Digilent DIO5 Peripheral Board Reference Manual

Revision: November 24, 2003

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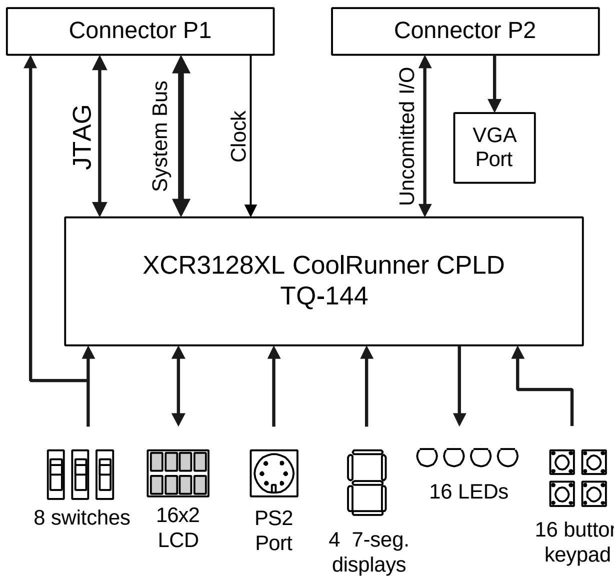
Overview

The DIO5 circuit board provides a ready-made source for many common I/O devices found in digital systems. It can be connected to Digilent system boards to create a digital development platform that is suitable for a wide range of projects. The DIO5 uses a Xilinx CoolRunner CPLD to facilitate interaction with system boards. The CLPD automatically appears in the JTAG scan chain when the DIO5 is attached to a system board, so new designs can easily be configured into the DIO5. DIO5 features include:

- A Xilinx CoolRunner XCR3128 CPLD for I/O device and system bus control;
- A 16x2 character LCD module;
- A 4-digit seven segment LED display;
- 16 LEDs in three different colors;
- A 16 button keypad;
- 8 slide switches;
- 3-bit VGA port;
- PS/2 mouse or keyboard port.

The DIO5 has been designed to work seamlessly with Digilent system boards and all versions of the Xilinx ISE CAD tools, including the free WebPack tools available from Xilinx. The CPLD on the DIO5 is configured during manufacturing with the project shown in Appendix 1, but new designs can easily be loaded into the CPLD.



DIO5 circuit board block diagram

Functional Description

The Digilab DIO5 can be attached to any Digilent system board to create a digital design platform that has many useful I/O devices. The DIO5 draws power from the system board, so no separate power supply is required. All I/O device signals are routed through the on-board CPLD so that a customized I/O controller can be created for any given design. For example, if all on-board I/O devices are needed, a register-based controller can be implemented. Or, if only a subset of I/O devices are needed, a much simpler controller can be used to map device signals directly through the CPLD to the system board. Because the CPLD appears in the JTAG scan chain when the DIO5 is attached to a system board, it can easily be configured. The CPLD is programmed during manufacture with register-based controller shown in Appendix 1.

Power Supplies

The DIO5 board draws power from three pins on the 40-pin connectors: pin 37 supplies 3.3V; pin 39 provides system GND, and pin 40 supplies unregulated voltage (VU). Pin 40 (VU) is connected directly to an LM1117 5VDC LDO regulator on the DIO5. 5VDC is used by the LCD display and the PS/2 interface. The 3.3V supply is used to drive the CPLD and all other I/O devices on the board. During normal operation, the DIO5 consumes 10-20mA from the 5V supply, and 50-100mA from the 3.3V supply depending on how many LEDs are illuminated. The DIO5 uses a four-layer board, with two layers dedicated to 3.3V and GND, and several bulk and high-frequency decoupling capacitors to keep the supplies stable under all loads.

CPLD Configuration

The JTAG scan chain is routed through the DIO5 board on pins 1-4 of connector P1, allowing the CPLD to be configured from any Digilent system board. Jumper-shunts must be loaded on pins 1 & 2 of jumper blocks JP2 and JP3 on the DIO5 to include the CPLD in the scan chain, or across pins 2 & 3 to remove the CPLD from the scan chain.

Jumper position JP1 allows the JTAG signals on the CPLD to be reclaimed if they are inadvertently programmed as user I/O's. Since the JTAG pins on the CPLD are used only for programming, this jumper block should not normally be loaded. The CPLD pinout is available in appendix 1.

System Board Interface

Signals from all I/O devices on the DIO5 are routed through the CPLD, with the exception of the VGA port (video data is too high bandwidth to pass through the CPLD). All I/O devices on the DIO5 can therefore be read or written via a register-based controller in the CPLD. Some device signals, including the eight slide switches, the PS/2 data and clock, and an LCD enable are also routed around the CPLD and directly to the connectors. These signals can be accessed either through the CPLD or directly from the system board.

The CPLD offers several options for moving data between the DIO5 and a system board: a memory-mapped bus interface can be defined where all devices are accessed via registers; a "direct connect" interface can be defined where I/O signals pass directly through the CPLD without the need for a bus (in this case, not all devices on the DIO5 can be accessed); or various controllers and compression/encoding schemes can be used to transfer device data over subsets of pins.

The default DIO5 CPLD circuit defines a "system bus" to transfer data to and from a system board. The bus uses 8 bi-directional data lines, six address lines, three control signals, and a clock signal (SCLK). The three control signals, write enable (WE), output enable (OE), and chip select (CS), are used to coordinate bus traffic, and the SCLK signal provides a clock for latches and controllers on the DIO5. Four 8-bit write-only registers are used to receive LED and seven-segment display data in the CPLD, and three readable locations contain pushbutton and switch data.

DIO5 Default Circuit Memory Map

Address	Read	Write
000	BtnLo (buttons 0-7)	LedLo (LEDs 0-7)
001	BtnHi (buttons 8-F)	LedHi (LEDs 8-F)
010	Swt (slide switches)	SsegLo
011	unused	SsegHi
100	LCD bus	LCD bus

Two read locations, BtnHi and BtnLo, arise from latches in the CPLD. Pushbutton signals are stored in these two 8-bit latches at each rising edge of SCLK. The third read location, Swt, simply passes switch signals to the system bus from the switch input pins.

The four writable registers in the CPLD all provide data to the LED devices (i.e., the seven-segment displays and discrete LEDs). The registers use rising-edge-triggered flip-flops clocked by the trailing edge of the write enable signal (WE is active low). Data written to these registers appears immediately on the LED's.

Ten additional pushbutton signals bypass the system bus, and are routed from the CPLD directly to pins on the expansion connectors. Four of these signals contain BCD codes for buttons 0-9, and six signals are simply the state of buttons A-F at the output of the latches. These ten signals are always available regardless of the system bus state.

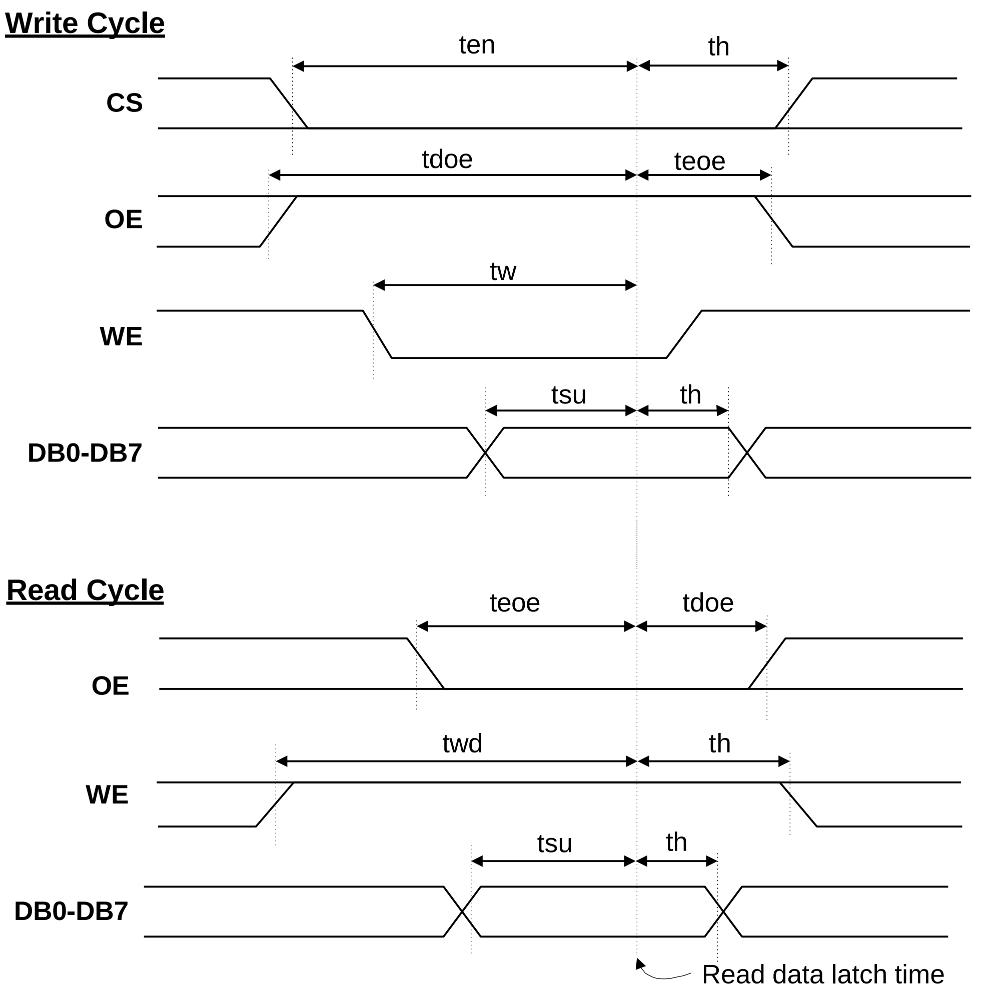
The CPLD also contains a seven-segment display controller. Binary data, in the form of four 4-bit fields spanning two bytes, can be written to the seven-segment data registers and it will be displayed as four hexadecimal characters on the seven-segment display. The display controller uses SCLK to control refresh timing.

Bi-directional LCD data transfers occur over the system bus. The default CPLD circuit synthesizes LCD control signals for bus cycles directed to the LCD memory space, but it is also possible to drive the LCD control signals directly. The “LCD” section below provides information on driving the LCD.

System bus timings are shown below. Data is written on the rising edge of write-enable (WE). DIO5 bus drivers are enabled whenever output enable (OE) is asserted (low). The diagrams below show signal timings assumed by Digilent to create peripheral devices. Different bus and timing models can be used by modifying circuits in the FPGA and attached peripheral devices.

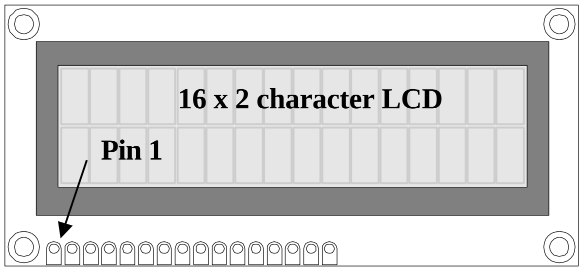
System Bus Timings

Symbol	**Parameter**	**Time (typ)**
ten	Time to enable after CS asserted	10ns
th	Hold time	1ns
tdoe	Disable time after OE deasserted	10ns
teoe	Enable time after OE asserted	15ns
tw	Write strobe time	10ns
tsu	Data setup time	5ns
twd	Write disable time	0ns



LCD

The DIO5 uses a 16-character, 2-line LCD module from the Powertip corporation (part number PC1602ARS-DWA-A). The LCD uses a Samsung KS0066U controller - data sheets for the display module and the controller chip are available from the Digilent website.



Powertip PC1602ARS

The KS0066U contains a character-generator ROM (CGROM) with 208 preset 5x8 character patterns, a character-generator RAM (CGRAM) that can hold 8 user-defined 5x8 characters, and a display data RAM (DDRAM) that can hold 80 character codes. Character codes written into the DDRAM serve as indexes into the CGROM (or CGRAM). Writing a character code into a particular DDRAM location will cause the associated 5x8 character pattern to appear at the corresponding display location. The display positions can be shifted left or right by setting a bit in the instruction register (IR). The write-only IR is used to direct display operations (such as clear display, shift left or right, set DDRAM address, etc). Available instructions are (and the associated IR codes) are shown in the rightmost column of table 3 below. A busy flag is available to indicate whether the display has competed the last requested operation; prior to initiating a new operation, the flag can be checked to see whether the previous operation has been completed.

The display has more DDRAM locations than can be displayed at any given time. DDRAM locations 00H to 27H map to the first display row, and locations 40H to 67H map to the second row. Normally, DDRAM location 00H maps to the upper left display corner, and 40H to the lower left. Shifting the display left or right can change this mapping. The display uses a temporary data register (DR) to hold data during DDRAM /CGRAM read or write operations, and an internal address register to select the RAM location. Address register contents, which can be set via the IR, are automatically incremented after each read or write operation. The LCD display uses ASCII character codes. Codes up through 7F are standard ASCII (which includes all “normal” alphanumeric characters). Codes above 7F produce various international characters – please see the manufacturers data sheet for more information on international codes.

The display is connected to the DIO5 board by a 16-pin connector (pins 15 and 16 are for an optional backlight, and they are not used). The 14-pin interface includes eight data bus signals, three control signals, and three voltage supply signals. The eight data bus signals are passed through the CPLD to/from the system bus for read/write cycles directed to the LCD memory space (address 100). The three control signals are generated by the CPLD as appropriate for read and write cycles. LCD bus timings are shown below. The enable signal (E) serves as both output enable and write strobe (with an active falling edge) depending on the state of the Read/Write (R/W) signal.

A startup sequence with specific timings must be followed to ensure proper LCD operation. After power-on, at least 20ms must elapse before the function-set instruction code can be written to set the bus width, number of lines, and character patterns (8-bit interface, 2 lines, and 5x8 dots are appropriate). After the function-set instruction, at least 37us must elapse before the display-control instruction can be written (to turn the display on, turn the cursor on or off, and set the cursor to blink or no blink). After another 37us, the display-clear instruction can be issued. After another 1.52ms, the entry-mode instruction can set address increment (or address decrement) mode, and display shift mode (on or off). After this sequence, data can be written into the DDRAM to cause information to appear on the display.

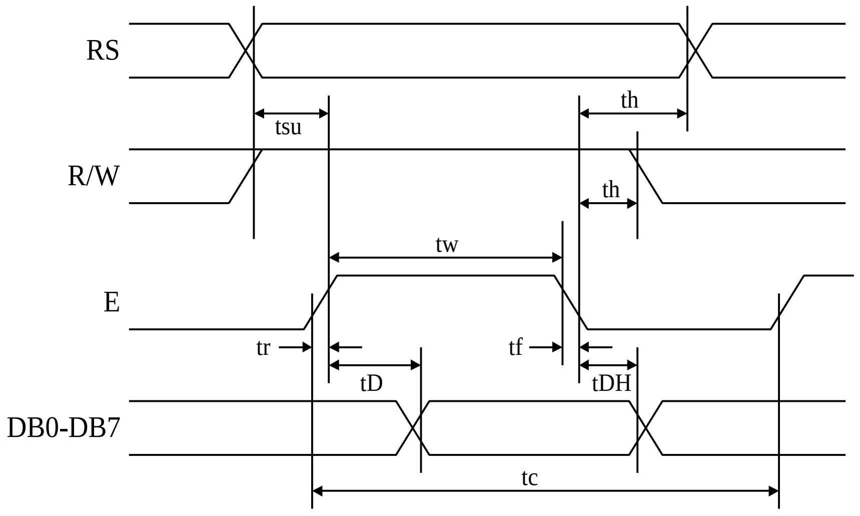
Table 3. LCD Instructions and Codes

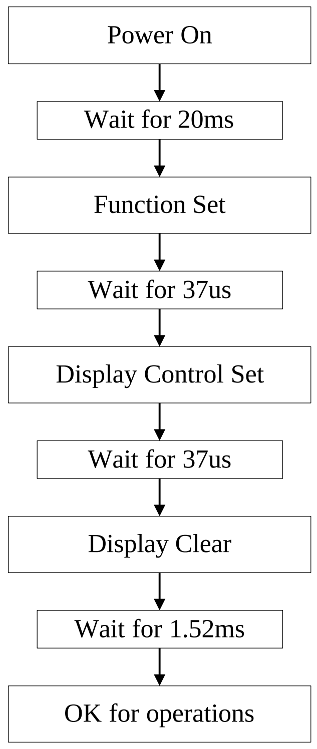
Instruction	Instruction bit assignments										Description
	RS	R/W	DB7	DB6	DB5	DB4	DB3	DB2	DB1	DB0	
Clear Display	0	0	0	0	0	0	0	0	0	1	Clear display by writing a 20H to all DDRAM locations; set DDRAM address register to 00H; and return cursor to home.
Return Home	0	0	0	0	0	0	0	0	1	X	Return cursor to home (upper left corner), and set DDRAM address to 0H. DDRAM contents not changed.
Entry mode set	0	0	0	0	0	0	0	1	I/D	SH	I/D = ‘1’ for right-moving cursor and address increment; SH = ‘1’ for display shift (direction set by I/D bit).
Display ON/OFF control	0	0	0	0	0	0	1	D	C	B	Set display (D), cursor (C), and blinking cursor (B) on or off.
Cursor or Display shift	0	0	0	0	0	1	S/C	R/L	X	X	SC = ‘0’ to shift cursor right or left, ‘1’ to shift entire display right or left (R/L = ‘1’ for right).
Function Set	0	0	0	0	1	DL	N	F	X	X	Set interface data length (DL = ‘1’ for 8 bit), number of display lines (N = ‘1’ for 2 lines), display font (F = ‘0’ for 5x 8 dots)
Set CGRAM Address	0	0	0	1	AC5	AC4	AC3	AC2	AC1	AC0	Set CGRAM address counter
Set DDRAM address	0	0	1	AC6	AC5	AC4	AC3	AC2	AC1	AC0	Set DDRAM address counter
Read busy flag/ address	0	1	BF	AC6	AC5	AC4	AC3	AC2	AC1	AC0	Read busy flag and address counter
Write data to RAM	1	0	D7	D6	D5	D4	D3	D2	D1	D0	Write data into DDRAM or CGRAM, depending on which address was last set
Read data from RAM	1	1	D7	D6	D5	D4	D3	D2	D1	D0	Read data from DDRAM or CGRAM, depending on which address was last set

Table 4. LCD Connector Signals

Pin No.	Symbol	Signal Description
1	Vss	Signal ground
2	Vdd	Power supply (5V)
3	Vo	Operating (contrast) voltage (LCD drive, typically 100mV at 20C)
4	RS	Register select: high for data transfer, low for instruction register
5	R/W	Read/write signal: high for read mode, low for write mode
6	E	Read/write strobe: high for read OE; falling edge writes data
7-14	Data Bus	Bi-directional data bus

LCD Read Cycle





LCD startup sequence

LCD Write Cycle

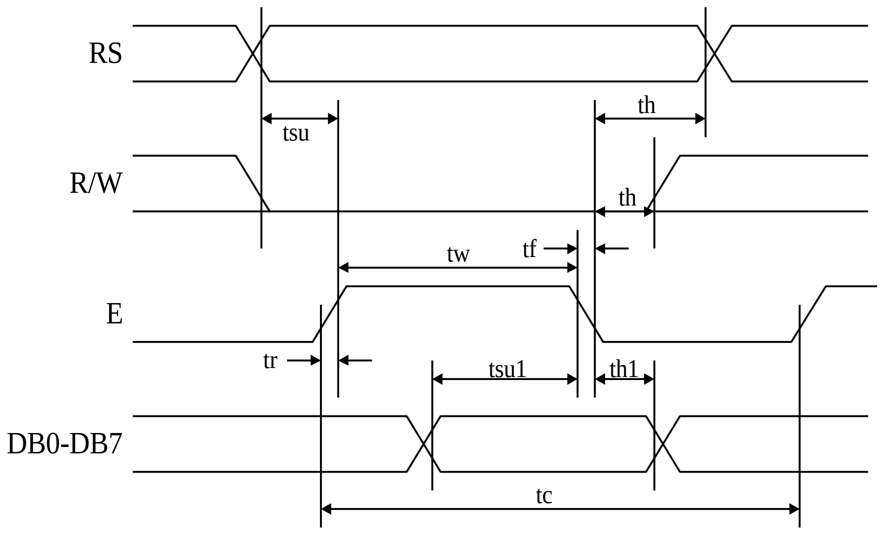


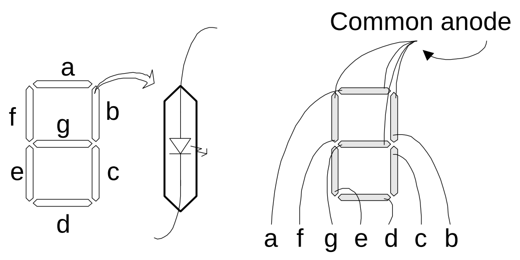
Table 5. LCD Bus Timings

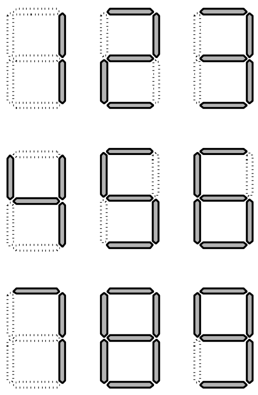
Parameter	Symbol	Min	Max	Unit	Test Pin
Enable cycle time	tc	500		ns	E
Enable High pulse width	tw	220		ns	E
Enable rise/fall time	tr, tf		25	ns	E
RS, R/W setup time	tsu	40		ns	RS, R/W
RS, R/W hold time	th	10		ns	RS, R/W
Read data output delay	tD	60	120	ns	DB0-DB7
Read data hold time	tDH	20		ns	DB0-DB7
Write data setup time	tsu1	40		ns	DB0-DB7
Write data hold time	th1	10		ns	DB0-DB7

Seven-Segment LED display

The DIO5 board contains a modular 4-digit, common anode seven-segment LED display. In a common anode display, the seven anodes of the LEDs forming each digit are connected to four common circuit nodes (labeled AN1 through AN4 on the DIO5). Each anode, and therefore each digit, can be independently turned on and off by driving these signals to a '1' or a '0'. The cathodes of similar segments on all four displays are also connected together into seven common circuit nodes labeled CA through CG. Thus, each cathode for all four displays can be turned on and off independently.

This connection scheme creates a multiplexed display, where driving the anode signals and corresponding cathode patterns of each digit in a repeating, continuous succession can create a 4-digit display. In order for each of the four digits to appear bright and continuously illuminated, all four digits should be driven once every 1 to 16ms (for a refresh frequency of 1KHz to 60KHz). For example, in a 60Hz refresh scheme, each digit would be illuminated for ¼ of the refresh cycle, or 4ms. The controller must assure that the correct cathode pattern is present when the corresponding anode signal is driven. To illustrate the process, if AN1 is driven high while CB and CC are driven low, then a "1" will be displayed in digit position 2. Then, if AN2 is driven high while CA, CB and CC are driven low, then a "7" will be displayed in digit position 2. If AN1 and CB, CC are driven for 4ms, and then AN2 and CA, CB, CC are driven for 4ms in an endless succession, the display will show "17" in the first two digits. An example timing diagram is provided below.

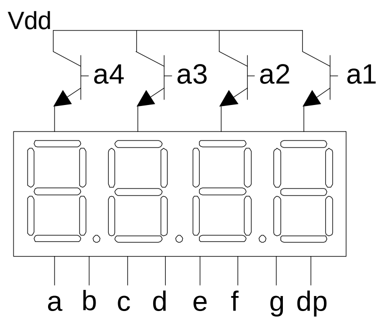




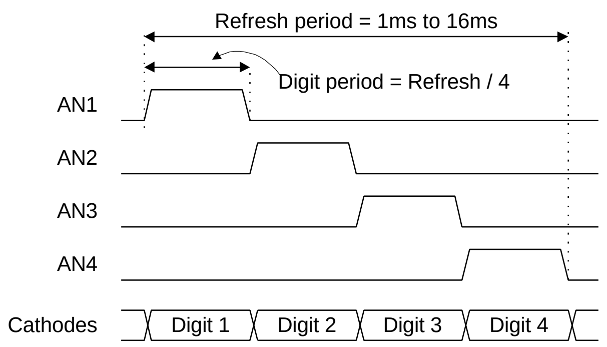
Digit Shown	a	b	c	d	e	f	g
	Illuminated Segment						
0	1	1	1	1	1	1	0
1	0	1	1	0	0	0	0
2	1	1	0	1	1	0	1
3	1	1	1	1	0	0	1
4	0	1	1	0	0	1	1
5	1	0	1	1	0	1	1
6	1	0	1	1	1	1	1
7	1	1	1	0	0	0	0
8	1	1	1	1	1	1	1
9	1	1	1	1	0	1	1

Seven-segment display detail and cathaode patterns to display the decimal digits.

Anodes are connected via transistors for greater current



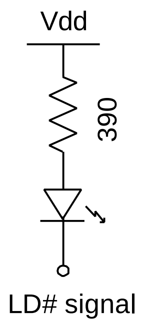
Cathodes are connected to Xilinx device via 100Ω resistors



When configured with the code shown in the appendix, the CPLD on the DIO5 board implements a seven-segment controller provided a suitable clock (256Hx to 1KHz) is provided on the SCLK pin. The controller accepts four 4-bit binary numbers in two successive registers, and decodes and displays them.

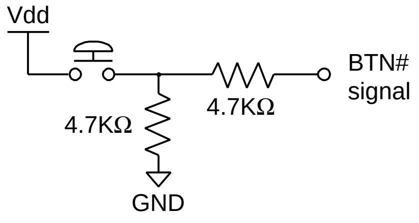
Discrete LEDs

Sixteen individual LEDs (5 green, 5 yellow, and 6 red) are provided for circuit outputs. The LED cathodes are driven directly from the CPLD, and the anodes are tied to Vdd via 390-ohm resistors (so the LED drive signals are active low). When the CPLD is configured with the code shown in the appendix, two 8-bit registers (at writable locations 000 and 001 in the CPLD) drive the LED cathode signals. Note the LED signals are inverted in the VHDL code, so a logic “1” turns on the LEDs.



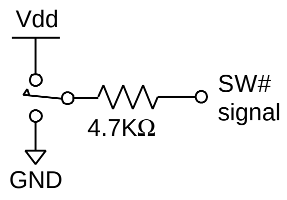
Pushbutton Inputs

Outputs from the 16 momentary-contact push buttons are normally low, and are driven high only while the button is actively pressed. The buttons exhibit a worst-case bounce time of about 1ms. A 4.7K series resistor provides some debounce filtering and ESD protection to each button. When configured with the code shown in the appendix, the CPLD on the DIO5 board makes all button signals available on the bus in two successive readable address locations (0 and 1).



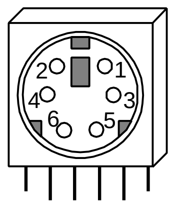
Switch Inputs

The eight slide switches on the DIO5 can be used to connect either Vdd or GND to eight pins on the CPLD. The switches exhibit about 2ms of bounce, and no active debouncing circuit is employed. A 4.7K-ohm series resistor is used for nominal input protection. When configured with the code shown in the appendix, the CPLD makes all switch signals available on the system bus at address location 2.

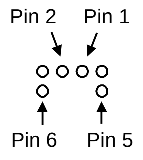


PS2 Port

The DIO5 board includes a 6-pin mini-DIN connector that can accommodate a PS2 mouse or PS2 keyboard connection. A 5VDC regulator provides the required voltage to keyboards and/or mice. Both the mouse and keyboard use a two-wire serial bus (including clock and data) to communicate with a host device. These signals are routed through the CPLD to provide voltage mapping, and to allow a controller to be placed in the CPLD.



PS2 Connector

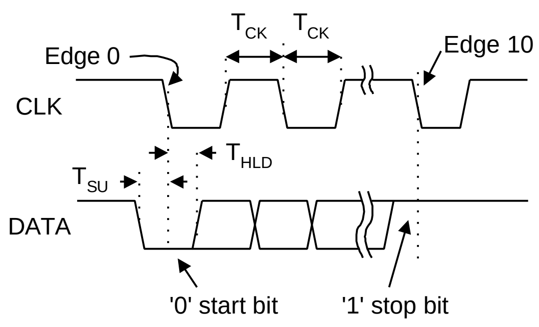


Bottom-up hole pattern

Pin Definitions

Pin	Function
1	Data
2	Reserved
3	GND
4	Vdd
5	Clock
6	Reserved

The keyboard and mouse both use identical signal timings. Both use 11-bit words that include a start, stop and odd parity bit, but the data packets are organized differently, and the keyboard interface allows bi-directional data transfers (so the host device can illuminate state LEDs on the keyboard). Bus timings are shown below. The clock and data signals are only driven when data transfers occur, and otherwise they are held in the “idle” state at logic ‘1’. The timings define signal requirements for mouse-to-host communications and bi-directional keyboard communications.



Symbol	Parameter	Min	Max
T_{CK}	Clock time	30us	50us
T_{SU}	Data-to-clock setup time	5us	25us
T_{HLD}	Clock-to-data hold time	5us	25us

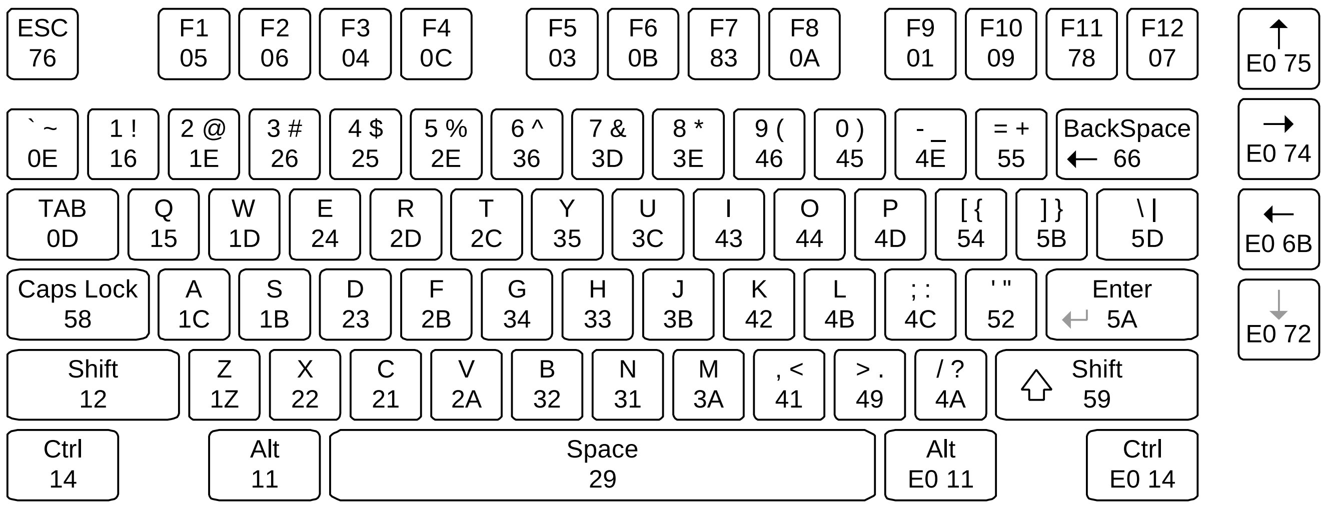
Keyboard

The keyboard uses open collector drivers so that either the keyboard or an attached host device can drive the two-wire bus (if the host device will not send data to the keyboard, then the host can use simple input-only ports).

PS2-style keyboards use scan codes to communicate key press data (nearly all keyboards in use today are PS2 style). Each key has a single, unique scan code that is sent whenever the corresponding key is pressed. If the key is pressed and held, the scan code will be sent repeatedly once every 100ms or so. When a key is released, a “F0” key-up code is sent, followed by the scan code of the released key. If a key can be “shifted” to produce a new character (like a capital letter), then a shift character is sent in addition to the original scan code, and the host device must determine which character to use. Some keys, called extended keys, send an “E0” ahead of the scan code (and they may send more than one scan code). When an extended key is released, an “E0 F0” key-up code is sent, followed by the scan code. Scan codes for most keys are shown in the figure below.

A host device can also send data to the keyboard. Below is a short list of some often-used commands.

ED	Set Num Lock, Caps Lock, and Scroll Lock LEDs. After receiving an “ED”, the keyboard returns an “FA”; then the host sends a byte to set LED status: Bit 0 sets Scroll Lock; bit 1 sets Num Lock; and Bit 2 sets Caps lock. Bits 3 to 7 are ignored.
EE	Echo. Upon receiving an echo command, the keyboard replies with “EE”.
F3	Set scan code repeat rate. The keyboard acknowledges receipt of an “F3” by returning an “FA”, after which the host sends a second byte to set the repeat rate.
FE	Resend. Upon receiving FE, the keyboard re-sends the last scan code sent.
FF	Reset. Resets the keyboard.



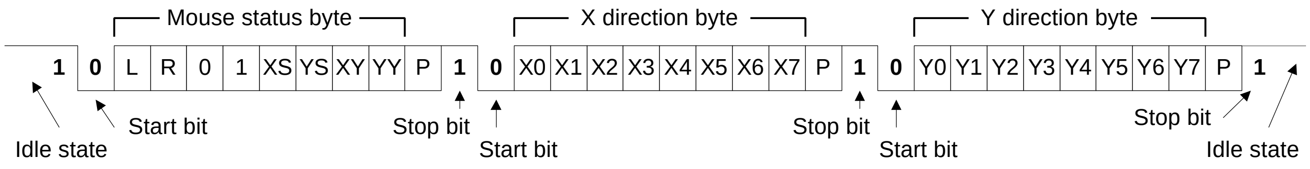
The keyboard should send data to the host only when both the data and clock lines are high (or idle). Since the host is the "bus master", the keyboard should check to see whether the host is sending data before driving the bus. To facilitate this, the clock line can be used as a "clear to send" signal. If the host pulls the clock line low, the keyboard must not send any data until the clock is released (host-to-keyboard data transmission will not be dealt with further here).

The keyboard sends data to the host in 11-bit words that contain a '0' start bit, followed by 8-bits of scan code (LSB first), followed by an odd parity bit and terminated with a '1' stop bit. The keyboard generates 11 clock transitions (at around 20 - 30KHz) when the data is sent, and data is valid on the falling edge of the clock.

Mouse

The mouse outputs a clock and data signal when it is moved; otherwise, these signals remain at logic '1'. Each time the mouse is moved, three 11-bit words are sent from the mouse to the host device. Each of the 11-bit words contains a '0' start bit, followed by 8 bits of data (LSB first), followed by an odd parity bit, and terminated with a '1' stop bit. Thus, each data transmission contains 33 bits, where bits 0, 11, and 22 are '0' start bits, and bits 11, 21, and 33 are '1' stop bits. The three 8-bit data fields contain movement data as shown below. Data is valid at the falling edge of the clock, and the clock period is 20 to 30KHz.

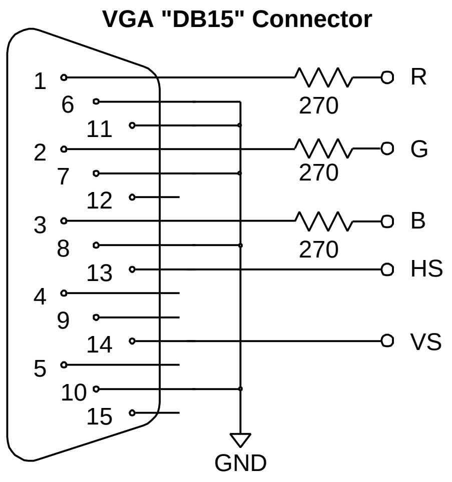
The mouse assumes a relative coordinate system wherein moving the mouse to the right generates a positive number in the X field, and moving to the left generates a negative number. Likewise, moving the mouse up generates a positive number in the Y field, and moving down represents a negative number (the XS and YS bits in the status byte are the sign bits – a '1' indicates a negative number). The magnitude of the X and Y numbers represent the rate of mouse movement – the larger the number, the faster the mouse is moving (the XV and YV bits in the status byte are movement overflow indicators – a '1' means overflow has occurred). If the mouse moves continuously, the 33-bit transmissions are repeated every 50ms or so. The L and R fields in the status byte indicate Left and Right button presses (a '1' indicates the button is being pressed).



VGA Port

The five standard VGA signals Red (R), Green (G), Blue (B), Horizontal Sync (HS), and Vertical Sync (VS) are routed directly to the VGA connector, bypassing the CPLD. A 270-ohm series resistor is used on each color signal. This resistor forms a divider with the 75-ohm VGA cable termination, resulting in a signal that conforms to the VGA specification (i.e., 0V for fully off and .7V for fully on).

VGA signal timings are specified, published, copyrighted and sold by the VESA organization (www.vesa.org). The following VGA system



timing information is provided as an example of how a VGA monitor might be driven in 640 by 480 mode. For more precise information, or for information on higher VGA frequencies, refer to document available at the VESA website (or experiment!).

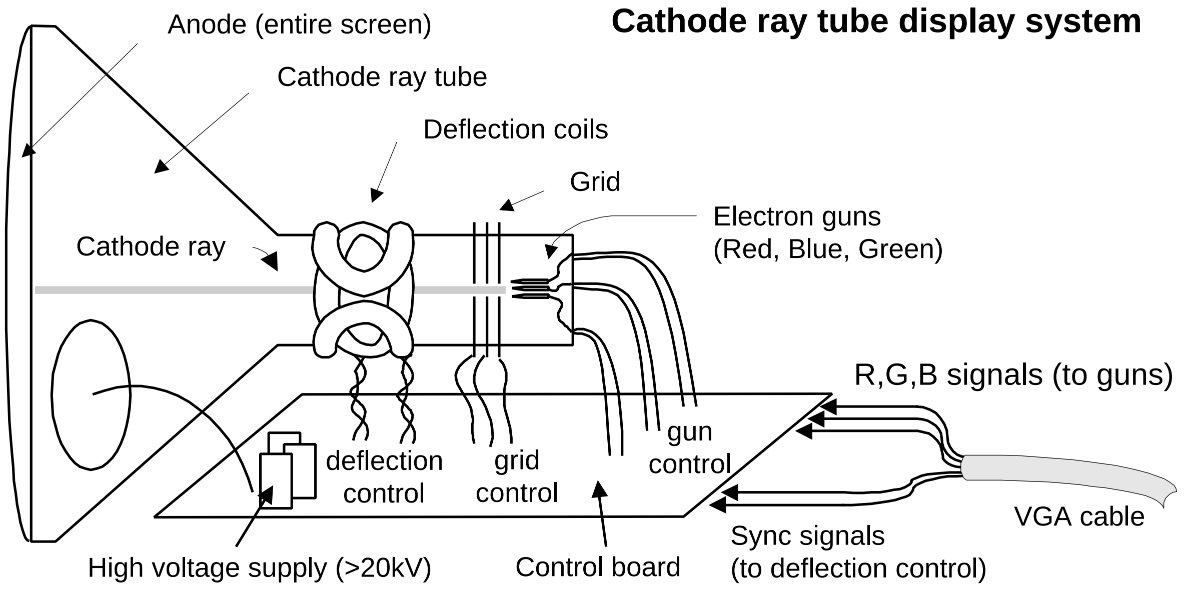
VGA system timing

CRT-based VGA displays use amplitude modulated, moving electron beams (or cathode rays) to display information on a phosphor-coated screen. LCD displays use an array of switches that can impose a voltage across a small amount of liquid crystal, thereby changing light permitivity through the crystal on a pixel-by-pixel basis. Although the following description is limited to CRT displays, LCD displays have evolved to use the same signal timings as CRT displays (so the “signals” discussion below pertains to both CRTs and LCDs).

CRT displays use electron beams (one for red, one for blue and one for green) to energize the phosphor that coats the inner side of the display end of a cathode ray tube (see drawing below). Electron beams emanate from “electron guns”, which are a finely pointed, heated cathodes placed in close proximity to a positively charged annular plate called a “grid”. The electrostatic force imposed by the grid pulls away rays of energized electrons as current flows into the cathodes. These particle rays are initially accelerated towards the grid, but they soon fall under the influence of the much larger electrostatic force that results from the entire phosphor coated display surface of the CRT being charged to 20kV (or more). The rays are focused to a fine beam as they pass through the center of the grids, and then they accelerate to impact on the phosphor coated display surface. The phosphor surface glows brightly at the impact point, and the phosphor continues to glow for several hundred microseconds after the beam is removed. The larger the current fed into the cathode, the brighter the phosphor will glow.

Between the grid and the display surface, the beam passes through the neck of the CRT where two coils of wire produce orthogonal electromagnetic fields. Because cathode rays are composed of charged particles (electrons), they can be deflected by these magnetic fields. Current waveforms are passed through the coils to produce magnetic fields that interact with the cathode rays and cause them to transverse the display surface in a “raster” pattern, horizontally from left to right and vertically from top to bottom. As the cathode ray moves over the surface of the display, the current sent to the electron guns can be increased or decreased to change the brightness of the display at the cathode ray impact point.

Cathode ray tube display system

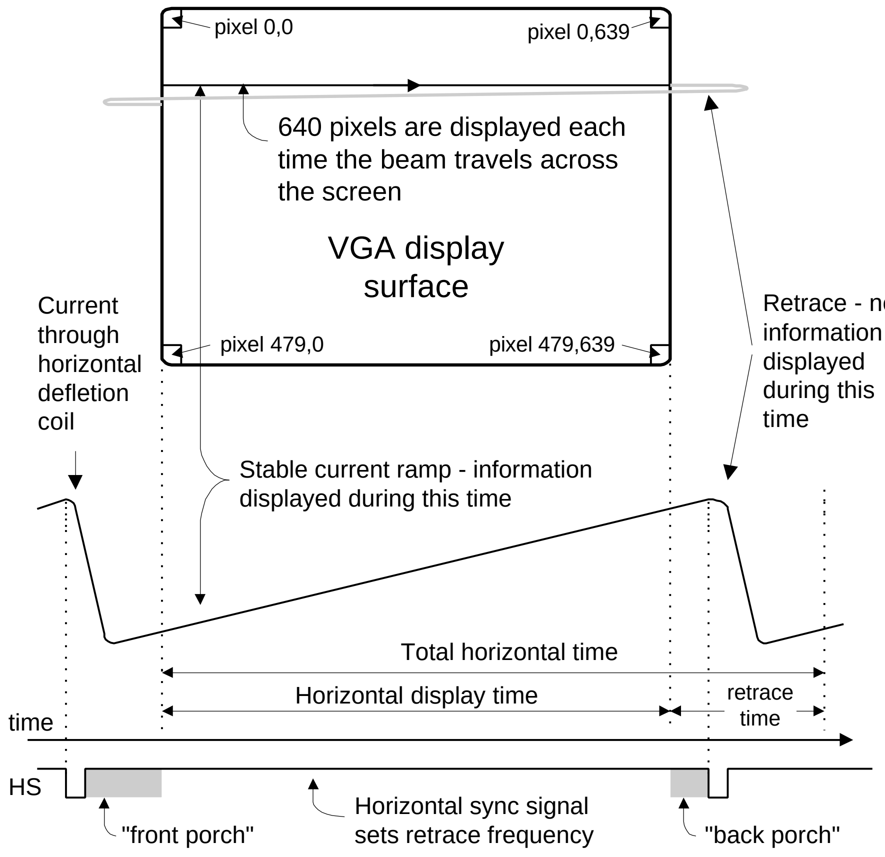


Information is only displayed when the beam is moving in the "forward" direction (left to right and top to bottom), and not during the time the beam is reset back to the left or top edge of the display. Much of the potential display time is therefore lost in "blanking" periods when the beam is reset and stabilized to begin a new horizontal or vertical display pass.

The size of the beams, the frequency at which the beam can be traced across the display, and the frequency at which the electron beam can be modulated determine the display resolution. Modern VGA displays can accommodate different resolutions, and a VGA controller circuit dictates the resolution by producing timing signals to control the raster patterns. The controller must produce synchronizing pulses at 3.3V (or 5V) to set the frequency at which current flows through the deflection coils, and it must ensure that video data is applied to the electron guns at the correct time. Raster video displays define a number of "rows" that corresponds to the number of horizontal passes the cathode makes over the display area, and a number of "columns" that corresponds to an area on each row that is assigned to one "picture element" or pixel. Typical displays use from 240 to 1200 rows, and from 320 to 1600 columns. The overall size of a display, and the number of rows and columns determines the size of each pixel.

Video data typically comes from a video refresh memory, with one or more bytes assigned to each pixel location (the DIO5 board uses 3-bits per pixel). The controller must index into video memory as the beams move across the display, and retrieve and apply video data to the display at precisely the time the electron beam is moving across a given pixel.

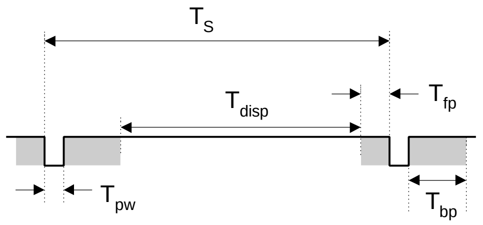
A VGA controller circuit must generate the HS and VS timings signals and coordinate the delivery of video data based on the pixel clock. The pixel clock defines the time available to display 1 pixel of information. The VS signal defines the "refresh" frequency of the display, or


pixel 0,0
pixel 0,639
640 pixels are displayed each time the beam travels across the screen
VGA display surface
pixel 479,0
pixel 479,639
Current through horizontal defletion coil
Retrace - no information displayed during this time
Stable current ramp - information displayed during this time
Total horizontal time
Horizontal display time
retrace time
time
HS
"front porch"
Horizontal sync signal sets retrace frequency
"back porch"

the frequency at which all information on the display is redrawn. The minimum refresh frequency is a function of the display's phosphor and electron beam intensity, with practical refresh frequencies falling in the 50Hz to 120Hz range. The number of lines to be displayed at a given refresh frequency defines the horizontal "retrace" frequency. For a 640-pixel by 480-row display using a 25MHz pixel clock and 60 +/-1Hz refresh, the signal timings shown in the table below can be derived. Timings for sync pulse width and front and back porch intervals (porch intervals are the pre- and post-sync pulse times during which information cannot be displayed) are based on observations taken from VGA displays.

A VGA controller circuit decodes the output of a horizontal-sync counter driven by the pixel clock to generate HS signal timings. This counter can be used to locate any pixel location on a given row. Likewise, the output of a vertical-sync counter that increments with each HS pulse can be used to generate VS signal timings, and this counter can be used to locate any given row. These two continually running counters can be used to form an address into video RAM. No time relationship between the onset of the HS pulse and the onset of the VS pulse is specified, so the designer can arrange the counters to easily form video RAM addresses, or to minimize decoding logic for sync pulse generation.

Symbol	Parameter	Vertical Sync			Horizontal Sync	
		Time	Clocks	Lines	Time	Clocks
T_S	Sync pulse time	16.7ms	416,800	521	32 us	800
T_{disp}	Display time	15.36ms	384,000	480	25.6 us	640
T_{pw}	VS pulse width	64 us	1,600	2	3.84 us	96
T_{fp}	VS front porch	320 us	8,000	10	640 ns	16
T_{bp}	VS back porch	928 us	23,200	29	1.92 us	48



XCR3128XL CoolRunner CPLD

The CPLD is in a TQ144 package that has 108 user I/Os available. Of these, 63 are routed to devices on the DIO5, 17 are assigned to form a "system bus" that connects the DIO5 and a system board, 10 connect pushbutton signals directly to a system board, 6 are uncommitted I/O signals routed to the system board, and 2 are used to pass PS/2 port signals through to a system board. The remaining 10 signals are not connected. CPLD pinouts are shown in the table below.

The CPLD can contain various controller circuits to pass DIO5 device signals to an attached system board. During manufacturing, the CPLD is configured with the register-based circuit shown in the Appendix, but the CPLD can easily be configured with other circuits.

JTAG programming signals are routed across the expansion connectors from the D2-SB, D2-FT, and other system boards, so the CPLD can be configured whenever the DIO5 is attached to one of these boards. The CPLD will appear in the scan chain when shorting blocks are loaded on pins 1 & 2 of jumpers JP2 & JP3 (conversely, if shorting blocks are loaded on pins 2 and 3, the CPLD will not appear in the scan chain). The center pins of JP2 & JP3 should not be left floating – jumpers should always be loaded across pins 1 & 2 or across pins 2 & 3.

Expansion Connectors

The connector pinouts are shown below. Separately available tables show pass-through connections for the devices on the DIO5 board when it is attached to various system boards.

XCR3128XL CPLD Pinout for DIO5 board

Pin #	Signal	Dir	Pin #	Signal	Dir	Pin #	Signal	Dir	Pin #	Signal	Dir
1	LCDRW	out	37	LD7	out	73	**VCC33**		109	BCOD0	in
2	LCDRS	out	38	LD8	out	74	ADR0	in	110	BCOD1	in
3	**GND**		39	LD9	out	75	NC		111	BCOD2	in
4	**TDI**		40	LDA	out	76	**VCC33**		112	BCOD3	in
5	IO-02	open	41	LDB	out	77	DB0	bidi	113	BOUTA	in
6	IO-01	open	42	LDC	out	78	ADR1	in	114	BOUTB	in
7	KDIN	in	43	NC		79	DB1	bidi	115	**VCC33**	
8	KCIN	in	44	LDD	out	80	ADR2	in	116	BOUTC	in
9	DSPA1	out	45	LDE	out	81	DB2	bidi	117	BOUTD	in
10	DSPA2	out	46	LDF	out	82	ADR3	in	118	BOUTE	in
11	DSPA3	out	47	NC		83	DB3	bidi	119	BOUTF	in
12	DSPA4	out	48	NC		84	ADR4	in	120	KCLK	out
13	**PORTEN**		49	NC		85	**GND**		121	KDAT	out
14	DSPDP	out	50	**VCC33**		86	DB4	bidi	122	NC	
15	DSPCG	out	51	**VCC33**		87	ADR5	in	123	**VCC33**	
16	DSPCF	out	52	**GND**		88	DB5	bidi	124	**GND**	
17	**GND**		53	BTN7	in	89	**TCK**		125	WE	in
18	DSPCE	out	54	BTN8	in	90	DB6	bidi	126	CLK2	in
19	NC		55	BTN9	in	91	OE	in	127	LCLK	in
20	**TMS**		56	BTNC	in	92	DB7	bidi	128	SCLK	in
21	DSPCD	out	57	**GND**		93	CS	in	129	**GND**	
22	DSPCC	out	58	**VCC33**		94	SW8	in	130	**VCC33**	
23	DSPCB	out	59	**GND**		95	**VCC33**		131	IO-03	open
24	**VCC33**		60	BTN4	in	96	SW7	in	132	IO-04	open
25	DSPCA	out	61	BTN5	in	97	SW6	in	133	IO-05	open
26	LD0	out	62	BTN6	in	98	SW5	in	134	LCDDB0	bidi
27	LD1	out	63	BTND	in	99	SW4	in	135	**GND**	
28	LD2	out	64	**GND**		100	SW3	in	136	LCDDB1	bidi
29	LD3	out	65	BTN1	in	101	SW2	in	137	LCDDB2	bidi
30	LD4	out	66	BTN2	in	102	SW1	in	138	LCDDB3	bidi
31	LD5	out	67	BTN3	in	103	NC		139	LCDDB4	bidi
32	LD6	out	68	BTNE	in	104	**TDO**		140	LCDDB5	bidi
33	**GND**		69	BTN0	in	105	**GND**		141	LCDDB6	bidi
34	NC		70	BTNA	in	106	IO-06	open	142	LCDDB7	bidi
35	NC		71	BTNB	in	107	LCDEN	out	143	LCD-EN	out
36	NC		72	BTNF	in	108	NC		144	**VCC33**	

DIO5 Expansion Connector Pinout					
P1	**Signal**	**Dir**	**P2**	**Signal**	**Dir**
1	**TDO**		1	nc	
2	**TDI**		2	nc	
3	**TMS**		3	nc	
4	**TCK**		4	nc	
5	nc		5	nc	
6	**JTSEL (VCC33)**		6	nc	
7	nc		7	nc	
8	nc		8	nc	
9	nc		9	nc	
10	nc		10	IO-06	open
11	SW1	out	11	CLK2	
12	nc		12	IO-05	open
13	SW3	out	13	IO-04	open
14	SW2	out	14	IO-03	open
15	SW5	out	15	IO-02	open
16	SW4	out	16	IO-01	open
17	SW7	out	17	nc	
18	SW6	out	18	nc	
19	SCLK	in	19	KDAT	out
20	SW8	out	20	KCLK	out
21	DB7	bidi	21	HS	in
22	CS	in	22	LCLK	in
23	DB6	bidi	23	BLU	in
24	OE	in	24	VS	in
25	DB5	bidi	25	RED	in
26	WE	in	26	GRN	in
27	DB4	bidi	27	BOUTE	out
28	ADR5	in	28	BOUTF	out
29	DB3	bidi	29	BOUTC	out
30	ADR4	in	30	BOUTD	out
31	DB2	bidi	31	BOUTA	out
32	ADR3	in	32	BOUTB	out
33	DB1	bidi	33	BCOD2	out
34	ADR2	in	34	BCOD3	out
35	DB0	bidi	35	BCOD0	out
36	ADR1	in	36	BCOD1	out
37	**VCC33**		37	**VCC33**	
38	ADR0	in	38	LCDEN	in
39	**GND**		39	**GND**	
40	**VU**		40	**VU**	

Appendix 1. Default CPLD configuration

```
------------------------------------------------------------------------
--  DlabDio5.vhd -- Digilab DIO5 Default CPLD Configuration
------------------------------------------------------------------------
--  Author:  Clint Cole
--           Copyright 2003 Digilent, Inc.
------------------------------------------------------------------------
--  This module contains the default configuration for the DIO5 XCR3128XL
--  CoolRunner CPLD. This project implements a bus-oriented, register-based
--  interface that can be used by a system board to interact with the DIO5
--  board. The 16 push buttons, 8 switches, 4 digit seven segment display, and
--  16 discrete led's are accessed via the CPLD according to the memory map:
--     address     read       write
--       000       BtnLo      LedLo
--       001       BtnHi      LedHi
--       010       Swt        SsegLo
--       010       -          SsegHi
--
--  The sixteen buttons on the DIO5 are arranged as a decimal keypad and
--  six directly-connected function buttons. All buttons are routed through
--  the CPLD and are readable via the bus interface. Additionally, Buttons 0-9
--  are encoded to BCD by the CPLD logic. The remaining six buttons pass
--  through the CPLD and connect directly to the system board interface
--  connectors. All buttons are debounced by latches driven by the
--  input clock (signal LCLK).
--
--  The eight slide switches bypass the CPLD and connect directly
--  to the interface connectors, and they also pass through the CPLD to allow
--  reading via the bus interface.
--
--  The LCD display signals pass through the CPLD to provide logic level
--  conversion from the 5V logic levels of the LCD display to the 3.3V
--  logic levels used by system boards.
--
--  The VGA signals on the DIO5 board go directly to the connectors and are
--  not connected to the CPLD.
--
--  The keyboard signals pass through the CPLD to provide logic level
--  shifting. The standard implementation provides an input only keyboard
--  and does not support writing to the keyboard.
--
------------------------------------------------------------------------
-- Revision History:
--  08/20/2003(ClintC): created
------------------------------------------------------------------------

library IEEE;
use IEEE.STD_LOGIC_1164.ALL;
use IEEE.STD_LOGIC_ARITH.ALL;
use IEEE.STD_LOGIC_UNSIGNED.ALL;

entity DlabDio5 is
    Port ( db       : inout std_logic_vector(7 downto 0);
           adr      : in std_logic_vector(5 downto 0);
           lclk      : in std_logic;
           cs       : in std_logic;
           we       : in std_logic;
           oe       : in std_logic;
           lcen     : in std_logic;
           rgbLcd   : inout std_logic_vector(7 downto 0);
           lcden    : out std_logic;
           lcdrw    : out std_logic;
           lcdrs    : out std_logic;
           rgbBtnIn : in std_logic_vector(15 downto 0);
           rgbSwt   : in std_logic_vector(7 downto 0);
           encBtn   : out std_logic_vector(3 downto 0);
           rgbBtnOt : out std_logic_vector(5 downto 0);
           rgbLed   : out std_logic_vector(15 downto 0);
           rgbSsgAn : out std_logic_vector(3 downto 0);
           rgbSsgCa : out std_logic_vector(7 downto 0);
           kclk     : out std_logic;
           kdat     : out std_logic;
           kcin     : in  std_logic;
           kdin     : in  std_logic);
end DlabDio5;

architecture Behavioral of DlabDio5 is

    ------------------------------------------------------------------------
    -- Component Declarations
    ------------------------------------------------------------------------


    ------------------------------------------------------------------------
    -- Constant and Signal Declarations
    ------------------------------------------------------------------------

    -- Internal registers for output devices
    signal  regLed     : std_logic_vector(15 downto 0);
    signal  regSsg     : std_logic_vector(15 downto 0);
    signal  regBtn     : std_logic_vector(15 downto 0);
    signal  rgbSyncBtn : std_logic_vector(15 downto 0);

    -- Other needed signals
    signal  busDout    : std_logic_vector(7 downto 0);
    signal  cntDig     : std_logic_vector(1 downto 0) := "00";
    signal  ssg        : std_logic_vector(6 downto 0);
    signal  dig        : std_logic_vector(3 downto 0);
    signal  an         : std_logic_vector(3 downto 0);

----------------------------------------------------------------------------
-- Module Implementation
----------------------------------------------------------------------------

begin

    ------------------------------------------------------------------------
    -- Bus drive control logic. Data bus is driven only when oe and cs are valid.
    ------------------------------------------------------------------------

    db <= busDout when (oe = '0' and cs = '0') else "ZZZZZZZZ";

    -- Output mux to place selected data on bus
    busDout <= rgbSyncBtn(7 downto 0) when adr = "000000" else
               rgbSyncBtn(15 downto 8) when adr = "000001" else
               rgbSwt when adr = "000010" else
               rgbLcd;

    ------------------------------------------------------------------------
    -- Registers for On-Board Output Devices            (LEDs and Sseg display)
    ------------------------------------------------------------------------

    -- The WE signal is driven from a global clock buffer.
    process (we)
        begin
            if (we'event and we = '1') then
                if (adr = "000000" and cs = '0') then regLed( 7 downto 0) <= db; end if;
                if (adr = "000001" and cs = '0') then regLed(15 downto 8) <= db; end if;
                if (adr = "000010" and cs = '0') then regSsg( 7 downto 0) <= db; end if;
                if (adr = "000011" and cs = '0') then regSsg(15 downto 8) <= db; end if;
            end if;
        end process;

    -- Assign outputs of the LED holding registers to the led outputs
    rgbLed  <= not regLed;

    ------------------------------------------------------------------------
    -- Synthesize control signals for the LCD display
    ------------------------------------------------------------------------

    rgbLcd <= db when (cs = '0' and we = '0') else "ZZZZZZZZ";
    lcden  <= '1' when (adr = "0001--" and cs = '0' and not ((we = '1') and (oe = '1'))) or
        lcen = '1' else '0';
    lcdrw  <= we;
    lcdrs  <= adr(0);

    ------------------------------------------------------------------------
    -- Get button inupts: All 16 button inputs are registered. Six buttons
    -- (A through F) are passed directly through to output pins on the CPLD,
    -- and ten buttons (0 through 9) are encoded to BCD.
    ------------------------------------------------------------------------

    -- Register all buttons
    process(rgbBtnIn, lclk)
        begin
            if lclk = '1' and lclk'Event
                                                    then regBtn <= rgbBtnIn;
            end if;
        end process;
    rgbSyncBtn <= regBtn;

    -- Assign debounced pass-through buttons to their outputs
    rgbBtnOt <= rgbSyncBtn(15 downto 10);

    -- 10-4 Line BCD Encoder for Buttons
    encBtn <=   "0000" when rgbSyncBtn(0) = '1' else
                "0001" when rgbSyncBtn(1) = '1' else
                "0010" when rgbSyncBtn(2) = '1' else
                "0011" when rgbSyncBtn(3) = '1' else
                "0100" when rgbSyncBtn(4) = '1' else
                "0101" when rgbSyncBtn(5) = '1' else
                "0110" when rgbSyncBtn(6) = '1' else
                "0111" when rgbSyncBtn(7) = '1' else
                "1000" when rgbSyncBtn(8) = '1' else
                "1001" when rgbSyncBtn(9) = '1' else
                "1111";

    ------------------------------------------------------------------------
    --  Seven Segment Display Driver
    ------------------------------------------------------------------------

    -- Counter to cycle around the four digit numbers.
    process (lclk)
        begin
            if lclk = '1' and lclk'Event then
                cntDig <= cntDig + 1;
            end if;
        end process;

    -- Seven Segment Display Decoder. This logic defines a four bit binary to
    -- seven segment decoder. The output produces a logic 1 for each segment
    -- that should be on and a logic 0 for each segment that should be off.
    -- Segment A is the least significant bit.
```

```
ssg <= "0111111" when dig = "0000" else
       "0000110" when dig = "0001" else
       "1011011" when dig = "0010" else
       "1001111" when dig = "0011" else
       "1100110" when dig = "0100" else
       "1101101" when dig = "0101" else
       "1111101" when dig = "0110" else
       "0000111" when dig = "0111" else
       "1111111" when dig = "1000" else
       "1101111" when dig = "1001" else
       "1110111" when dig = "1010" else
       "1111100" when dig = "1011" else
       "0111001" when dig = "1100" else
       "1011110" when dig = "1101" else
       "1111001" when dig = "1110" else
       "1110001" when dig = "1111" else
       "0000000";

    -- Digit multiplexor. The anode for each digit in enabled
    -- in succession, and the appropriate cathode data is muxed onto
    -- the cathode lines while the corresponding anode is driven.
    an <= "1110" when cntDig = "00" else
          "1101" when cntDig = "01" else
          "1011" when cntDig = "10" else
          "0111" when cntDig = "11" else
          "1111";

    dig <= regSsg(15 downto 12) when cntDig = "00" else
           regSsg(11 downto  8) when cntDig = "01" else
           regSsg( 7 downto  4) when cntDig = "10" else
           regSsg( 3 downto  0);

    -- Map the internal signals to the pins on the CPLD.
    rgbSsgAn <= an;
    rgbSsgCa <= '1' & (not ssg);

    kclk <= kcin;
    kdat <= kdin;

end Behavioral;
```