FH University of Applied Sciences TECHNIKUM WIEN

Chip Design 1

Specification of Calculator Project Part 2: IO Control Unit

Version: 1.0

Author: R. Höller

Introduction

This document describes the IO control unit of the calculator project. The IO control unit handles all I/O ports (except the clock and reset signal). It includes the multiplexer needed for the 7-segment digits, debounces the switches and push buttons and makes the debounced signals available for FPGA-internal logic. The IO control unit implements a generic interface which can be useful for many projects. This means, that not all IOs are actually used for the calculator project. For example, some of the LEDs are unused.

I/O Circuitry of Basys3 FPGA Board

Figure 1 shows an extract of the circuit diagram of the Basys3 FPGA development board. The 16 LEDs are anode-connected to the FPGA via 330 ohm resistors, so they will turn on when a logic high voltage is applied to their respective I/O pin.

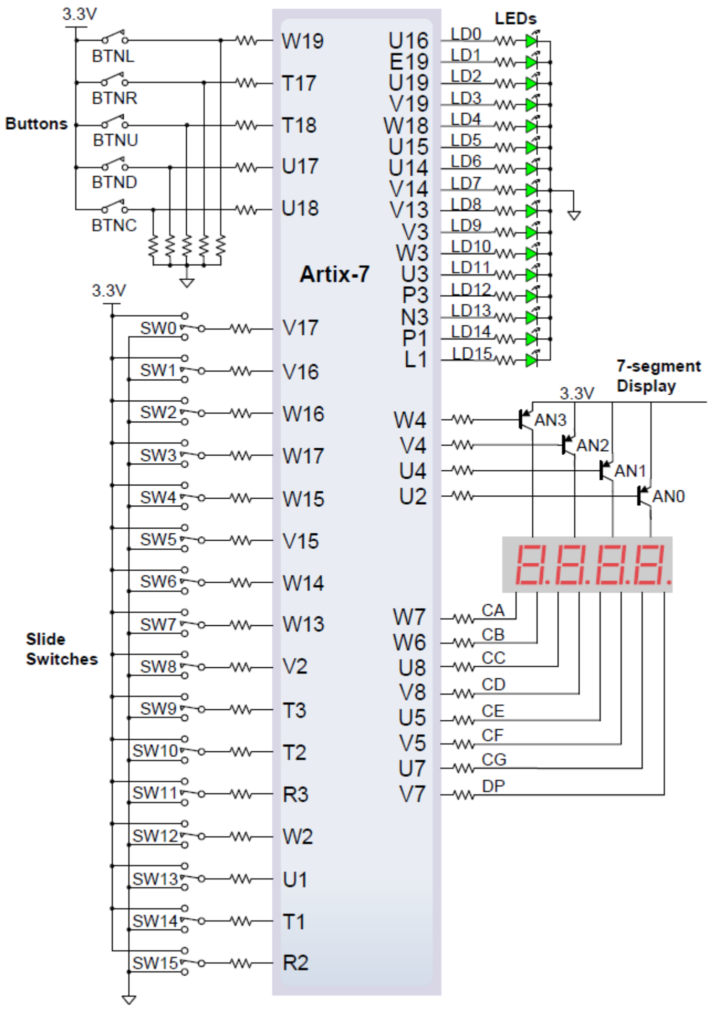

Figure 1: Schematics of the Basys3 FPGA board (extract)

Push buttons and switches often generate spurious open/close transitions when pressed, due to mechanical and physical issues. These transitions may be read as multiple presses in a very short time fooling the application. Thus, the IO control unit must use a debounce mechanism for the 16 switches and 4 push buttons of the Basys3 board in order to eliminate the unwanted transitions. Note, that only the four buttons BNTL, BTNC, BTNR and BTND are handled by the IO control unit while button BTNU is used as the global asynchronous reset signal for the whole design.

The Basys3 board contains one four-digit 7-segment LED display. Eight data signals (CA, CB … CG, DP) and four control signals (AN0-AN3) are used to control the 7-segment display. Each digit consists of eight LEDs which are connected to a common anode as well as individual cathodes. The common anode signals AN0-AN3 are used to enable the four digits. The cathodes of all four digits are connected to eight signals labeled CA, CB, … CG through DP. Figure 2 shows the connections of a single digit. To illuminate a segment, the anode is driven high while the cathode is driven low. Since the FPGA board uses transistors to drive enough current into the common anode, the anode enables are inverted. Therefore, both the AN0-AN3 and the CA..G/DP signals have to be driven low when a LED shall be turned on.

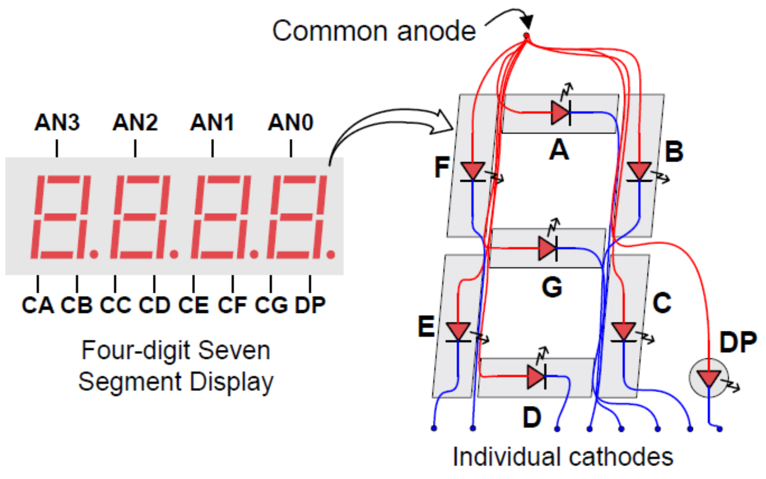

Figure 2: 7-segment display

A scanning display controller circuit can be used to display a four-digit number. This circuit drives the anode signals and corresponding cathode patterns of each digit in a repeating, continuous succession at an update rate that is faster than the human eye can detect. Each digit is illuminated just one-fourth of the time, but because the eye cannot perceive the darkening of a digit before it is illuminated again, the digit appears continuously illuminated. For each digit to appear bright, a refresh frequency of 1 kHz can be used. This frequency is also suitable for debouncing the push buttons and switches.

Code Skeleton of IO Control Unit

A code skeleton for the IO control unit of the calculator project is shown in the following.

```
-------------------------------------------------------------------------------
--                                                                           --
--       XXXXXXXX X      X XXXXXXXXX X       X       XXXXXXX  XXXXXXX        --
--       X        X      X     X     X       X      X         X      X       --
--       X        X      X     X     X       X      X         X      X       --
--       X        X      X     X     X       X      X         X      X       --
--       XXXXXXX  XXXXXXXX     X     X       X XXXX  XXXXXXX  X      X       --
--       X        X      X     X     X   X   X              X X      X       --
--       X        X      X     X     X  X X  X              X X      X       --
--       X        X      X     X     X X   X X              X X      X       --
--       X        X      X     X     X       X       XXXXXXX  XXXXXXX        --
--                                                                           --
--       F A C H H O C H S C H U L E   -   T E C H N I K U M   W I E N       --
--                                                                           --
--                         Embedded Systems Department                       --
--                                                                           --
-------------------------------------------------------------------------------
--                                                                           --
--         Web:           http://www.technikum-wien.at/                      --
--                                                                           --
--         Contact:       hoeller@technikum-wien.at                          --
--                                                                           --
-------------------------------------------------------------------------------
--
--         Author:                 Roland Höller
--
--         Filename:               io_ctrl_.vhd
--
--         Date of Creation:       Sun Oct 20 12:14:48 2002
--
--         Version:                $Revision$
--
--         Date of Latest Version: $Date$
--
--         Design Unit:            IO Control Unit (Entity)
--
--         Description: The IO Control unit is part of the calculator project.
--                      It manages the interface to the 7-segment displays,
--                      the LEDs, the push buttons and the switches of the
--                      Digilent Basys3 FPGA board.
--
-------------------------------------------------------------------------------
--
--  CVS Change Log:
```

A well written file header is an essential part of reusable and readable HDL Code. It is industrial practice to include entries for a version control system (in this case CVS).

```
--
--  $Log$
-------------------------------------


library ieee;
use ieee.std_logic_1164.all;

entity io_ctrl is

  port (clk_i    : in    std_logic;                     -- 100 MHz system clock
        reset_i  : in    std_logic;                     -- asynchronous reset
        ...);

end io_ctrl;
```

Entity of the IO control unit. The ports *clk_i*, *reset_i*, *ss_o*, *ss_sel_o*, *sw_i, pb_i* and *led_o* are IOs of the FPGA. All other signals reside inside the FPGA and are connected to the calculator control unit (see distance learning letter “Overview of Calculator Project” for a list of all entity ports of the IO control unit).

The architecture of the IO control unit is held in a separate file:

```
-------------------------------------------------------------------------------
--                                                                           --
--       XXXXXXXX X      X XXXXXXXXX X       X       XXXXXXX  XXXXXXX        --
--       X        X      X     X     X       X      X         X      X       --
--       X        X      X     X     X       X      X         X      X       --
--       X        X      X     X     X       X      X         X      X       --
--       XXXXXXX  XXXXXXXX     X     X       X XXXX  XXXXXXX  X      X       --
--       X        X      X     X     X   X   X              X X      X       --
--       X        X      X     X     X  X X  X              X X      X       --
--       X        X      X     X     X X   X X              X X      X       --
--       X        X      X     X     X       X       XXXXXXX  XXXXXXX        --
--                                                                           --
--       F A C H H O C H S C H U L E   -   T E C H N I K U M   W I E N       --
--                                                                           --
--                         Embedded Systems Department                       --
--                                                                           --
-------------------------------------------------------------------------------
--                                                                           --
--         Web:           http://www.technikum-wien.at/                      --
--                                                                           --
--         Contact:       hoeller@technikum-wien.at                          --
--                                                                           --
-------------------------------------------------------------------------------
--
--         Author:                 Roland Höller
--
--         Filename:               io_ctrl_rtl.vhd
--
--         Date of Creation:       Sun Oct 20 12:17:48 2002
--
--         Version:                $Revision$
```

```
--
--         Date of Latest Version: $Date$
--
--         Design Unit:            IO Control Unit (Architecture)
--
--         Description: The IO Control unit is part of the calculator project.
--                      It manages the interface to the 7-segment displays,
--                      the LEDs, the push buttons and the switches of the
--                      Digilent Basys3 FPGA board.
--
-------------------------------------------------------------------------------
--
--  CVS Change Log:
--
--  $Log$
-------------------------------------------------------------------------------

library ieee;
use ieee.std_logic_1164.all;
use ieee.std_logic_arith.all;

architecture rtl of io_ctrl is

  constant C_ENCOUNTVAL : std_logic_vector(16 downto 0):= "11000011010100000";

  signal s_enctr    : std_logic_vector(16 downto 0);
  signal s_1khzen   : std_logic;
  signal swsync     : std_logic_vector(            );
  signal pbsync     : std_logic_vector(            );
  signal s_ss_sel   : std_logic_vector(            );
  signal s_ss       : std_logic_vector(            );

begin  -- rtl

  -----------------------------------------------------------------------------
  --
  -- Generate 1 kHz enable signal.
  --
  -----------------------------------------------------------------------------
  p_slowen: process (clk_i, reset_i)
  begin
    if reset_i = '1' then                   -- asynchronous reset (active high)


    elsif clk_i'event and clk_i = '1' then  -- rising clock edge
        -- Enable signal is inactive per default.


        -- As long as the terminal count is not reached: increment the counter.
```

Every 1 ms, this signal will be set to a logic ‘1’ for a single 100 MHz clock period.

```
      -- When the terminal count is reached, set enable signal and reset the
      -- counter.



  end if;
end process p_slowen;

-----------------------------------------------------------------------------
--
-- Debounce buttons and switches
--
-----------------------------------------------------------------------------
p_debounce: process (clk_i, reset_i)
begin
  if reset_i = '1' then                    -- asynchronous reset (active high)



  elsif clk_i'event and clk_i = '1' then  -- rising clock edge




  end if;
end process p_debounce;

swsync_o <= swsync;
pbsync_o <= pbsync;
```

The registers that are used to debounce the buttons and switches are connected to the respective ports of the entity. That way, other units (in this case the calculator control unit) can access the registers.

The switches and buttons are debounced and forwarded to internal signals. Both tasks are synchronous to the previously generated 1 kHz enable signal.

```
-----------------------------------------------------------------------------
--
-- Display controller for the 7-segment display
--
-----------------------------------------------------------------------------
p_display_ctrl: process (clk_i, reset_i)
begin
  if reset_i = '1' then                    -- asynchronous reset (active high)



  elsif clk_i'event and clk_i = '1' then  -- rising clock edge



  end if;
end process p_display_ctrl;
```

Set one of the four 7-segment select signals s_ss_sel to logic 0 and multiplex dig0_i - dig3_i to s_ss in a circular fashion using the 1 kHz enable signal.

```
    ss_o <= s_ss;
    ss_sel_o <= s_ss_sel;
    -----------------------------------------------------------------------------
    --
    -- Handle the 16 LEDs
    --
    -----------------------------------------------------------------------------
    led_o <= led_i;  -- simply connect the internal to the external signals

  end rtl;
```

How to Proceed?

The next steps in the project are as follows:

- Write a VHDL entity for the IO control unit (see the previously described code skeleton), name the file, for example, "io_ctrl_.vhd" and store it in the "vhdl" sub-folder of your project directory. The entity ports can be found in the distance learning letter "Overview of Calculator Project". Have a look at the block diagram (which is also included in the distance learning letter "Overview of Calculator Project") to understand, how the IO control unit communicates with other units in the design.
- Write a VHDL architecture for the IO control unit (see the previously described code skeleton), name the file, for example, "io_ctrl_rtl.vhd" and store it in the "vhdl" sub-folder of your project directory. Break down the functionality into smaller sub-blocks (generation of 1 kHz signal, buttons & switches debouncing, display controller for the 7-segment display …) and decide which of these blocks need to be coded as combinatorial logic and which of them need storage elements (registers). You can also create VHDL sub-components for certain pieces of functionality but since the complexity of the IO control unit is not that high, it is rather recommended that you include everything that is described in this document in a single architecture.
- You can also create a VHDL configuration if you like to, but this is completely optional!
- Create a VHDL entity/architecture pair (and an optional configuration) for the testbench of the IO control unit, name the files, for example, "tb_io_ctrl_.vhd" and "tb_io_ctrl_sim.vhd" and store them in the "tb" sub-folder of your project directory.
- Write "do-"scripts to compile and simulate the IO control unit as described in the distance learning letter "Introduction to ModelSim-Intel FPGA Starter Edition" and store them in the "sim" sub-folder of your project directory.
- Simulate the IO control unit using ModelSim and fix all bugs that you find.
- If the IO control unit was tested successfully, proceed with the distance learning letter "Part 3: Calculator Control Unit".

Version

Version 1.0	Update to entire document for CHIP1

If you find mistakes or inconsistencies, please report them to the course supervisors via email. Thank you!