end process getIncrement;
69
70 end Behavioral;

```

---

Figure 12: keyboardTB.vhd

```
1 -----  
2 -- Company:  
3 -- Engineer:  
4 --  
5 -- Create Date: 14:17:41 08/25/2014  
6 -- Design Name:  
7 -- Module Name: C:/Users/F000JW7/Desktop/octave-keyboard/OctaveKeyboard/keyboardTB.vhd  
8 -- Project Name: OctaveKeyboard  
9 -- Target Device:  
10 -- Tool versions:  
11 -- Description:  
12 --  
13 -- VHDL Test Bench Created by ISE for module: OctaveKeyboardTop  
14 --  
15 -- Dependencies:  
16 --  
17 -- Revision:  
18 -- Revision 0.01 - File Created  
19 -- Additional Comments:  
20 --  
21 -- Notes:  
22 -- This testbench has been automatically generated using types std_logic and  
23 -- std_logic_vector for the ports of the unit under test. Xilinx recommends  
24 -- that these types always be used for the top-level I/O of a design in order  
25 -- to guarantee that the testbench will bind correctly to the post-implementation  
26 -- simulation model.  
27 -----  
28 LIBRARY ieee;  
29 USE ieee.std_logic_1164.ALL;  
30  
31 ENTITY keyboardTB IS  
32 END keyboardTB;  
33  
34 ARCHITECTURE behavior OF keyboardTB IS  
35  
36     -- Component Declaration for the Unit Under Test (UUT)  
37  
38     COMPONENT OctaveKeyboardTop  
39     PORT(  
40         clk : IN  std_logic;  
41         keys : IN  std_logic_vector(7 downto 0);  
42         led_disable : IN  std_logic;  
43         song_enable : IN  std_logic;  
44         tone : OUT  std_logic;  
45         shutdown : OUT  std_logic;  
46         led_out : OUT  std_logic_vector(7 downto 0)  
47     );  
48 END COMPONENT;  
49
```

```

50
51      --Inputs
52      signal clk : std_logic := '0';
53      signal keys : std_logic_vector(7 downto 0) := (others => '0');
54      signal led_disable : std_logic := '0';
55      signal song_enable : std_logic := '0';
56
57      --Outputs
58      signal tone : std_logic;
59      signal shutdown : std_logic;
60      signal led_out : std_logic_vector(7 downto 0);
61
62      -- Clock period definitions
63      constant clk_period : time := 10 ns;
64
65 BEGIN
66
67      -- Instantiate the Unit Under Test (UUT)
68      uut: OctaveKeyboardTop PORT MAP (
69          clk => clk,
70          keys => keys,
71          led_disable => led_disable,
72          song_enable => song_enable,
73          tone => tone,
74          shutdown => shutdown,
75          led_out => led_out
76      );
77
78      -- Clock process definitions
79      clk_process :process
80      begin
81          clk <= '0';
82          wait for clk_period/2;
83          clk <= '1';
84          wait for clk_period/2;
85      end process;
86
87
88      -- Stimulus process
89      stim_proc: process
90      begin
91          -- hold reset state for 100 ns.
92          wait for 100 ns;
93
94          wait for clk_period*5;
95
96          led_disable <= '0';
97          song_enable <= '0';
98
99          keys <= "10000000";
100         wait for 250us;
101         keys <= "10001000";

```

```
102         wait for 50us;
103         keys <= "00010000";
104         wait for 200us;
105         keys <= "00100010";
106         wait for 300us;
107         led_disable <= '1';
108         wait for 200us;
109         keys <= "00000010";
110         wait for 200us;
111         keys <= "00000100";
112         wait for 200us;
113         keys <= "00001000";
114         wait for 200us;
115         keys <= "00011111";
116         led_disable <= '0';
117         wait for 50us;
118         keys <= "00000000";
119         wait for 200us;
120         keys <= "10111000";
121         song_enable <= '1';
122         wait;
123     end process;
124
125 END;
```

---

### 7.2.3 Resource utilization

Figure 13: Advanced HDL Synthesis Report

```

Macro Statistics
# Counters : 3
  14-bit up counter : 1
  32-bit up counter : 1
  4-bit up counter : 1
# Accumulators : 1
  13-bit up accumulator : 1
# Registers : 8
  Flip-Flops : 8
# Comparators : 2
  10-bit comparator greater : 1
  4-bit comparator equal : 1
# Multiplexers : 10
  1-bit 2-to-1 multiplexer : 2
  13-bit 2-to-1 multiplexer : 7
  8-bit 2-to-1 multiplexer : 1
# FSMs : 1

```

Figure 14: Device Utilization Summary

<b>Slice Logic Utilization:</b>				
Number of Slice Registers:	189	out of	18224	1%
Number of Slice LUTs:	335	out of	9112	3%
Number used as Logic:	335	out of	9112	3%
 <b>Slice Logic Distribution:</b>				
Number of LUT Flip Flop pairs used:	346			
Number with an unused Flip Flop:	157	out of	346	45%
Number with an unused LUT:	11	out of	346	3%
Number of fully used LUT-FF pairs:	178	out of	346	51%
Number of unique control sets:	20			
 <b>IO Utilization:</b>				
Number of IOs:	29			
Number of bonded IOBs:	29	out of	232	12%
IOB Flip Flops/Latches:	2			
 <b>Specific Feature Utilization:</b>				
Number of BUFG/BUFGCTRLs:	2	out of	16	12%

## 7.2.4 UCF

Figure 15: UCF file

```

## Clock signal
NET "clk" LOC = "V10" | IOSTANDARD = "LVCMOS33";
Net "clk" TNM.NET = sys_clk_pin;
TIMESPEC TS_sys_clk_pin = PERIOD sys_clk_pin 100000 kHz;

## Leds
NET "led_out<0>" LOC = "U16" | IOSTANDARD = "LVCMOS33";
NET "led_out<1>" LOC = "V16" | IOSTANDARD = "LVCMOS33";
NET "led_out<2>" LOC = "U15" | IOSTANDARD = "LVCMOS33";
NET "led_out<3>" LOC = "V15" | IOSTANDARD = "LVCMOS33";
NET "led_out<4>" LOC = "M11" | IOSTANDARD = "LVCMOS33";
NET "led_out<5>" LOC = "N11" | IOSTANDARD = "LVCMOS33";
NET "led_out<6>" LOC = "R11" | IOSTANDARD = "LVCMOS33";
NET "led_out<7>" LOC = "T11" | IOSTANDARD = "LVCMOS33";

## Switches
NET "led_disable" LOC = "T10" | IOSTANDARD = "LVCMOS33";
NET "song_enable" LOC = "T9" | IOSTANDARD = "LVCMOS33";

##JA
NET "keys<4>" LOC = "T12" | IOSTANDARD = "LVCMOS33";
NET "keys<0>" LOC = "V12" | IOSTANDARD = "LVCMOS33";
NET "keys<5>" LOC = "N10" | IOSTANDARD = "LVCMOS33";
NET "keys<1>" LOC = "P11" | IOSTANDARD = "LVCMOS33";

##JB
NET "keys<6>" LOC = "K2" | IOSTANDARD = "LVCMOS33";
NET "keys<2>" LOC = "K1" | IOSTANDARD = "LVCMOS33";
NET "keys<7>" LOC = "L4" | IOSTANDARD = "LVCMOS33";
NET "keys<3>" LOC = "L3" | IOSTANDARD = "LVCMOS33";

##JD, LX16 Die only
NET "tone" LOC = "G11" | IOSTANDARD = "LVCMOS33";
NET "shutdown" LOC = "E11" | IOSTANDARD = "LVCMOS33";

```

### 7.3 Memory Map

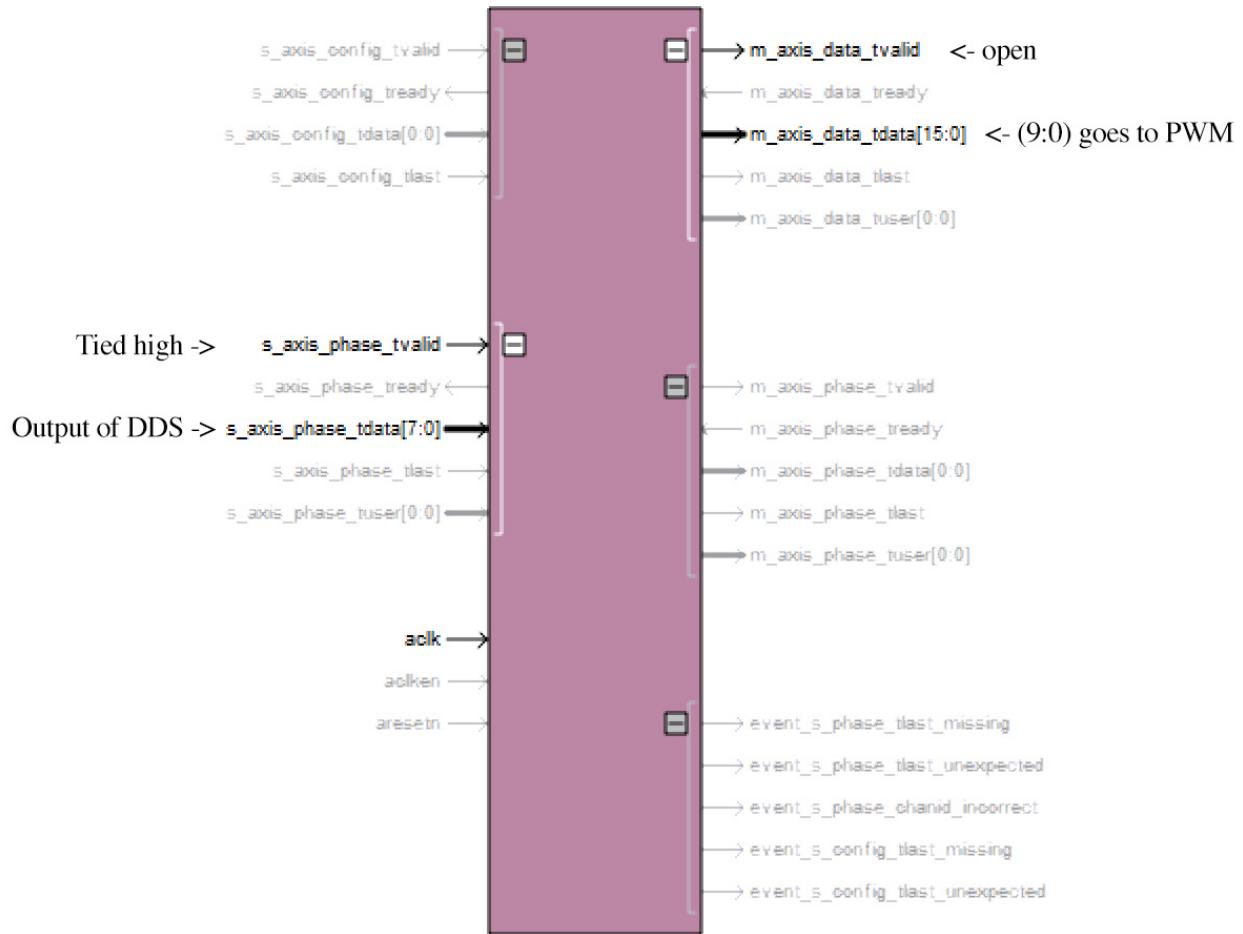


Figure 16: Memory Map for Sine LUT

## 7.4 Timing Diagram

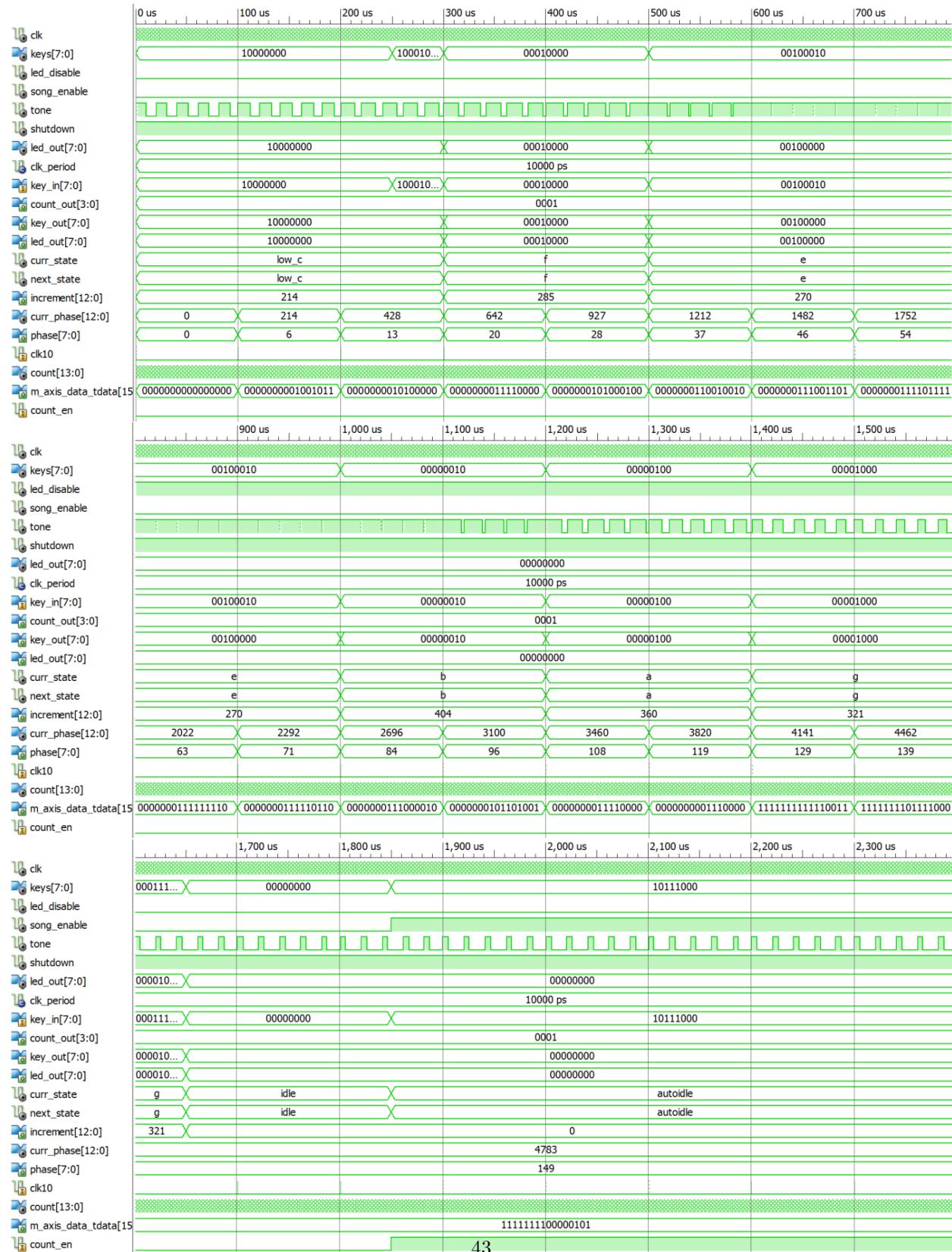


Figure 17: Timing Diagram of Test Bench

The critical path is between clkcount\_8 and clkcount\_23 in kidsCounter. The delay is 4.866ns. Here is the excerpt from the synthesis report:

```
Timing constraint: Default period analysis for Clock 'clk_en'
Clock period: 4.866ns (frequency: 205.508MHz)
Total number of paths / destination ports: 3669 / 262
```

---

Delay:	4.866 ns (Levels of Logic = 3)
Source:	kidsCounter/clkcount_8 (FF)
Destination:	kidsCounter/clkcount_23 (FF)
Source Clock:	clk_en rising
Destination Clock:	clk_en rising

Data Path: kidsCounter/clkcount\_8 to kidsCounter/clkcount\_23

Cell:in->out	fanout	Gate Delay	Net Delay	Logical Name (Net Name)
FD:C->Q	3	0.525	1.221	kidsCounter/clkcount_8 (kidsCounter/clkcount_8)
LUT6: I0->O	7	0.254	1.186	kidsCounter/GND_11_o_clkcount[31]_equal_1_o<31>4 (kidsCounter/GND_11_o_clkcount[31]_equal_1_o<31>3)
LUT5: I1->O	13	0.254	1.098	kidsCounter/_n00281 (kidsCounter/_n0028)
LUT4: I3->O	1	0.254	0.000	kidsCounter/clkcount_23_rstpot (kidsCounter/clkcount_23_rstpot)
FD:D		0.074		kidsCounter/clkcount_23
Total		4.866 ns (1.361 ns logic, 3.505 ns route)		(28.0% logic, 72.0% route)

Based on this information, the maximum clock speed for this circuit is 205.508MHz, meaning the clock period must be at least 4.866ns.

## 7.5 Data Sheets

The proceeding pages contain data sheets for parts used in this project that are not already on the class website. They include data sheets for these parts:

- PmodAMP2
- PmodBB

# PmodAMP2™ Reference Manual

Revision: August 2, 2012

Note: This document applies to REV B of the board.



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## Overview

The PmodAMP2 amplifies low power audio signals to drive a monophonic output. The module features a digital gain select that allows output at 6 dB and 12 dB with pop-and-click suppression. A Digilent 6-pin connector provides the audio input to the module and a 1/8-inch mono jack supplies the speaker output.

For customer convenience, Digilent has an inexpensive speaker and enclosure available for sale that is suitable for use with the PmodAMP2. Also, unlike most Digilent Pmod modules that accept only digital inputs, the PmodAMP2 accepts analog inputs and pulse width modulated digital inputs.

## Inputs and Outputs (I/O)

The PmodAMP2 accepts either digital or analog inputs at a voltage range of 0-Vcc. Typically a Digilent system board supplies power to the module at 3.3V, though the maximum supply voltage is 5.0V. The connector J1 provides the audio input, gain select, shutdown select, and power. (See figure 1)

There are several suitable inputs for the PmodAMP2. The typical input is a pulse width modulated (PWM) signal produced by a digital output from a Digilent programmable logic system board or microcontroller board. The low pass filter on the input acts as a reconstruction filter to convert the PWM digital signal into an analog voltage on the amplifier input.

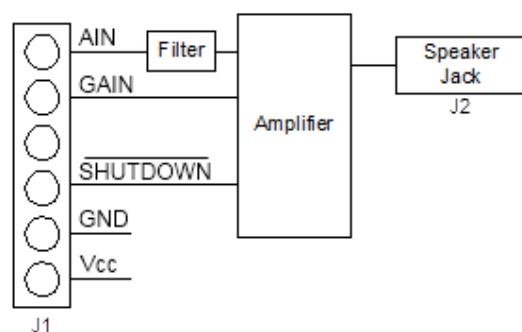
The PmodAMP2 also accepts analog inputs with an input voltage range of 0-Vcc. These inputs will often be from an analog to digital converter module, like the Digilent PmodDA1 or PmodDA2. The output of a digital to analog



### Features Include:

- Analog Devices SSM2377: Filterless, High Efficiency, Mono 2.5 Watt Class-D Audio Amplifier
- Digital gain select
- Pop -and-click suppression
- Micropower shutdown mode
- 1/8-inch mono speaker jack
- A 6-pin header for input
- 2.5V – 5V operating voltage

Figure 1



converter module will normally have a voltage range of 0-3.3V and should have a sample rate of at least 16Khz. The low pass filter on the input removes the high frequency artifacts generated during the sampling process.

Additionally, the PmodAMP2 accepts inputs from a variety of line level audio signals. A line level input, like the output of a portable CD player or MP3 player, will typically be a 1V peak-to-peak analog voltage. The input band-pass filter clarifies and amplifies the input voltage from the signal source and then directs the signal to the output jack to drive a speaker. The connector J2 operates as the speaker output. (See figure 1)

## Functional Description

The gain on the PmodAMP2 may be selected by tying the GAIN input to either logic '1' or logic '0'. (See table 1)

**Table 1**

GAIN Input	Gain
1	6 decibels (dB)
0	12 decibels (dB)

The PmodAMP2 features a micropower shutdown mode with a typical shutdown current of 100 nA. Users can enable the shutdown by applying a logic low to the SHUTDOWN pin. A10K-ohm resistor pulls the pin down to ground. To operate the AMP2 users must ensure the SHUTDOWN pin is in the highest position.

Customers will generally use the PmodAMP2 module with a Digilent programmable logic system board or microcontroller board. These boards produce either a pulse width modulated digital signal or an analog signal via a digital to analog converter. Most Digilent system boards have 6-pin connectors that allow the PmodAMP2 to plug directly into the system board or to connect via a Digilent 6-pin cable.

Some older model Digilent boards may need a Digilent Module Interface Board (MIB) and a 6-pin cable to connect to the PmodAMP2. The MIB plugs into the system board and the cable connects the PmodAMP2 to the MIB.

*Note: For more information about the operation and features of the Analog Devices SSM2377 Audio Amplifier integrated circuit please see the datasheet available at [www.analog.com](http://www.analog.com).*

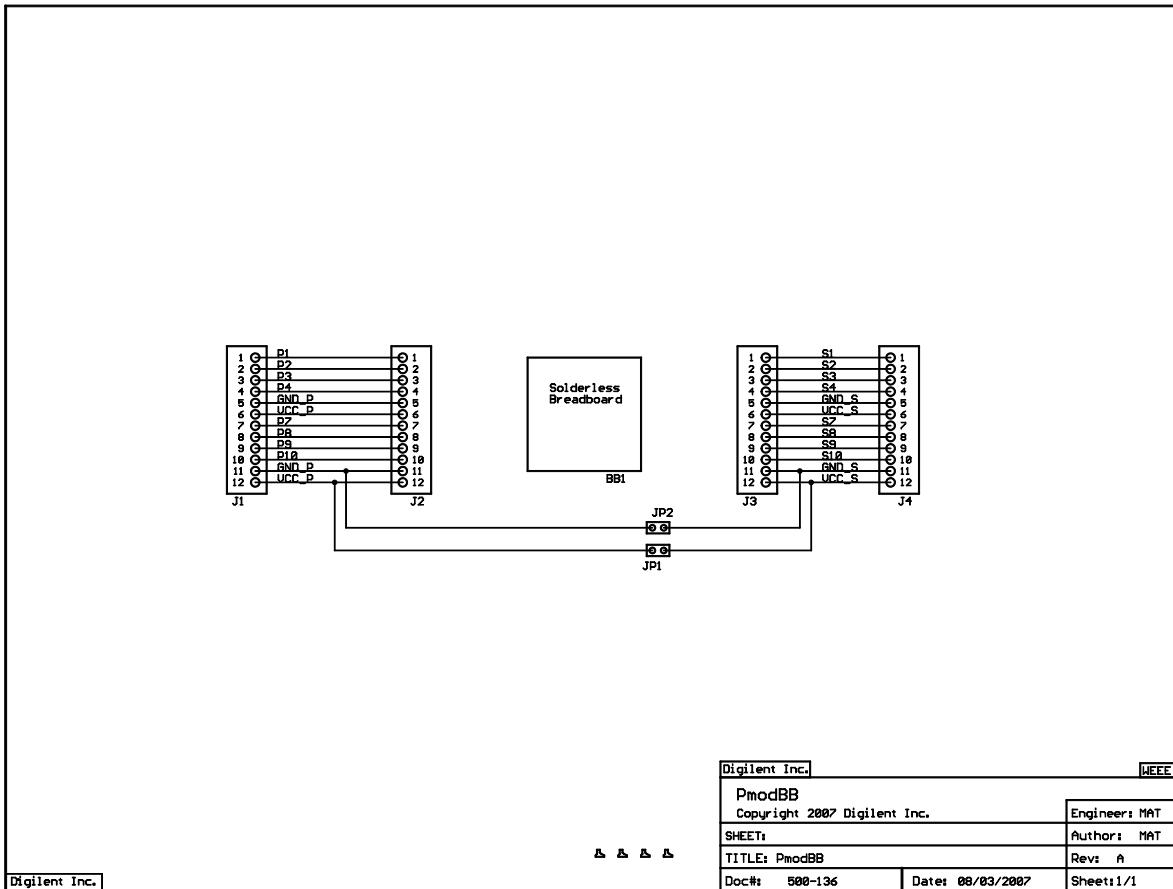


Figure 20: PmodBB Schematic