Digital Piano Keyboard Design using FPGA Implementation for Beginner

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Abstract. With the future technology and architecture, the digital musical instruments have been designed into a pack of electronic hardware and software with no strings or animal skins for producing an instruments sound. One of the musical instruments with high interest to learn by a beginner is piano. To solve this problem, this research aimed to design and development of basic digital piano keyboard using FPGA for rapid prototyping. The core of this project is keynotes which is a common input peripheral device that is connected with FPGA which is DE1-SoC-MTL2 and speaker to complete a basic learning system of piano. The architecture is designed using Verilog HDL through the Altera Quartus Prime software. Verilog has been designed to export every 13 keys to 13 certain note then implemented on DE1-SoC-MTL2. The basic system process is a keynote press is needed to activate or produce the certain piano sound. MTL2 used to display a pressed keynote. There are 13 keys in total of piano keynotes for this design where each key represents a different note or frequency to match the existing piano at the present day. The 13 different notes are low octave C, C#, D, D#, E, F, F#, G#, A#, B and high octave C basically for beginner user knowledge. All the components of the system are verified using oscilloscope. This digital piano keyboard designed on FPGA has been implemented for user beginner needs, who want to learn to play piano at very basic stage.

1. Introduction

On the eighteenth century, ascribed to Bartolomeo Cristofori, piano is a famous keyboard instrument generally operated for individual performance in westerly music and background music, and in addition as a conducive support to composing and practice session. Sound of piano produced by stroke hammers that hitting a steel strings. Vibrations of steel strings are transferred through the soundboard of piano and launched acoustically through a soundboard. The piano ever since been an essential as role model genres of music, from medieval times to present day [1]. Similar to traditional piano, another type of keyboard that designed with using electronic component as an alternative to the acoustic piano are digital piano [2]. Both of the instruments have precise composed sound and its piano give a player same feeling action. Digital piano designed to bring a traditional piano precise simulation. Digital piano designed same look alike a common piano that have a vertical or grand piano. Digital piano amplified a simulation of synthesizer or a traditional piano sample through an audio jack or built-in loudspeaker. To recreate a traditional piano feel, weighted keys are applied to digital piano.

Although digital pianos may occasionally descent sort of an actual piano in the aura and sound, it has other advantages than traditional pianos. Digital piano cost much less than a traditional piano and most digital piano models is small-scale and airy in weight than a traditional piano. In inclusion, digital
pianos are tuned needless and their tune can be adjusted to match with another instrument like a harpsichord. Same like another instruments, speaker system like a public address system (PA system) and speaker amplifier can be connected to produce a loud sound for a large area and event in a place like in hall or concert. Digital piano not only can demonstrate a piano sound, but also can be simulate the sounds of another instrument such as string sections (violin, viola), brass section (trombone, trumpet), pipe organ and many more depend on the manufacturer of the digital piano.

With the revolution of music changes, as a growth of the number of musicians in this era, they need a basic music instrument as their gear equipment to start learning. Recently, a beginner for piano keyboard, they need a quick learning to understand a piano keyboard. A beginner needs to learn a basic note along with the keynotes to play a keyboard. Some kind, they also need a portable small size piano keyboard to bring anywhere. This piano keyboard has 13 notes where it provides a middle C as a first key and it will last with high octave C key. At first sight, the beginner will allow their both hands to be free, or get used to using a single hand either left or right hand to get ready with hand flow of the note arrangement of basic melody or songs. Therefore, they will remember the note arrangement with the specific notes without hesitation.

In the previous years, there are many designs and technologies applied approaches for music keyboard using an FPGA. For example, CORDIC and Taylor Based FPGA Music Synthesizer [3] use expansion algorithms to calculate those function to generate a certain sound on synthesizer. Another project that have same concept are music synthesizer designed on FPGA [4] where variable modulating sound of instrument has been included and it can provide a wide sounds variety by different frequencies by generating and combining that signals. Another FPGA piano modelling are virtual grand piano on FPGA [5] which focusses on the utilizes FPGA to generate music notes with varying pitch and amplitude controlled by the user’s fingers. In other design, a virtual electronic piano based on FPGA has been implemented using a sampling synthesizing keyboard [6] where sampling technology used to play the samples back at different speed of frequencies and rates are formed and it has generated a samples of shifted frequency where 8 notes are generated, that might be played back at the same time. One more methodology that have been designed are FPGA piano [7] where this project used the PS2 keyboard as the keys of piano that can be tracked with using an FPGA as a central processing. This paper aim to design a portable digital piano keyboard for a beginner musician by using an FPGA DE1-SoC board as a platform to design and as a brain for processing a digital piano keyboard. FPGA process the input signal from the keyboard switches either one key pressed or more keys pressed. Next, the certain keys will trigger one of the selected frequencies of piano and thus, the outcome of certain frequency will generate via a speaker or headphone output. As a prototype will packed with 13 keynotes that can be multi pressed and MTL2 used for displaying the certain notes. Hence, the FPGA will be easier for beginners to learn anywhere and anytime.

2. Digital Piano Keyboard Design

DE1-SoC is the brain or central processing in the proposed digital piano keyboard design to produce the piano notes based on the pressed key and play the stored melody of keynotes. FPGA Cyclone V SoC started by initialization of keynotes and delay timer for booting. FPGA read any keynote input and after the certain keynote has pressed, a keynote sends a data input to FPGA for processing a data and generate a frequency. This frequency is generated based on the corresponding keys and this frequency sent via a serial I2C bus from connected Cyclone V SoC FPGA and Audio CODEC produced a piano frequency audio on the Line Out jack output. This operation then continues to proceed its objectives on producing a piano note corresponding pressed key.

In hardware section, two inputs are connected with DE1-SoC is keyboard that give a certain data notes into the processing of Cyclone V and 12VDC power supply that generate the electricity through all the board. This DE1-SoC processed the data from the keyboard and generate the certain frequency based on which key are pressed. Then the output signal produced by using a speaker or headphone. The frequency of notes verified by using an oscilloscope. The oscilloscope connected to output and display
the certain waveform based on pressed key. MTL2 give a display for pressed key and speaker produces sound of piano. Figure 1 shows the block diagram of the digital piano keyboard design.

![Digital piano keyboard IO block diagram](image)

**Figure 1.** Digital piano keyboard IO block diagram

### 3. Hardware prototype

The design of the prototype must be done in an environment of portable and user-friendly. The keyboard that holds the 13 notes is placed in front where the beginner user can play freely in the keynotes. The prototype also has a cover for protecting the board and the circuit against the dust and water to prevent the damage of the prototype. Figure 2 show a prototype design of the digital piano keyboard designed on FPGA. The user just needs to plug the power supply and external speaker into this prototype. The USB type B cable needed for uploading the Verilog into DE1-SoC.

Internal connection for this prototype is simple as the user can disconnect and reconnected again. First, the keyboard is connected with 16 pin header of IDC connector. Then this 16 pin header is connected to DE1-SoC via 16 pin ribbon cable where at the keyboard has 16 pin header and 40 pin header at the GPIO_0 of DE1-SoC. Another GPIO_1 are connected with MTL2 to interact the processing output for displaying the GUI on MTL2. IDE cable is used to provide a high-speed signal transmission for 33 MHz video signals. ITG adapter is created to map the standard IDE pin assignment to the 2x20 GPIO interface on the FPGA boards. DE1-SoC produce the notes sound via Line Out where can be connected with speaker or headphone.

All 13 keys are located in front to make it easier for users to learn the piano notes with use of learning aspect of vision, hearing and touch. MTL2 screen are located near with keys for better visualize and DE1-SoC located at behind of the prototype for easy maintenance and upgrading.
4. Result and Analysis

Frequencies measurement using oscilloscope have been made and compared between the output notes on FPGA with the actual keyboard piano. The measured frequencies of 13 keynotes are a low octave C, C#, D, D#, E, F, F#, G, G#, A, A#, B and a high octave C. This oscilloscope measured the one over period of each notes where the frequency of notes is generated. Previously in Quartus Prime software, the assigned frequency needs to be calculated first to obtain the bit counter of each frequencies. The actual frequencies of 13 notes are referenced from measured of actual digital piano.

The bit counter has been calculated by using Equation 1, where bit counter is counter for frequency in bit number, reference clock is based on FPGA clock (for DE1-SoC is 50MHz) and frequency of notes is based on frequency of actual piano. Bit counter used as a bit of frequency for generate sampling frequency signal in digital form of signal. All 13 notes from the general piano notes have been measured to be inserted into FPGA as shown in Table 1.

\[
\text{bit counter} = \frac{\text{reference clock}}{\text{frequency of notes}} = 176
\]

| No | Note          | Bit counter (d’) | Frequency (Hz) |
|----|---------------|------------------|----------------|
| 1. | Low octave C | 191              | 261.6256       |
| 2. | C#            | 181              | 277.1826       |
| 3. | D             | 170              | 293.6648       |
| 4. | D#            | 161              | 311.127        |
| 5. | E             | 151              | 329.6276       |
| 6. | F             | 143              | 349.2282       |
| 7. | F#            | 135              | 369.9944       |
| 8. | G             | 128              | 391.9954       |
| 9. | G#            | 120              | 415.3047       |
| 10. | A             | 114              | 440            |
| 11. | A#            | 107              | 466.1638       |
| 12. | B             | 101              | 493.8833       |
The measured bit counter assign with each note in decimal number where it be encoded in hexadecimal or binary inside the FPGA platform operation. Later the assigned notes are synchronized with hardware where the keynotes represent all the notes. The output sound at DE1-SoC are produced from Cyclone V processor and PLL extract the bit counter and the bit frequency converted into analogue via Audio CODEC and to be connected with speaker or headphone on the Line Out. Oscilloscope are connected to Line Out at DE1-SoC via 3.5mm audio jack cable. The output frequencies are measured on oscilloscope to compare with actual piano either its same or different. Due to the testing equipment and external noise during the testing and measurement, the measured waveform curves of all 13 notes do not look perfect sine wave. They might be generating an imperfect sine wave or harsh sine wave. Measuring have been made from low octave C until high octave C. For example, measurement for low octave C note frequency waveform have been compared within actual digital piano and FPGA. Measurement on actual digital piano in Figure 3(a) resulting a 261.64Hz with period of 3.8220ms. Compare with FPGA measurement in Figure 3(b), result is 262.05Hz with period of 3.8160ms.

![Figure 3](image_url)

**Figure 3.** Low octave C note frequency waveform on (a) digital piano, (b) FPGA.

Table 2 show the frequency notes comparison between measured output of FPGA digital piano keyboard and actual digital piano with standard frequency of actual piano on worldwide. The overall frequency waveform measurement show that both frequency waveform from the FPGA and the piano have equivalent value as the available measurement with the reference standard sound for the piano frequency. This design used 439 from 32070 logics for logic utilization in the FGPA. On register creation, 533 registers have been used for creating the internal project flows from Cyclone V processor into hardware. FPGA pins of 108 pins has been assigned from 457 pins. This project has been using only one PLL from six PLLs. For the total block memory bits, from 4065280 block memory bits, 8192 block memory bits has been used for logic utilization.

**Table 2:** Comparison between measured output of FPGA digital piano keyboard and actual digital piano with standard frequency of actual piano

| No | Note   | Measured FPGA output (Hz) | Measured actual digital piano (Hz) | Standard piano frequency (Hz) |
|----|--------|---------------------------|-----------------------------------|------------------------------|
| 13 | High octave C | 96 | 523.2511 |                         |
5. Conclusion

As a conclusion, the digital piano keyboard system that implemented on an FPGA board has been designed. This design suitable for beginner user that have no knowledge about the piano. The proposed Digital Piano Keyboard designed on FPGA was working successfully and verified by measuring the frequencies from low octave C until high octave C, and compared with existing piano keyboard.

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