Proceedings of the 9th International Conference on Applied Informatics
Eger, Hungary, January 29–February 1, 2014. Vol. 2. pp. 57–63
doi: 10.14794/ICAI.9.2014.2.57

Multiway switching controller design using FPGA*

Szabolcs Szilágyi

Faculty of Informatics, University of Debrecen, Hungary
szilagyi.szabolcs@inf.unideb.hu

Abstract

Multiway switching has become nowadays quite frequently used in building wiring. It can be defined as an interconnection of two or more electrical switches in order to control an electrical load from more than one location. Although the electrical load is often a lamp, electrical outlets, fans, pumps, heaters or other appliances, it can also be controlled by multiway switching. However, in this paper we will deal only with lighting systems.

Special switches are required to implement the system (three-way and four-way switches) that have additional contacts, and extra wires must be run between them. In this way the light can be controlled from different spots, e.g. the top and bottom of stairs or the end of a long hallway.

Externally there is a resemblance between these switches and the standard single-pole ones. Extra connections make possible the control of a circuit from multiple locations. By connecting one or more four-way switches in-line, with three-way switches at either end, the light can be controlled from three or more locations. Toggling any switch changes the state of the light from off to on, or from on to off.

We would like to introduce a solution in this paper, based on FPGA for the mentioned system and using HDL. The aim is to attain a high level of generalization by applying any (even quite large) number of switches and lights.

Keywords: multiway switching, FPGA, controller, HDL

1. Introduction

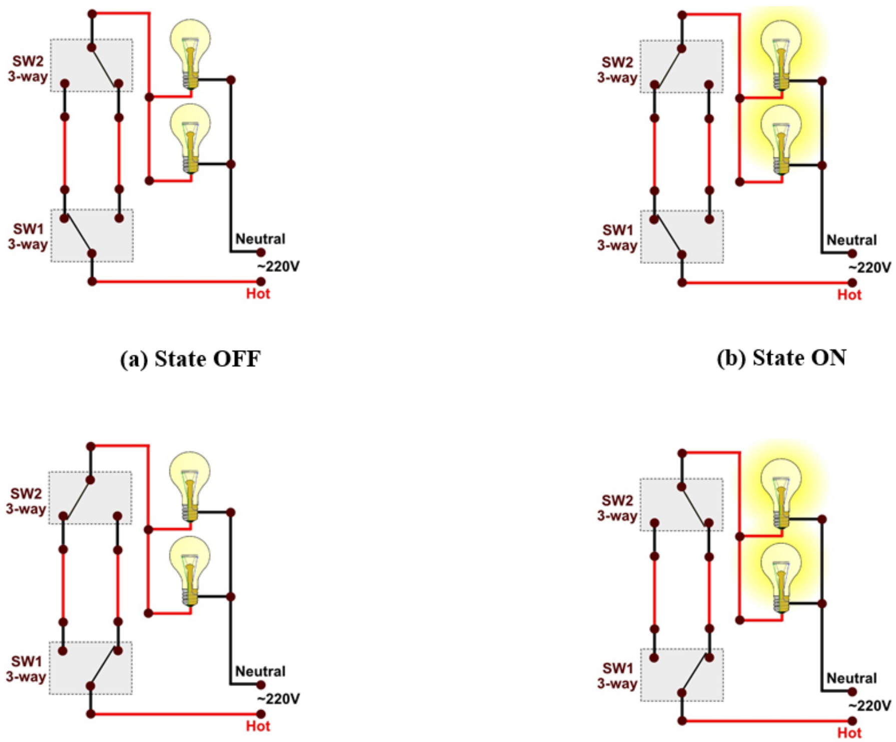
Multiway Switching is a switching system used in building wiring. It ensures the control of one or more electrical loads using two or more switches activated from different locations. The loads can be light bulbs, pumps or ventilators [1]. In

*The work was supported by the TÁMOP-4.2.2.C-11/1/KONV-2012-0001 project. The project has been supported by the European Union, co-financed by the European Social Fund.

this paper we use the terminology of “light bulbs” for the load, but in the real life development it may represent any kind of electrical load.

Let’s take two practical examples, where these control systems can be applied. First of all, consider buildings with multiple floors. Suppose that we live in a storey house and arrive home late from work when it’s already dark. It is a standard requirement today that we switch on the light at the ground floor, get upstairs and turn off the light, there is no need to walk down again to switch it off. We may think of long corridors too: instead of having only one switch at the end of the corridor it is more favorable to install a switch next to each door.

Now, let us see in detail, how these systems work. Consider the simplest example, when the system contains only two switches. (see Figure 1.)



(a) State OFF (b) State ON

(c) State OFF (d) State ON

Figure 1: Classical multiway switching with 2 switches

In this case we use two three-way switches which allow us to control the system from two different locations. The number of light bulbs is arbitrary. The idea is to connect them to the system in a parallel way. To understand the main principle of the system, we use the following notations: if the position of the switch is left, we use 0, if it is right, we use 1. By applying two switches, four cases can be encountered. To represent these cases, we used the reflected binary code, also known as Gray code (see e.g. [2,3]). In two cases the light bulbs will be on and in the other two they will be off (see Table 1.). We can notice that a next state is always the opposite of the previous one.

Case	**SW1**	**SW2**	**Light**
(a)	0	0	OFF
(b)	0	1	ON
(c)	1	1	OFF
(d)	1	0	ON

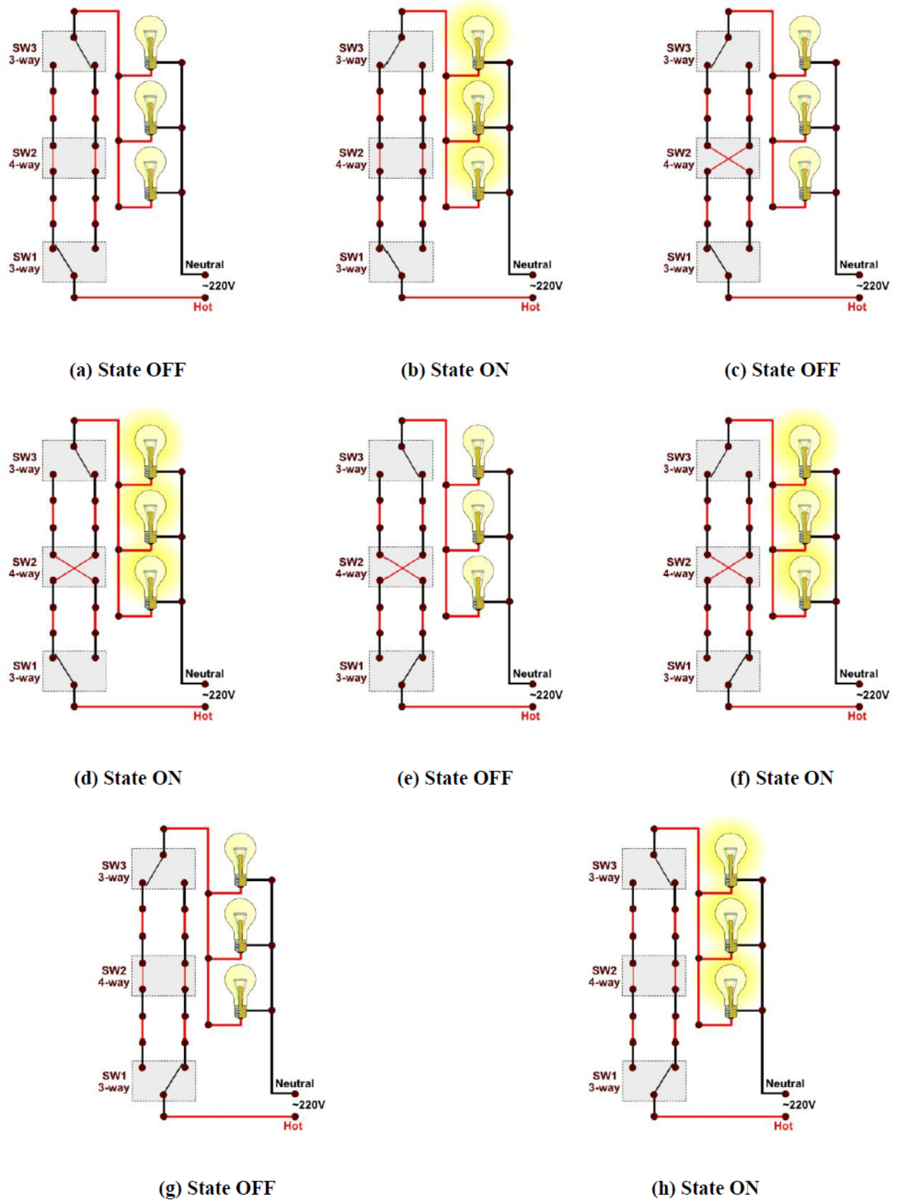
Table 1: ON/OFF table for multiway switching with 2 switches

If we would like to enlarge the system with more switches we need four-way or crossover switches. The rule is that these have to be connected between the three-way switches as it can be seen on the Figure 2.

In this example we used three switches, but the same logic can be extended for multiple switches. We can state that a system with N switches must contain two three-way switches and N-2 four-way switches. In the case of a system with three switches, eight different states are possible, where in four cases the light bulbs will be on, and in the other cases, the light bulbs will be off (see Figure 2.). In this case, for the representation of the system states, the Gray code was used similarly, having the main properties that the Hamming distance between the current state and the next system state is always one (see e.g. [2,3]). The following chart (Table 2.) shows that in the case of three switches the next state is always the opposite of the previous one, and the light bulb will be on only if an odd number of switches are on.

Case	**SW1**	**SW2**	**SW3**	**Light**
(a)	0	0	0	OFF
(b)	0	0	1	ON
(c)	0	1	1	OFF
(d)	0	1	0	ON
(e)	1	1	0	OFF
(f)	1	1	1	ON
(g)	1	0	1	OFF
(h)	1	0	0	ON

Table 2: ON/OFF table for multiway switching with 3 switches



(a) State OFF (b) State ON (c) State OFF

(d) State ON (e) State OFF (f) State ON

(g) State OFF (h) State ON

Figure 2: Classical multiway switching with 3 switches

2. Development environment

In order to implement the controller, Quartus II Web Edition software was used, developed by Altera Corporation [4]. If we study the operating logic of the classical multiway switching we get to the conclusion that it is enough to examine parity to control the multiway switching system. We should also take into consideration that the HDL code written by us should be universal and portable. The controller was implemented using VHDL then Verilog language (see e.g. [5]-[7]). Designing N number of inputs makes possible to control a multiway switching system with N switches. Although the controller has only one output, just like the classical multiway switching systems, unidentified number of loads, in this case bulbs can be connected to it. Similar FPGA controllers have been designed by other people too (see e.g. [8,9]). The pseudo-code of our design is as shown below:

```
Pseudo-code:

generic (N : integer := N);
port (inputs : in std_logic_vector(N-1 downto 0);
      output : out std_logic);
PROCESS (inputs)
  VARIABLE temp : std_logic;
    BEGIN temp := '0';
        for I in 0 to N-1 loop
          temp := temp xor inputs(I);
        end loop;
      output <= temp;
END PROCESS;
```

On Figure 3. we can see the implementation of a controller which is capable to direct a system with 3 switches and 3 bulbs. As we have already mentioned, the Quartus II software makes this possible. In this case the value of N is 3, and this code determines the controller. (On Figure 3. it is marked with mws_3.) We connect 3 switches (SW2-SW0) to the input of the controller by the help of a bus. There are also 3 parallel red LEDs (LEDR0-LEDR2) bound to the output. The number of bulbs (LEDs) is optional.

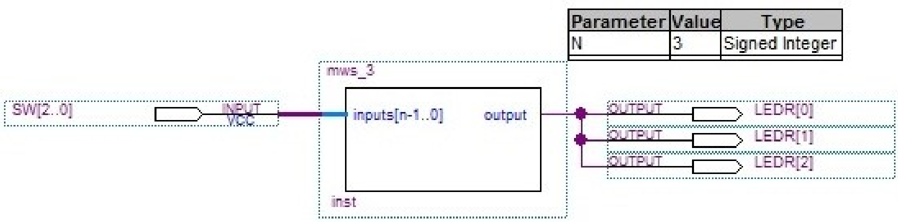


Figure 3: Controller design for a system with 3 switches using Quartus II

The compilation of the project is followed by the simulation process with the help of the well-known Quartus II software [4]. We can see the results on Figure 4.

It is evident that a certain output state is the opposite of the former one and the output will be active only if an odd number of inputs (switches) are on.

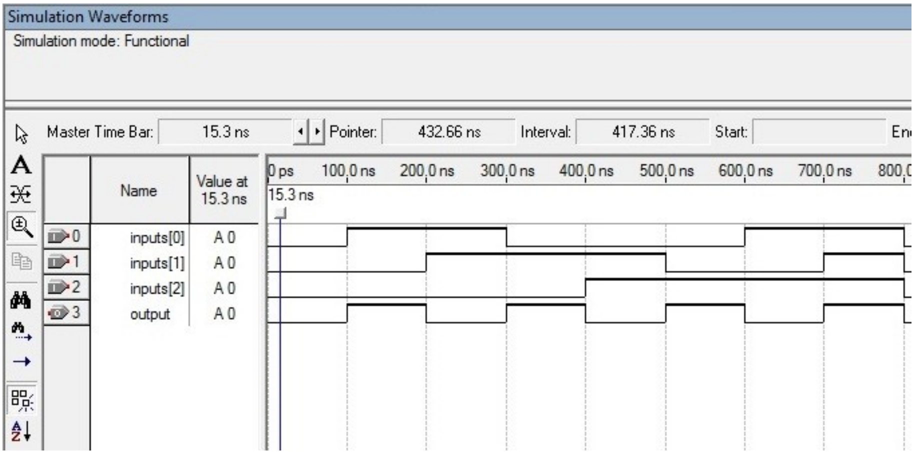


Figure 4: Simulation results for a system controller with 3 inputs

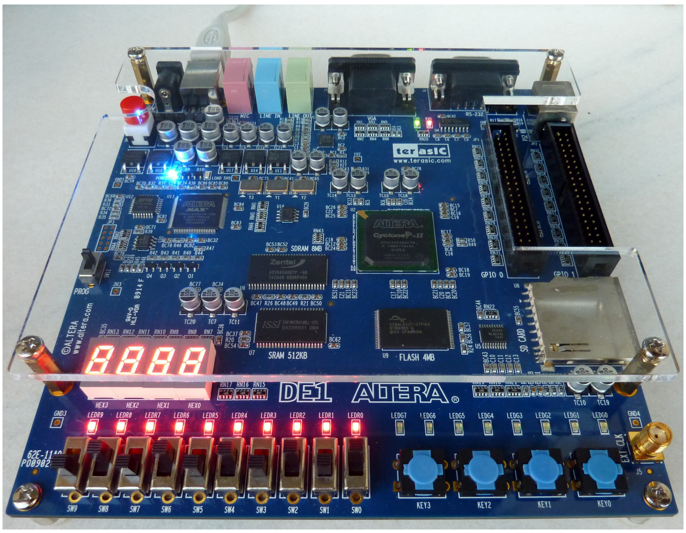


Figure 5: Altera DE1 development board with Cyclone II FPGA chip

The next step is the testing of the controller on a physical device, using Altera DE1 Development and Education board with Cyclone II FPGA chip (see Figure 5). The way the controller works can be checked on Table 2. and Figure 4., which consist the result of the simulation. We have the possibility to test the

FPGA controller for systems with different sizes because the card has 10 single pole switches (SW0-SW9), 10 red LEDS (LEDR0-LEDR9) and 8 green LEDS (LEDG0-LEDG7) [10]. Satisfactory results can be obtained in each case.

3. Conclusions

We managed to design an FPGA based controller, which fulfills the multiway switching system requirements. The HDL code used for the implementation is universal and portable. Our solution eliminates the use of four-way and three-way switches [11], which are more expensive: our system uses N pieces of two-way Single Pole, Single Throw (SPST) switches. Another advantage of the using FPGA controllers is that the system is controlled by low pressure current circuit. The controller presented by us is used most efficiently at new buildings.

References

[1] "Multiway switching." Wikipedia: The Free Encyclopedia, Wikimedia Foundation, Inc., 10 Apr. 2014. `http://en.wikipedia.org/wiki/Multiway_switching`.

[2] DORAN, R. V., The Gray Code, Journal of Universal Computer Science, Vol. 13, No. 11 (2007), 1573–1597.

[3] DEWAR, M., STEVENS, B., Ordering Block Designs – Gray Codes, Universal Cycles and Configuration Orderings, Springer Science+Business Media, ISBN 978-1-4614-4325-4 (2012).

[4] ALTERA official homepage, www.altera.com, downloaded on 15 Apr. 2014.

[5] HASKELL, R. E., HANNA, D. M., Digital Design using Digilent FPGA Boards – VHDL/ Active-HDL Edition, 2nd Edition, LBE Books, LLC, ISBN 978-0-9801337-8-3 (2012).

[6] BROWN, S., VRANESIC, Z., Fundamentals of Digital Logic with VHDL Design, 3rd Edition, McGraw-Hill, ISBN 978-0-07-352953-0 (2009).

[7] HASKELL, R. E., HANNA, D. M., Introduction to Digital Design using Digilent FPGA Boards – Block Diagram/ Verilog Examples, LBE Books, LLC, ISBN 978-0-9801337-6-9 (2009).

[8] DILIP, B., ALEKHYA, Y., BHARATHI, P. D., FPGA Implementation of an Advanced Traffic Light Controller using Verilog HDL, International Journal of Advanced Research in Computer Engineering & Technology, Vol. 1, Issue 7 (2012), 1–6.

[9] NATH, S., PAL, C., SAU, S., MUKHERJEE, S., ROY, A., GUCHHAIT, A., KANDAR, D., Design of an FPGA Based Intelligence Traffic Light Controller with VHDL, 2012 International Conference on Radar, Communication and Computing, India (2012), 92–97.

[10] TERASIC official homepage, www.terasic.com, downloaded on 20 Apr. 2014.

[11] LITCHFIELD, M., McALISTER, M., Wiring Complete – Expert Advice from Start to Finish, Revised Edition, Taunton Press, Inc., (2008).