



Introduction to WebPACK 6.3

Using Xilinx WebPACK Software to Create
FPGA Designs for the XSA Board

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What This Is and *Is Not*

There are numerous requests on newgroups that go something like this:

"I am new to using programmable logic like FPGAs and CPLDs. How do I start? Is there a tutorial and some free tools I can use to learn more?"

XILINX has released their WebPACK on the web so that anyone can download a free set of tools for CPLD and FPGA-based logic designs. And XESS Corp. has written this tutorial that attempts to give you a gentle introduction to using the WebPACK tools. (Other programmable logic manufacturers have also released free toolsets. Someone else will have to write a tutorial for them.)

This tutorial shows the use of the WebPACK tools on two simple design examples: 1) an LED decoder and 2) a counter which displays its current value on a seven-segment LED. Along the way, you will see:

- How to start an FPGA project.
- How to target a design to a particular type of FPGA.
- How to describe a logic circuit using VHDL and/or schematics.
- How to detect and fix VHDL syntactical errors.
- How to synthesize a netlist from a circuit description.
- How to fit the netlist into an FPGA.
- How to check device utilization and timing for an FPGA.
- How to generate a bitstream for an FPGA.
- How to download a bitstream into an FPGA.
- How to test the programmed FPGA.

That said, it is important to say what this tutorial will not teach you:

- It will not teach you how to design logic with VHDL.
- It will not teach you how to choose the best type of FPGA or CPLD for your design.

- It will not teach you how to arrange your logic for the most efficient use of the resources in an FPGA.
- It will not teach you what to do if your design doesn't fit in a particular FPGA.
- It will not show you every feature of the WebPACK software and discuss how to set every option and property.
- It will not show you how to use the variety of peripheral devices available on the XSA Boards.

In short, this is just a tutorial to get you started using the XILINX WebPACK FPGA tools. After you go through this tutorial you should be able to move on to more advanced topics.

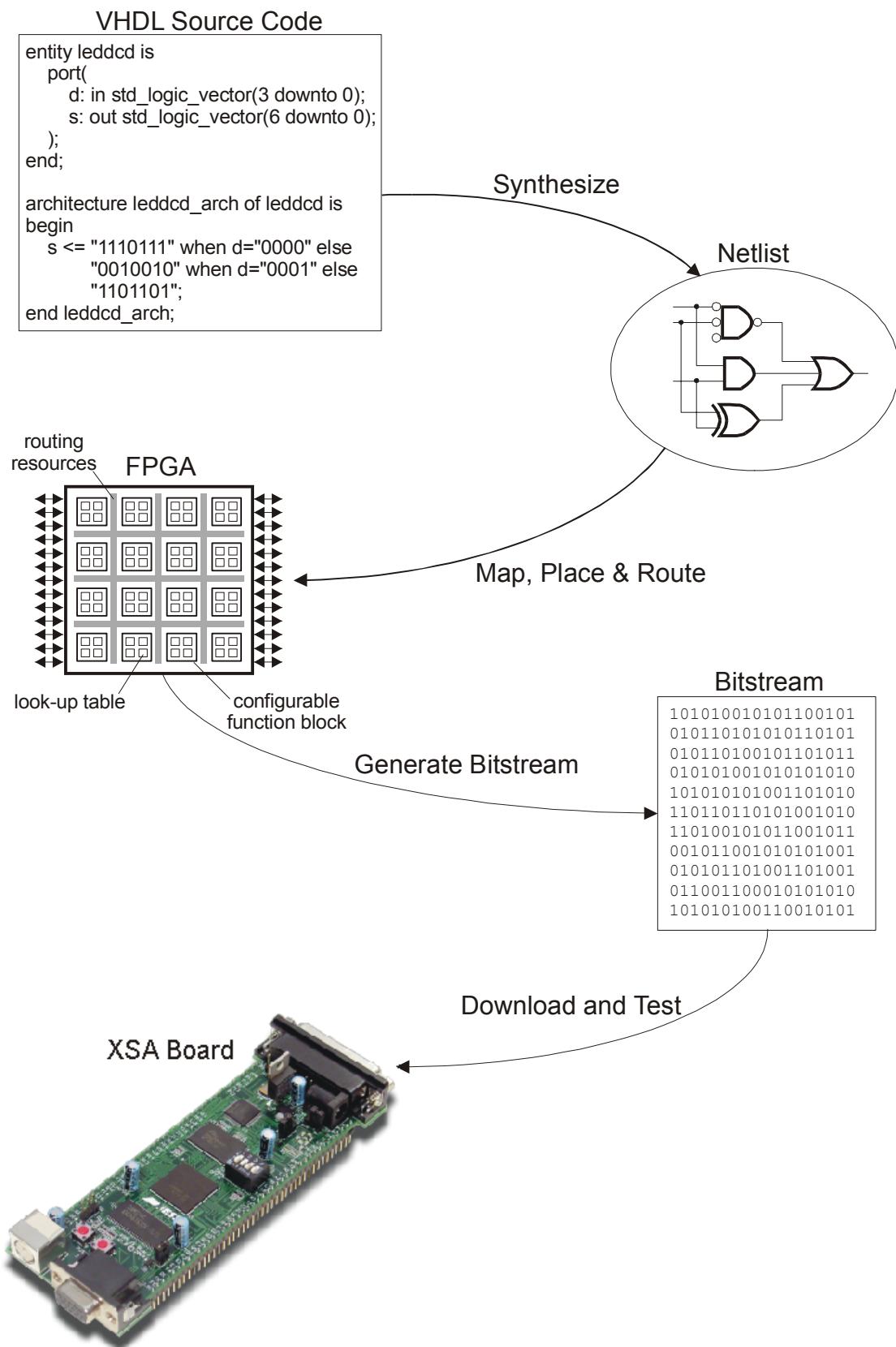
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FPGA Programming

Implementing a logic design with an FPGA usually consists of the following steps (depicted in the figure which follows):

1. You enter a description of your logic circuit using a *hardware description language* (HDL) such as VHDL or Verilog. You can also draw your design using a schematic editor.
2. You use a *logic synthesizer* program to transform the HDL or schematic into a *netlist*. The netlist is just a description of the various logic gates in your design and how they are interconnected.
3. You use the *implementation tools* to map the logic gates and interconnections into the FPGA. The FPGA consists of many *configurable logic blocks* which can be further decomposed into *look-up tables* that perform logic operations. The CLBs and LUTs are interwoven with various *routing resources*. The mapping tool collects your netlist gates into groups that fit into the LUTs and then the place & route tool assigns the groups to specific CLBs while opening or closing the switches in the routing matrices to connect them together.
4. Once the implementation phase is complete, a program extracts the state of the switches in the routing matrices and generates a *bitstream* where the ones and zeroes correspond to open or closed switches. (This is a bit of a simplification, but it will serve for the purposes of this tutorial.)
5. The bitstream is *downloaded* into a physical FPGA chip (usually embedded in some larger system). The electronic switches in the FPGA open or close in response to the binary bits in the bitstream. Upon completion of the downloading, the FPGA will perform the operations specified by your HDL code or schematic.

That's really all there is to it. XILINX WebPACK provides the HDL and schematic editors, logic synthesizer, fitter, and bitstream generator software. The XSTOOLS from XESS provide utilities for downloading the bitstream into the FPGA on the XSA Board.

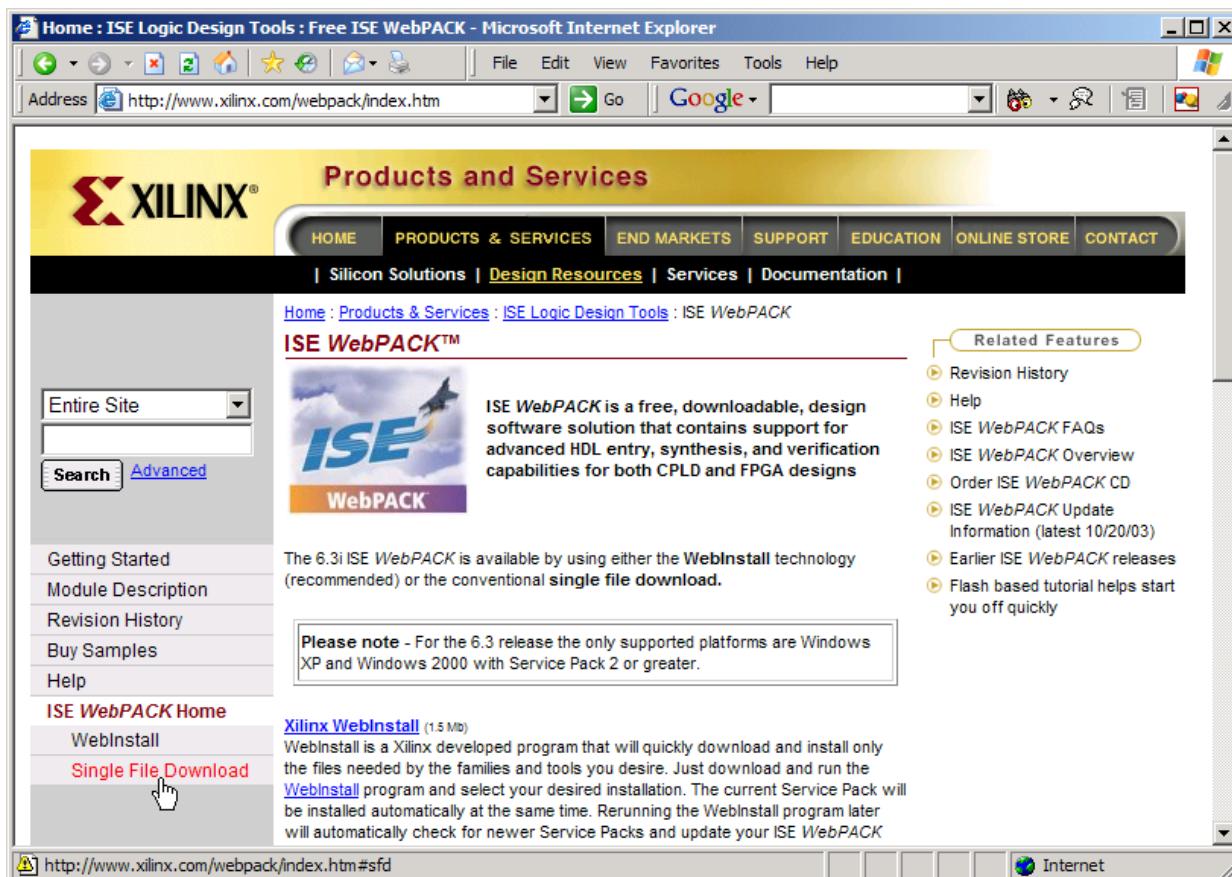


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Installing WebPACK

Getting WebPACK

Before downloading the WebPACK software you will have to [create an account](#). You will choose a user ID and password and then you will be allowed to enter the site. Then you can go to <http://www.xilinx.com/webpack/index.htm> to begin downloading the WebPACK software. After entering the WebPACK homepage, click on the [Single File Download](#) link as shown below.



Next, click on the [Complete ISE WebPACK Software](#) link. This will initiate the download of all the WebPACK software modules that cover both FPGA and CPLD designs. After this download completes, you also need to download [Service Pack 3](#) to get the most current WebPACK updates.

ISE WebPACK Download Module (service pack required - see information below)	Download Size	PLD Design Environment	CPLD Device Support	FPGA Device Support
Complete ISE WebPACK Software - includes programming tools	207 Mb*	✓	✓	✓
Complete CPLD Tool Set - includes programming tools	130 Mb*	✓	✓	
Complete Programming Tools	45 Mb*		✓	✓

* Customers installing the above WebPACK modules also need to download and install the latest Service Pack. The latest service pack can be found [here](#).

Installing WebPACK

After the WebPACK software download completes, double-click the WebPACK_63_fcfull_i.exe file. The installation script will run and install the software. Accept the default settings for everything and you shouldn't have any problems. Then update the WebPACK software by running the Service Pack 3 install file 6_3_03i_pc.exe.

Getting XSTOOLS

If you are going to download your FPGA bitstreams into an XSA Board, then you will need to get the XSTOOLS software from <http://www.xess.com/ho07000.html>. Just download the [xstools4_0_5.exe](#) file.

Installing XSTOOLS

Double-click the xstools4_0_5.exe file. The installation script will run and install the software. Accept the default settings for everything.

Getting the Design Examples

You can download the project files for the designs shown in this tutorial from http://www.xess.com/projects/webpack-6_3-xsa.zip. The ZIP file contains versions of the project files for each XSA Board model.

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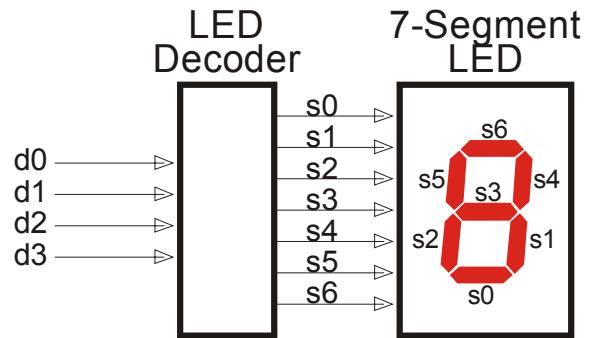
Our First Design

An LED Decoder

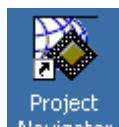
The first FPGA design you will try is an LED decoder. An LED decoder takes a four-bit input and outputs seven signals which drive the segments of an LED digit. The LED segments will be driven to display the digit corresponding to the hexadecimal value of the four input bits as follows:

Four-bit Input	Hex Digit	LED Display
0000	0	0
0001	1	1
0010	2	2
0011	3	3
0100	4	4
0101	5	5
0110	6	6
0111	7	7
1000	8	8
1001	9	9
1010	A	A
1011	B	b
1100	C	c
1101	D	d
1110	E	E
1111	F	F

A high-level diagram of the LED decoder looks like this:

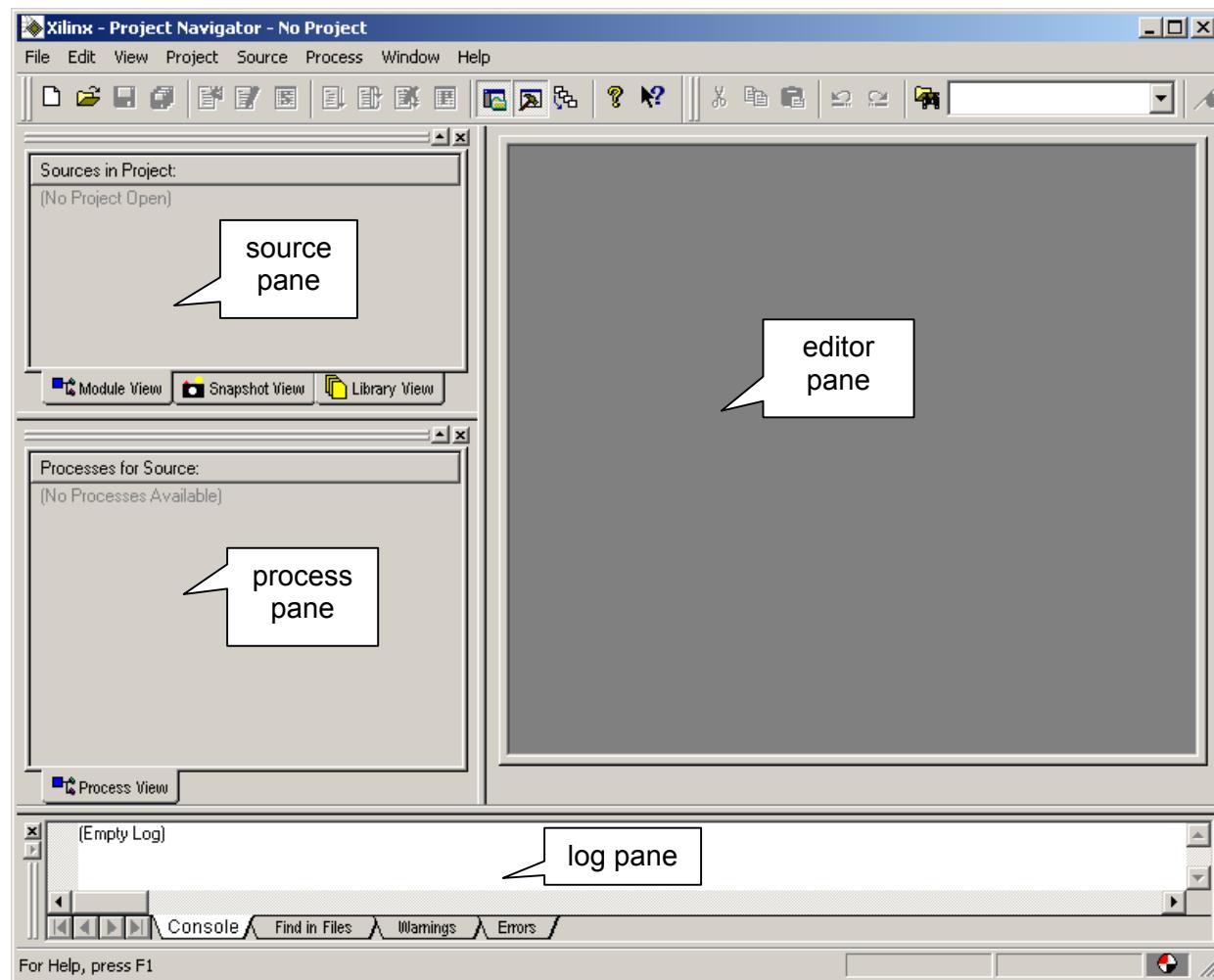


Starting WebPACK Project Navigator

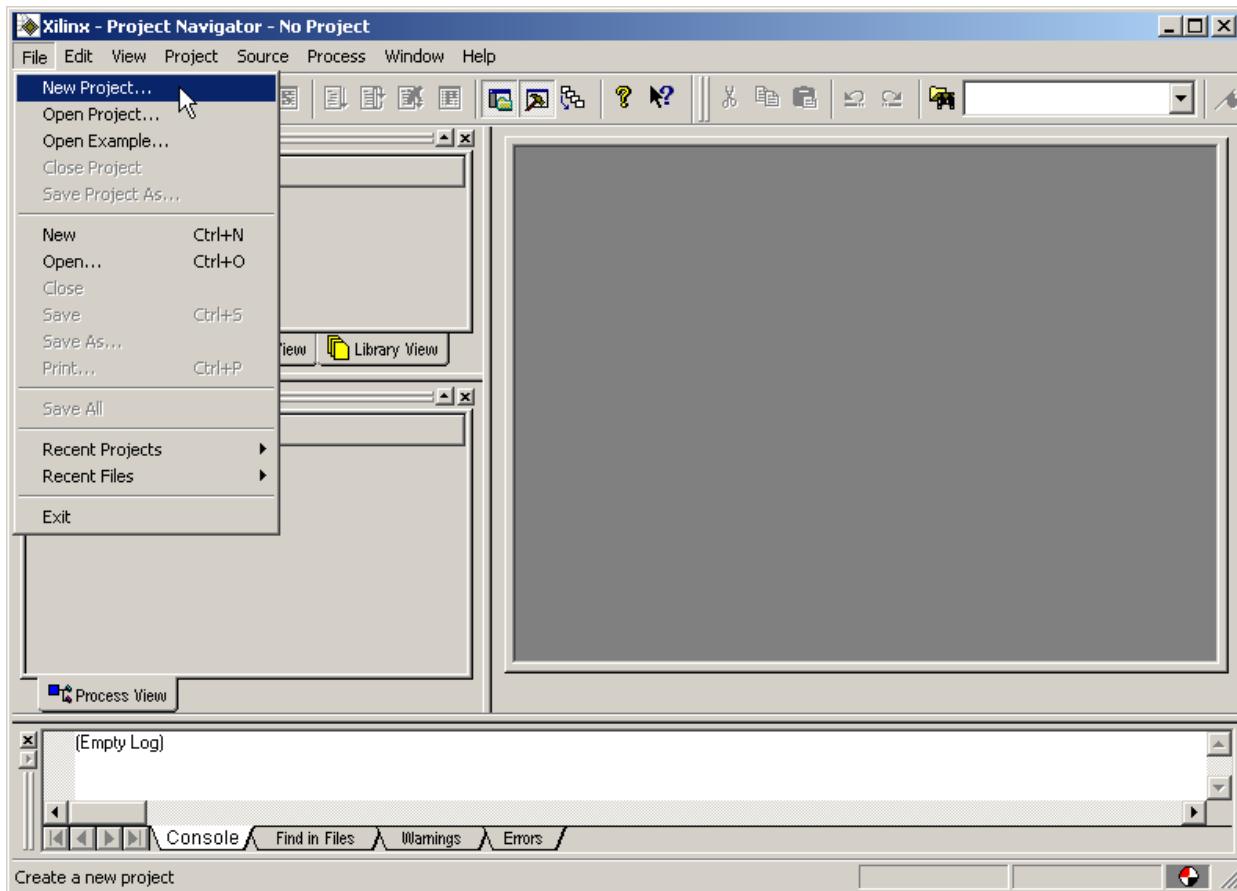


You start WebPACK by double-clicking the **Project Navigator** icon, ,on the desktop. This will bring up an empty project window as shown below. The window has four panes:

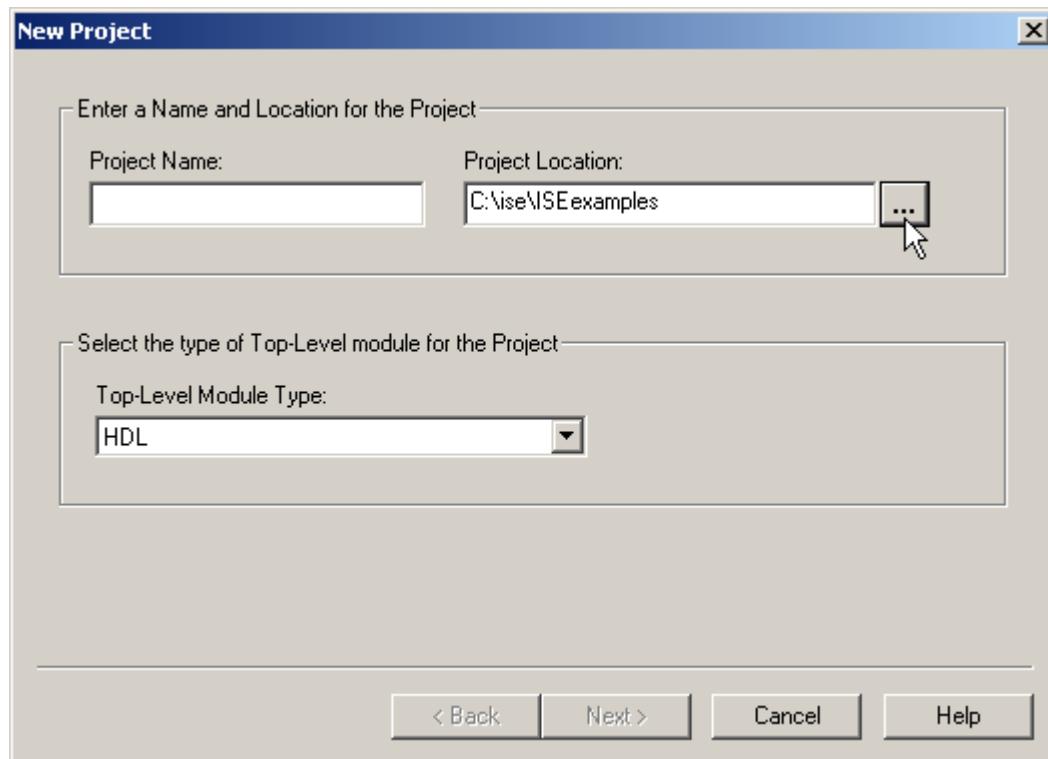
1. A **source pane** that shows the organization of the source files that make up your design. There are three tabs so you can view the functional modules, or HDL libraries for your project or look at various snapshots of the project.
2. A **process pane** that lists the various operations you can perform on a given object in the source pane.
3. A **log pane** that displays the various messages from the currently running process.
4. An **editor pane** where you can enter HDL code. Schematics are entered in a separate window.



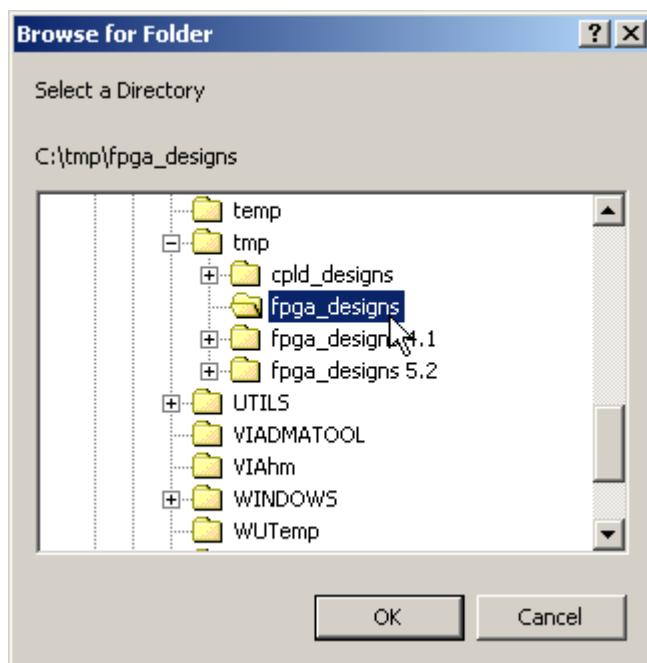
To start your design, create a new project by selecting the File→New Project item from the menu bar.



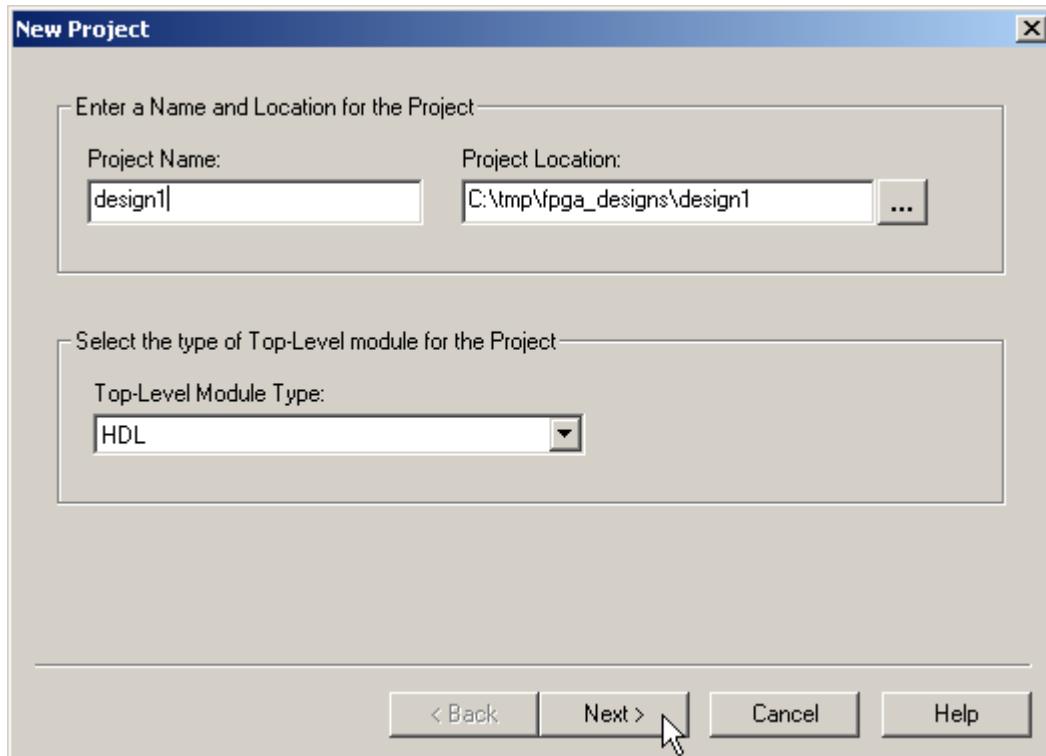
This brings up the **New Project** window where you can enter the location of your project files, project name, the target device for this design, and the tools used to synthesize logic from your source files.



Click on the ... button next to the Project Location field and use the **Browse for Folder** window to select a folder where your project files will be stored. For this tutorial, you will store everything in the C:\tmp\fpga_designs folder. Click on the OK button after highlighting this folder.



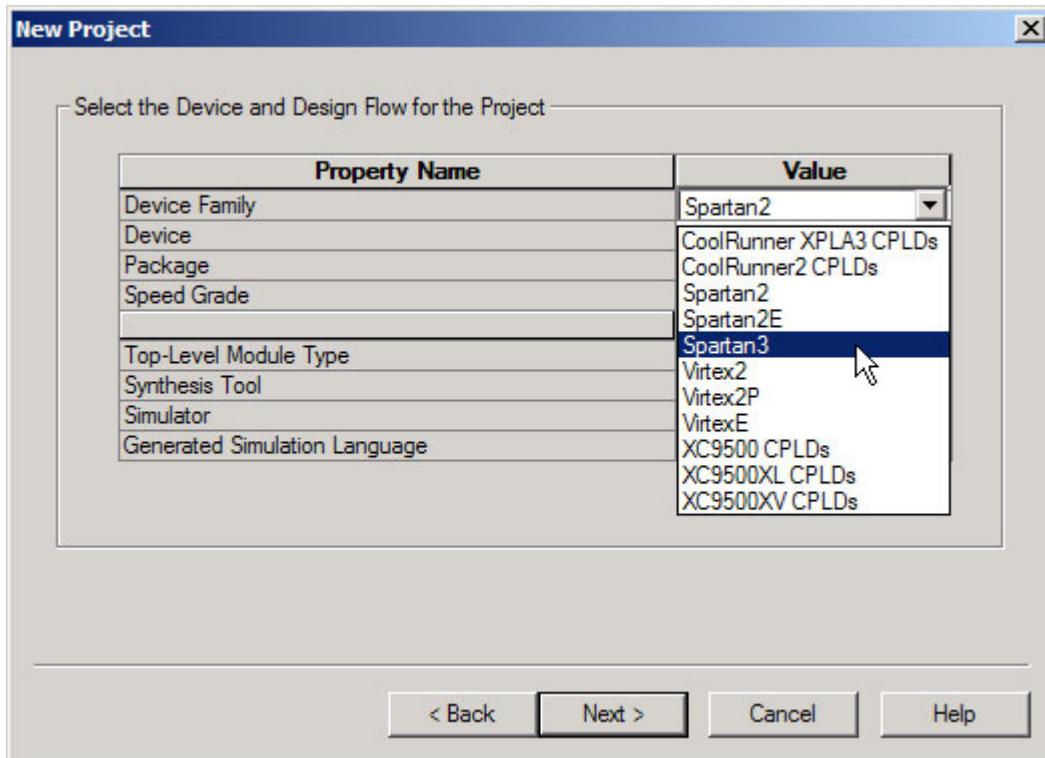
Next you will give your LED decoder design the descriptive title of `design1` by typing it into the Project name field. Then click on the Next button to continue creating this project.



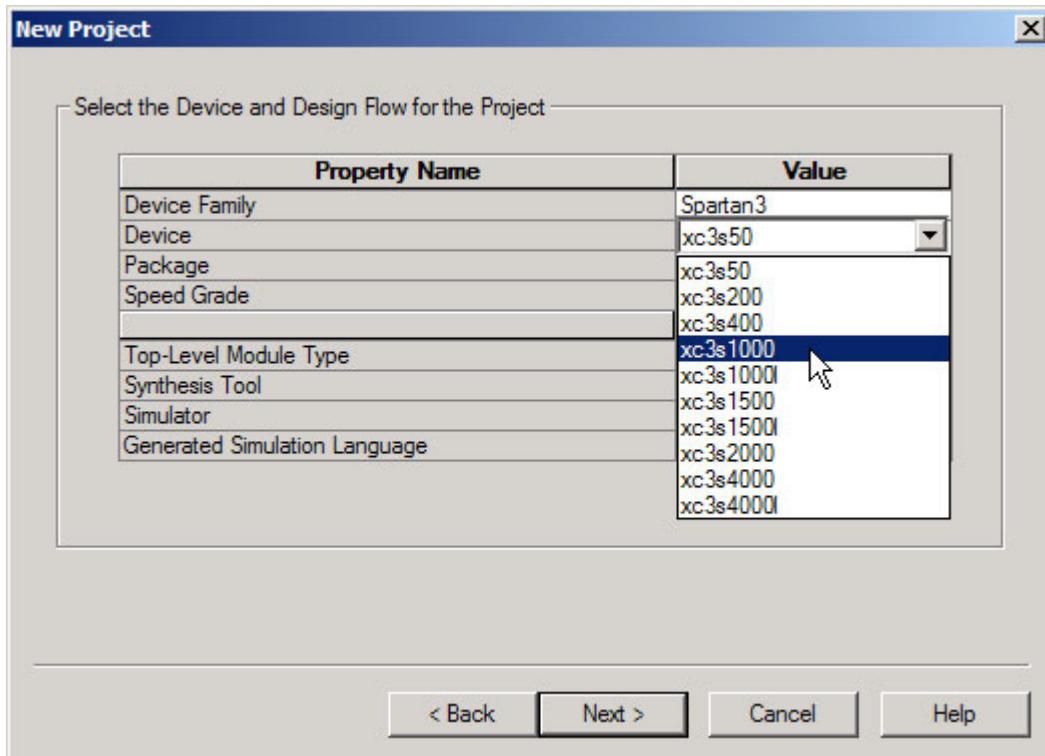
Now you need to tell WebPACK what FPGA you are going to use for your design. The device family, family member, package and speed grade for the FPGA on each model of XSA Board is shown below.

XSA Board	Device Family	Device	Package	Speed Grade
XSA-50	Spartan2	xc2s50	tq144	-5
XSA-100	Spartan2	xc2s100	tq144	-5
XSA-200	Spartan2	xc2s200	fg256	-5
XSA-3S1000	Spartan3	xc3s1000	ft256	-4

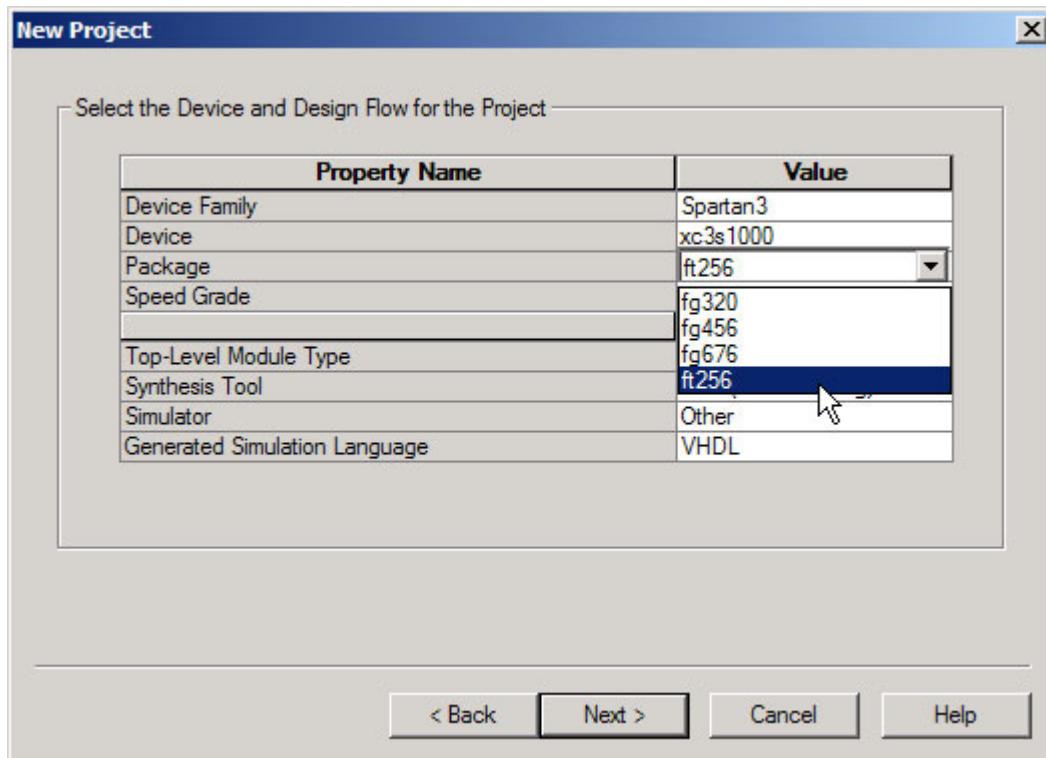
For this tutorial, you will target your design to the XSA-3S1000 Board. Click in the Value field of the Device Family property and select the Spartan3 entry in the drop-down menu that appears.



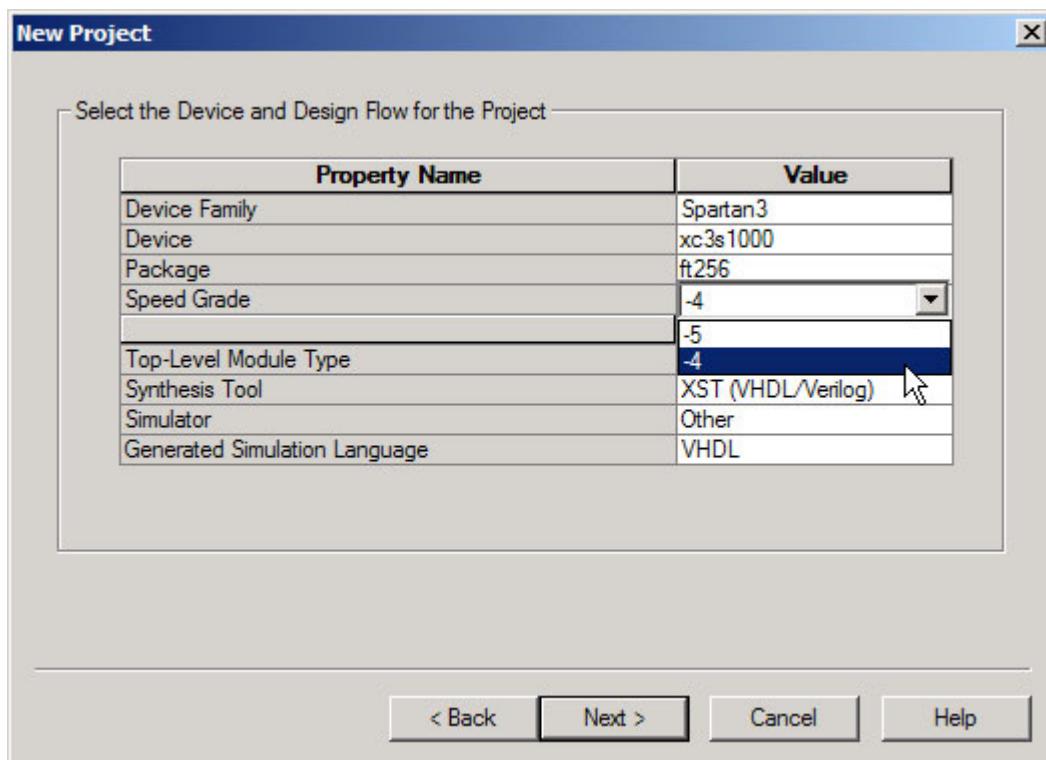
Then click in the Value field of the Device property and select the xc3s1000.



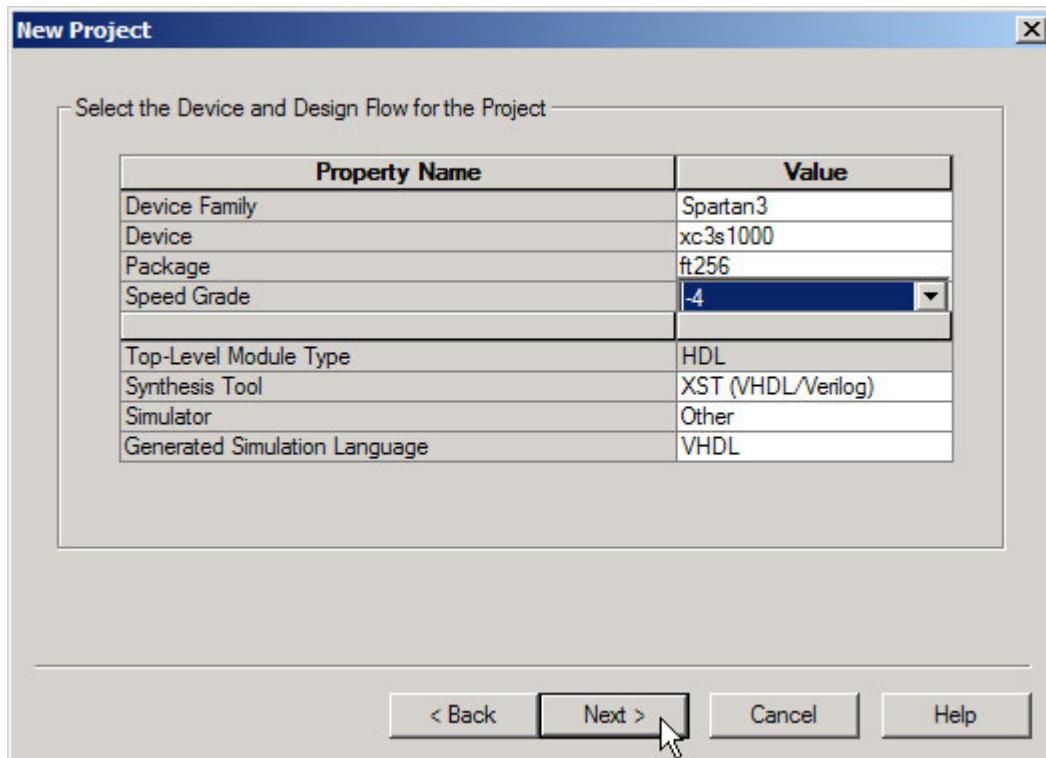
Now click in the Value field of the Package property and choose the ft256 package.



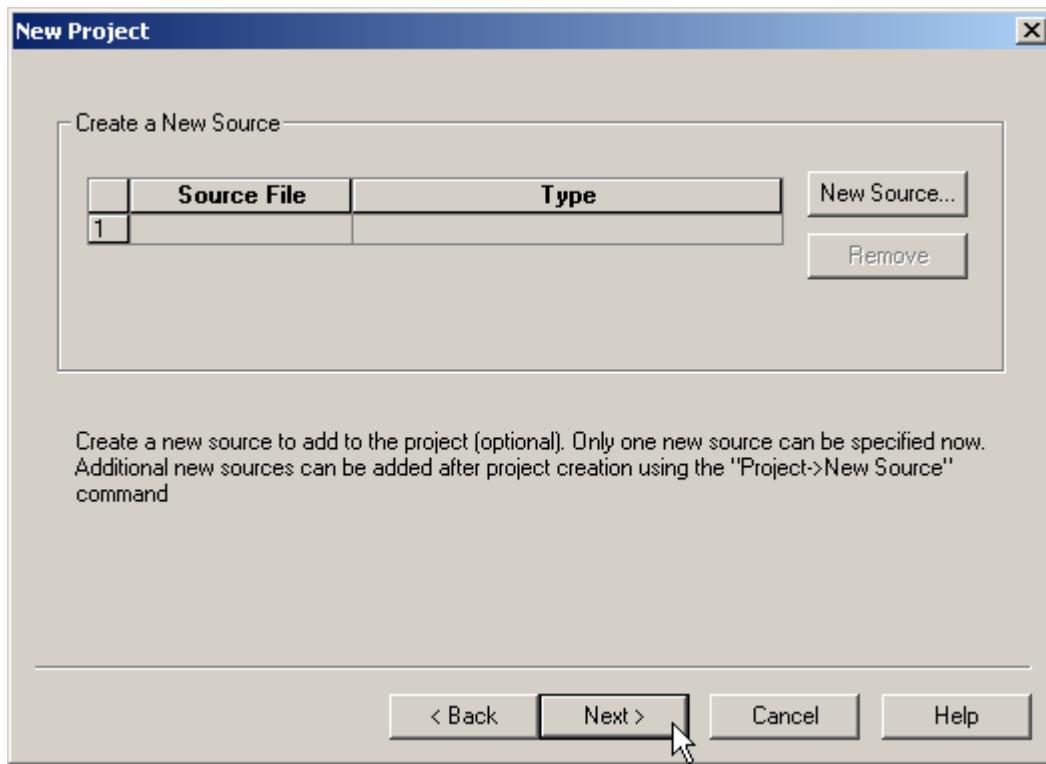
Then set the speed grade property for the FPGA to -4.



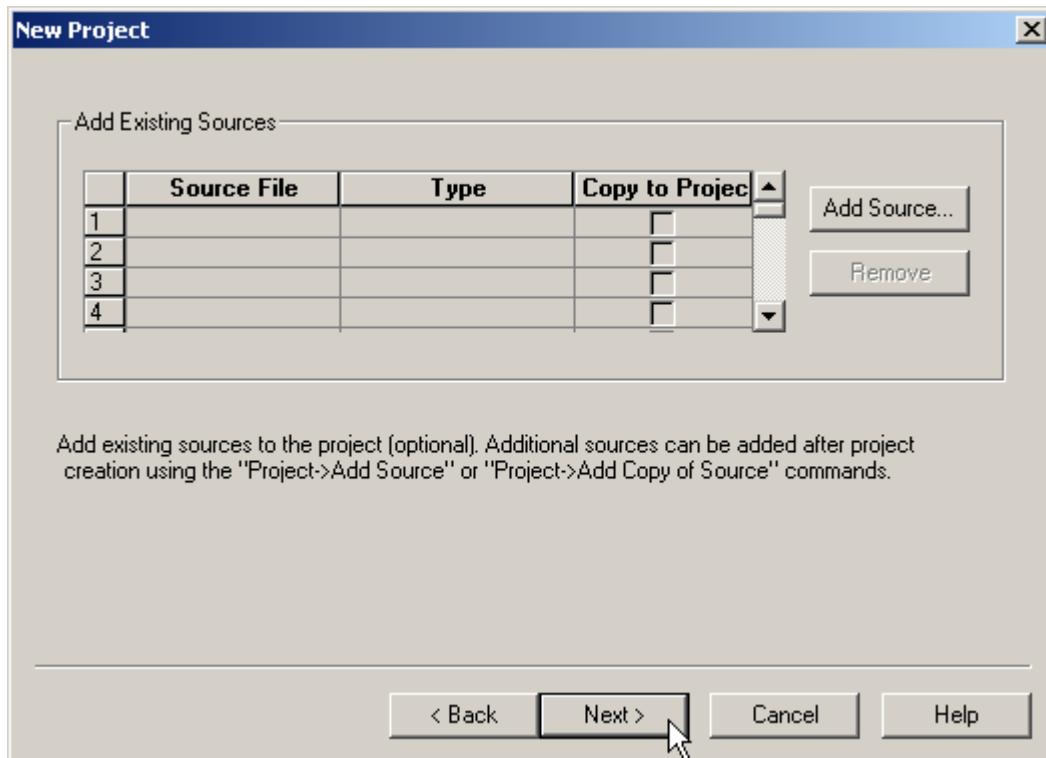
The Top-Level Module Type, Synthesis Tool, Simulator and Generated Simulation Language can all be left at their default values, so you can just click on the Next button to continue creating the project.



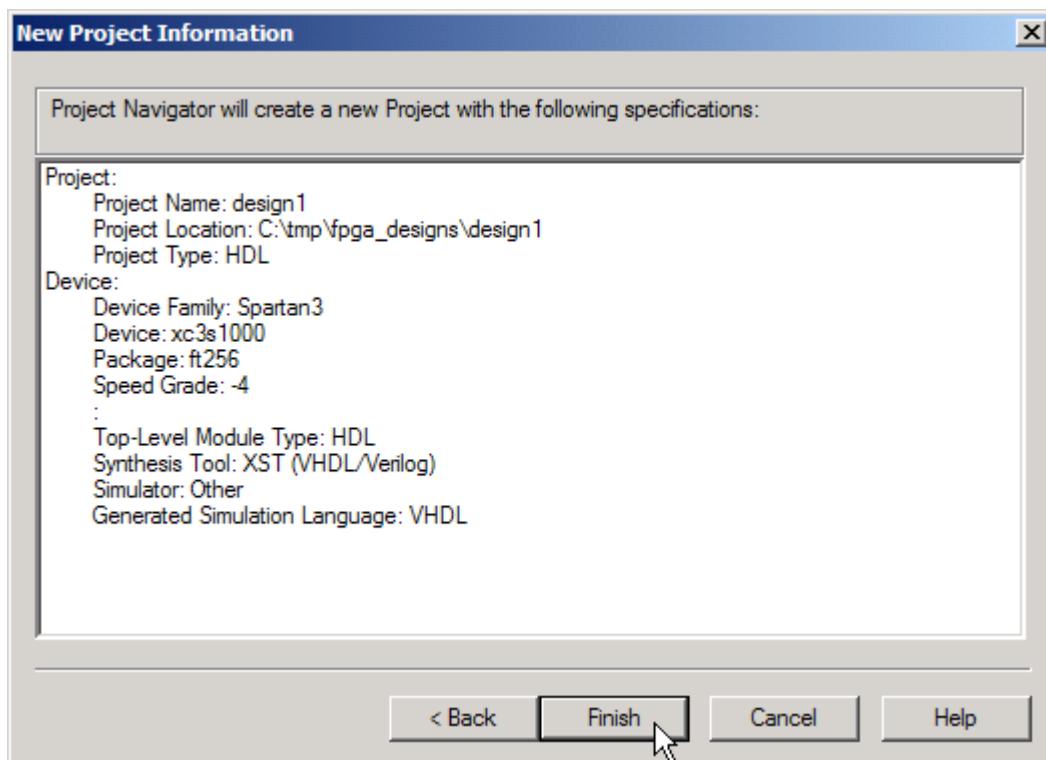
Click the Next button on the next window that appears. (You will create the VHDL source code at a later step.)



You have no existing source files to add to this project, so once again click the Next button.

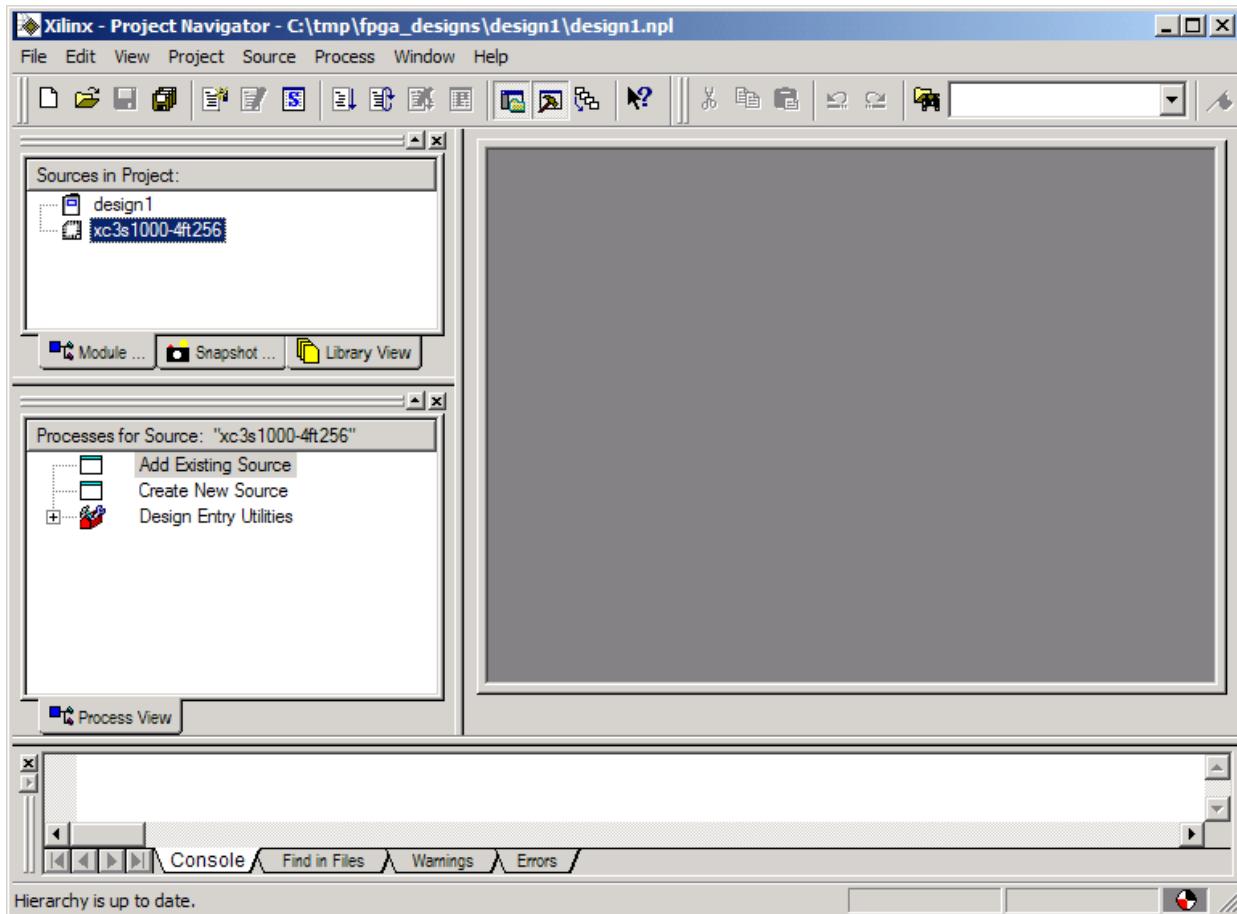


The final screen shows the pertinent information for the new project. Click on the Finish button to complete the creation of the project.



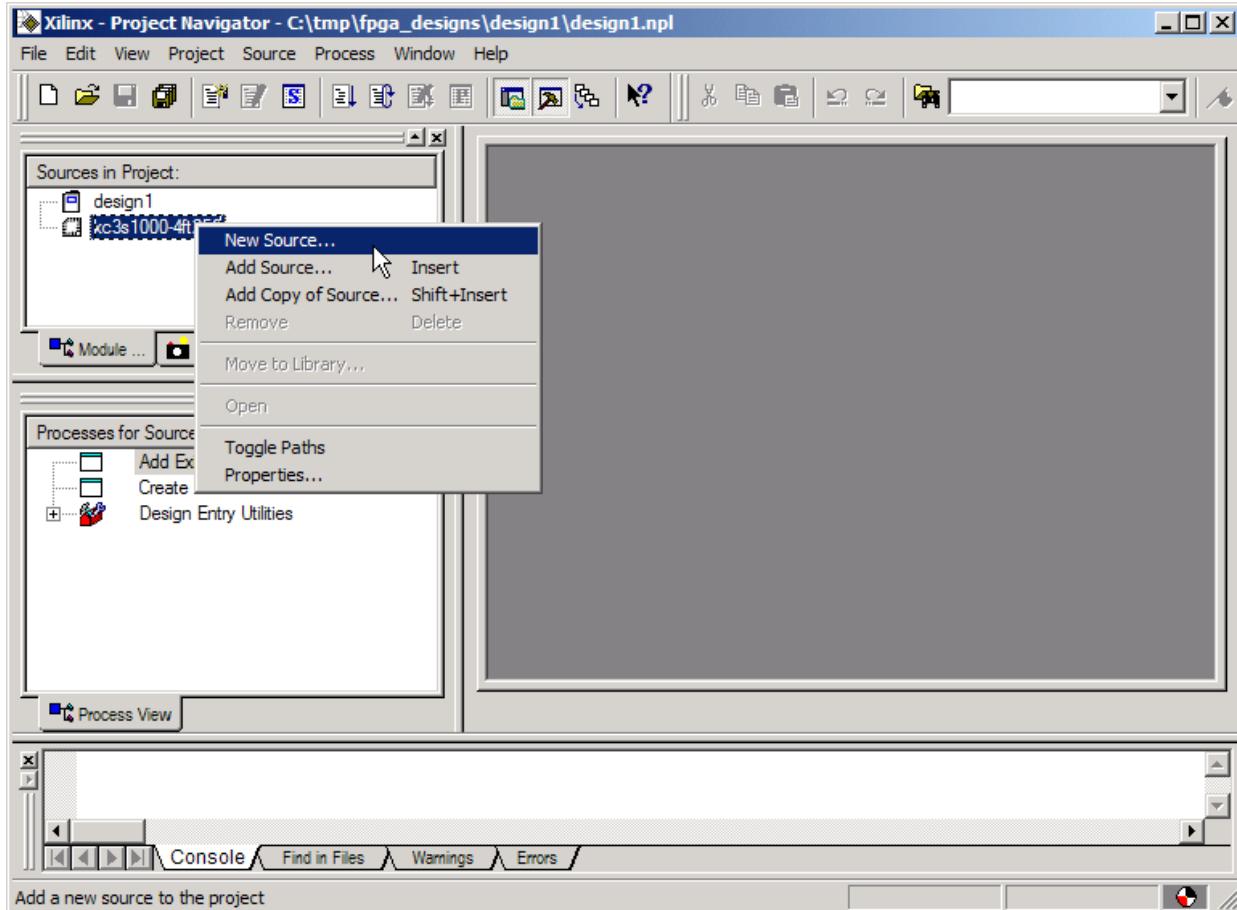
Now the Sources pane in the **Project Navigator** window contains two items:

1. A project object called design1.
2. A chip object called xc3s1000-4ft256.

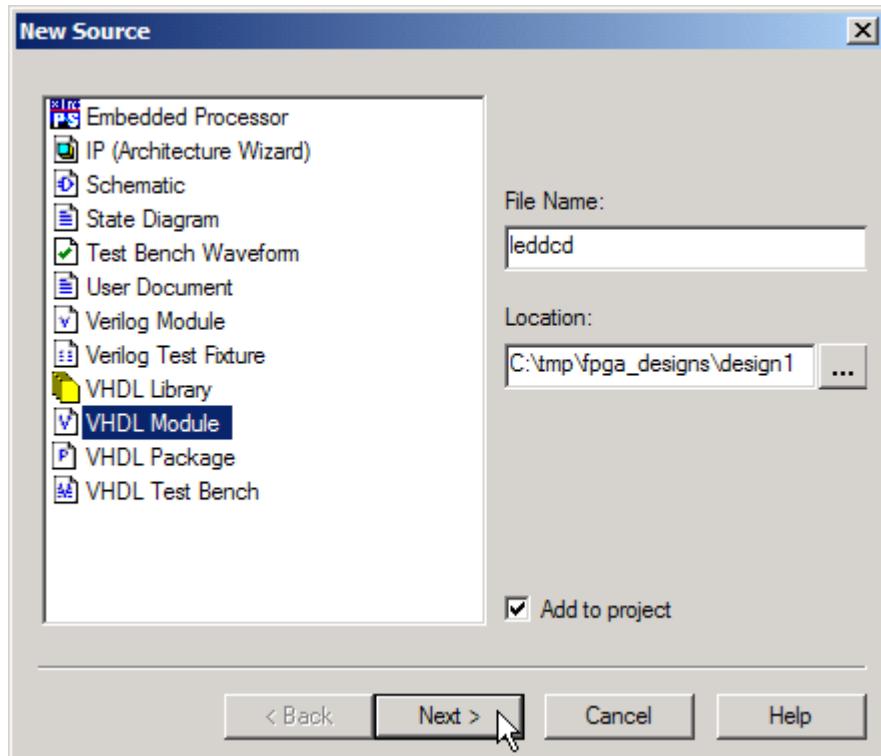


Describing Your Design With VHDL

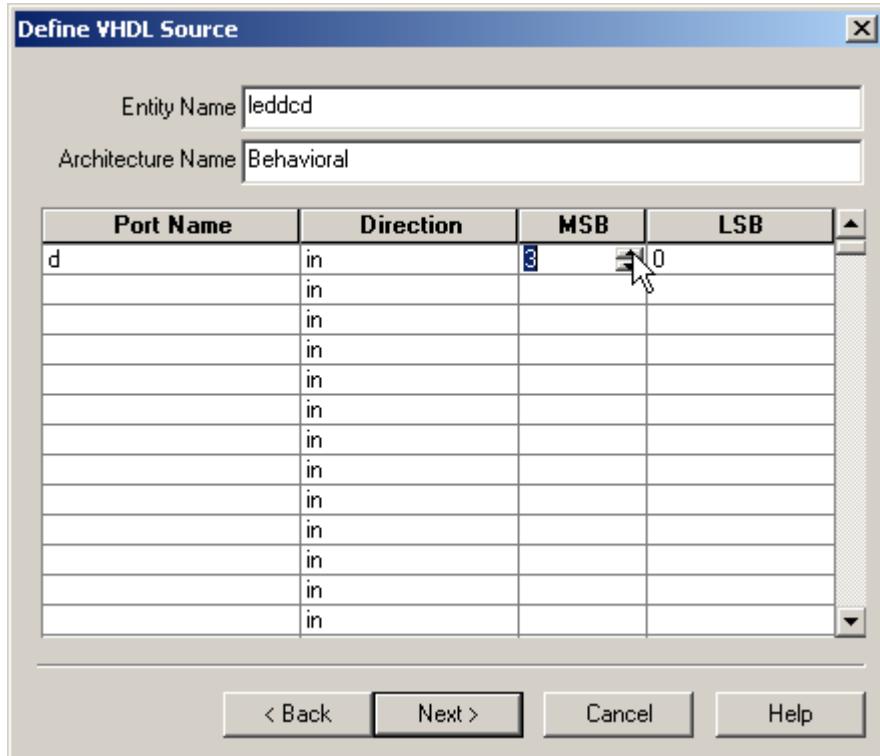
Once all the project set-up is complete, you can begin to actually design your LED decoder circuit. Start by adding a VHDL file to the **design1** project. Right-click on the xc3s1000-4ft256 object in the Sources pane and select New Source ... from the pop-up menu as shown below.



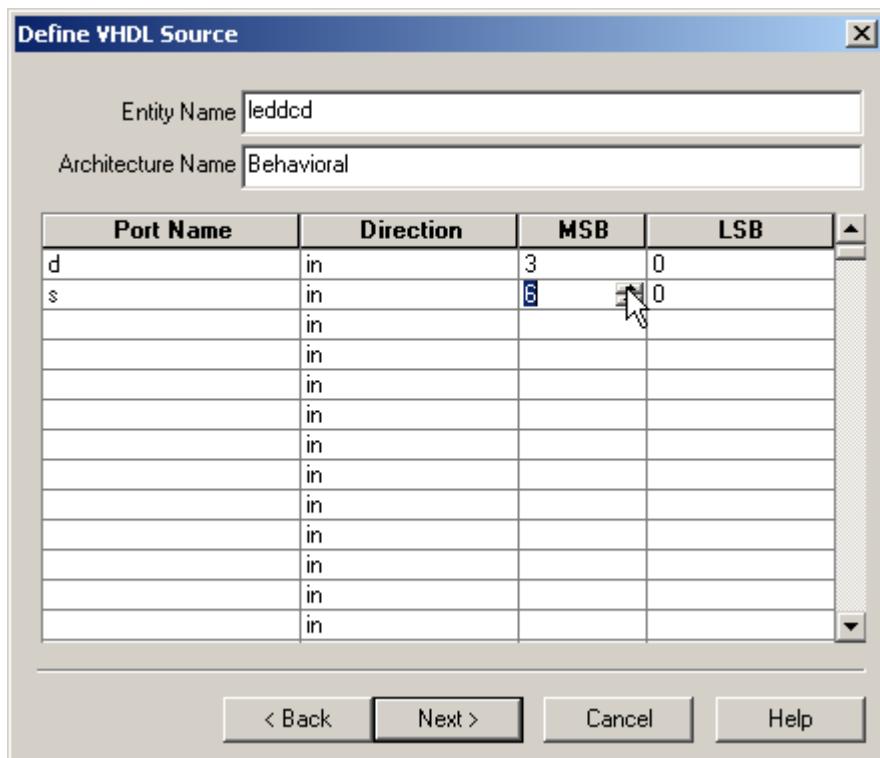
This causes a window to appear where you must select the type of source file you want to add. Since you are describing the LED decoder with VHDL, highlight the VHDL Module item. Then type the name of the module, ledgcd, into the File Name field and click on Next.



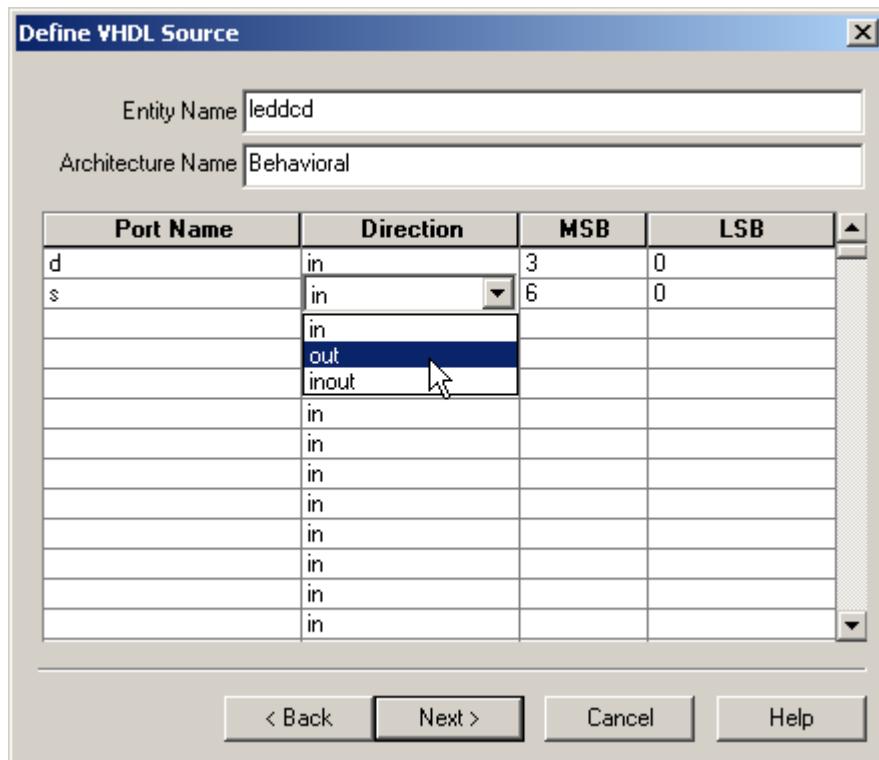
The **Define VHDL Source** window now appears where you can declare the inputs and outputs to the LED decoder circuit. In the first row, click in the Port Name field and type in `d` (the name of the inputs to the LED decoder). The `d` input bus has a width of four, so click in the MSB field and increment the upper range of the input field to 3 while leaving 0 in the LSB field.



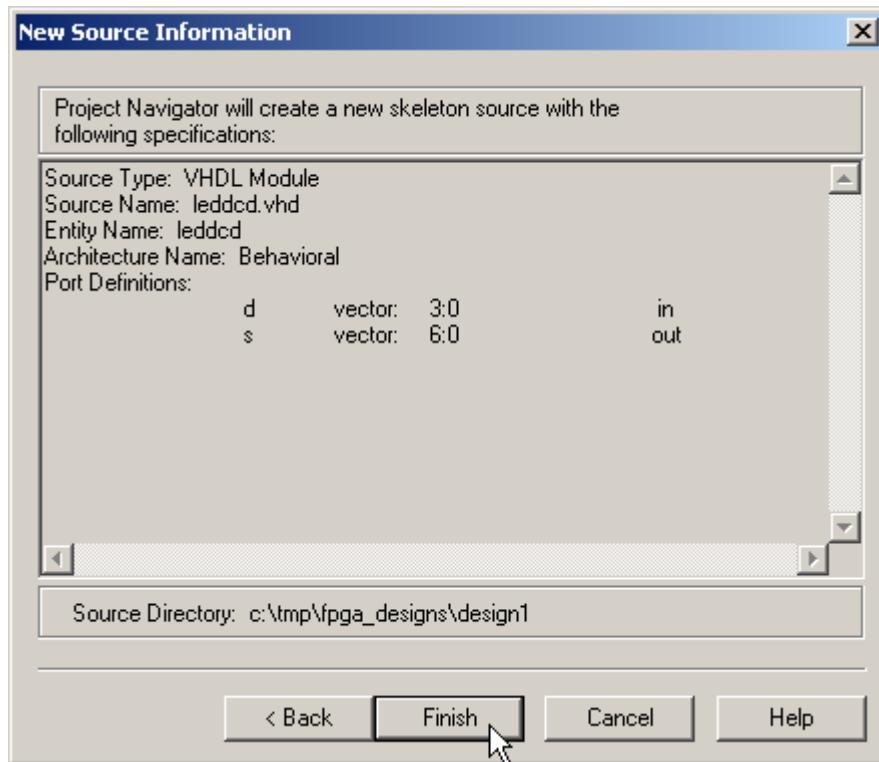
Perform the same operations to create the seven-bit wide **s** bus that drives the LEDs.



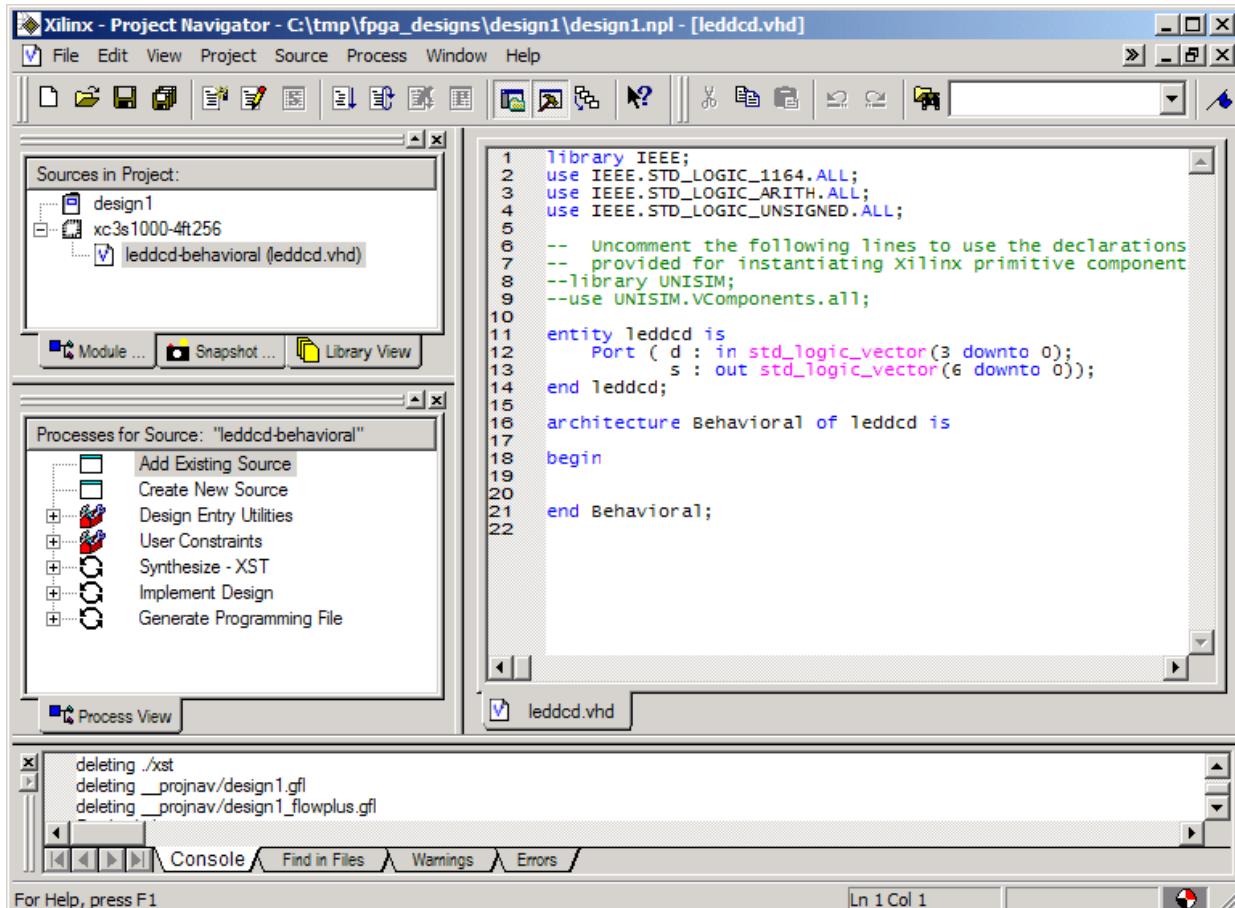
You must also click in the Direction field for the **s** bus and select out from the drop-down menu in order to make the **s** bus signals into outputs.



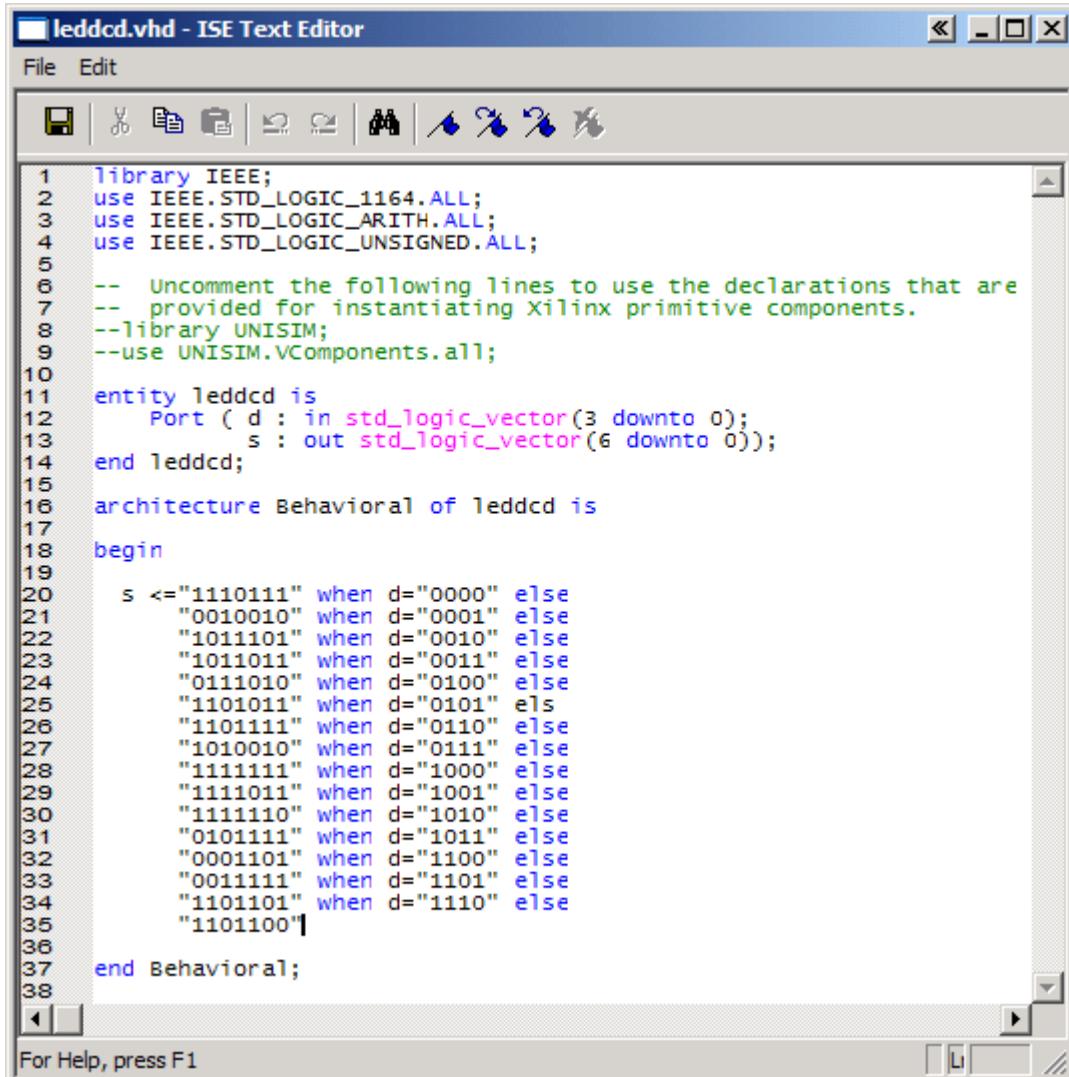
Click on Next in the **Define VHDL Source** window to get a summary of the information you just typed in:



After clicking on Finish, the editor pane of the **Project Navigator** window displays a VHDL skeleton for your LED decoder. (You can also see the ledcd.vhd file has been added to the Sources pane.) Lines 1-4 create links to the IEEE library and packages that contain various useful definitions for describing a design. The LED decoder inputs and outputs are declared in the VHDL entity on lines 11-14. You will describe the logic operations of the decoder in the architecture section between lines 18 and 21.



The completed VHDL file for the LED decoder is shown below. The architecture section contains a single statement which assigns a particular seven-bit pattern to the **s** output bus for any given four-bit input on the **d** bus (lines 20-35).



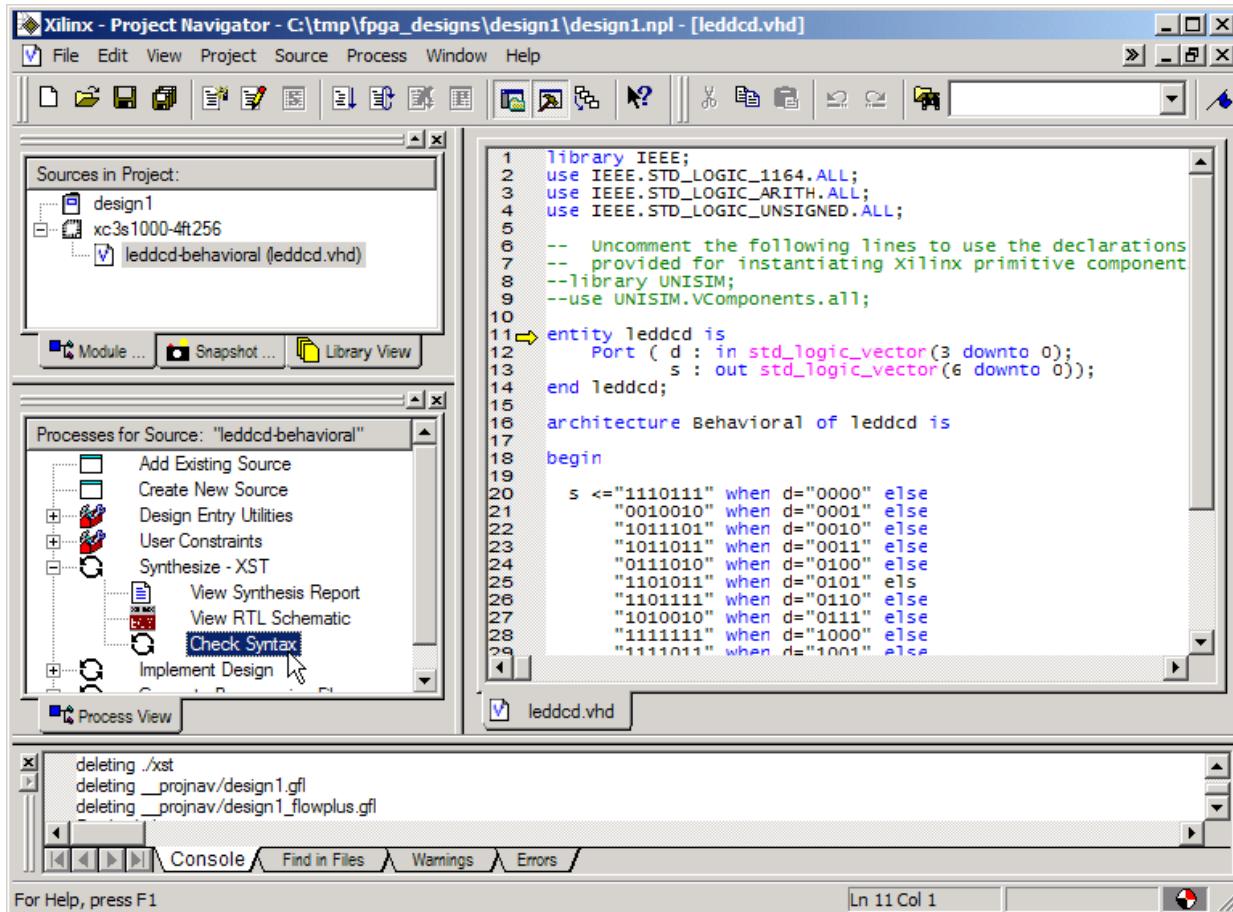
The screenshot shows the ISE Text Editor window with the title "leddcd.vhd - ISE Text Editor". The code is a VHDL entity and architecture definition for a 4-to-7 LED decoder. The entity "leddcd" has a 4-bit input "d" and a 7-bit output "s". The architecture "Behavioral" contains a large case statement that maps each 4-bit input value to a specific 7-bit output value for a 7-segment LED display. The code is color-coded for readability, with keywords in blue and comments in green.

```
1 library IEEE;
2 use IEEE.STD_LOGIC_1164.ALL;
3 use IEEE.STD_LOGIC_UNSIGNED.ALL;
4 use IEEE.STD_LOGIC_ARITH.ALL;
5
6 -- Uncomment the following lines to use the declarations that are
7 -- provided for instantiating Xilinx primitive components.
8 --library UNISIM;
9 --use UNISIM.VComponents.all;
10
11 entity leddcd is
12     Port ( d : in std_logic_vector(3 downto 0);
13             s : out std_logic_vector(6 downto 0));
14 end leddcd;
15
16 architecture Behavioral of leddcd is
17
18 begin
19
20     s <="1110111" when d="0000" else
21         "0010010" when d="0001" else
22         "1011101" when d="0010" else
23         "1011011" when d="0011" else
24         "0111010" when d="0100" else
25         "1101011" when d="0101" else
26         "1101111" when d="0110" else
27         "1010010" when d="0111" else
28         "1111111" when d="1000" else
29         "1111011" when d="1001" else
30         "1111110" when d="1010" else
31         "0101111" when d="1011" else
32         "0001101" when d="1100" else
33         "0011111" when d="1101" else
34         "1101101" when d="1110" else
35         "1101100";
36
37 end Behavioral;
38
```

Once the VHDL source is entered, click on the  button to save it in the leddcd.vhd file.

Checking the VHDL Syntax

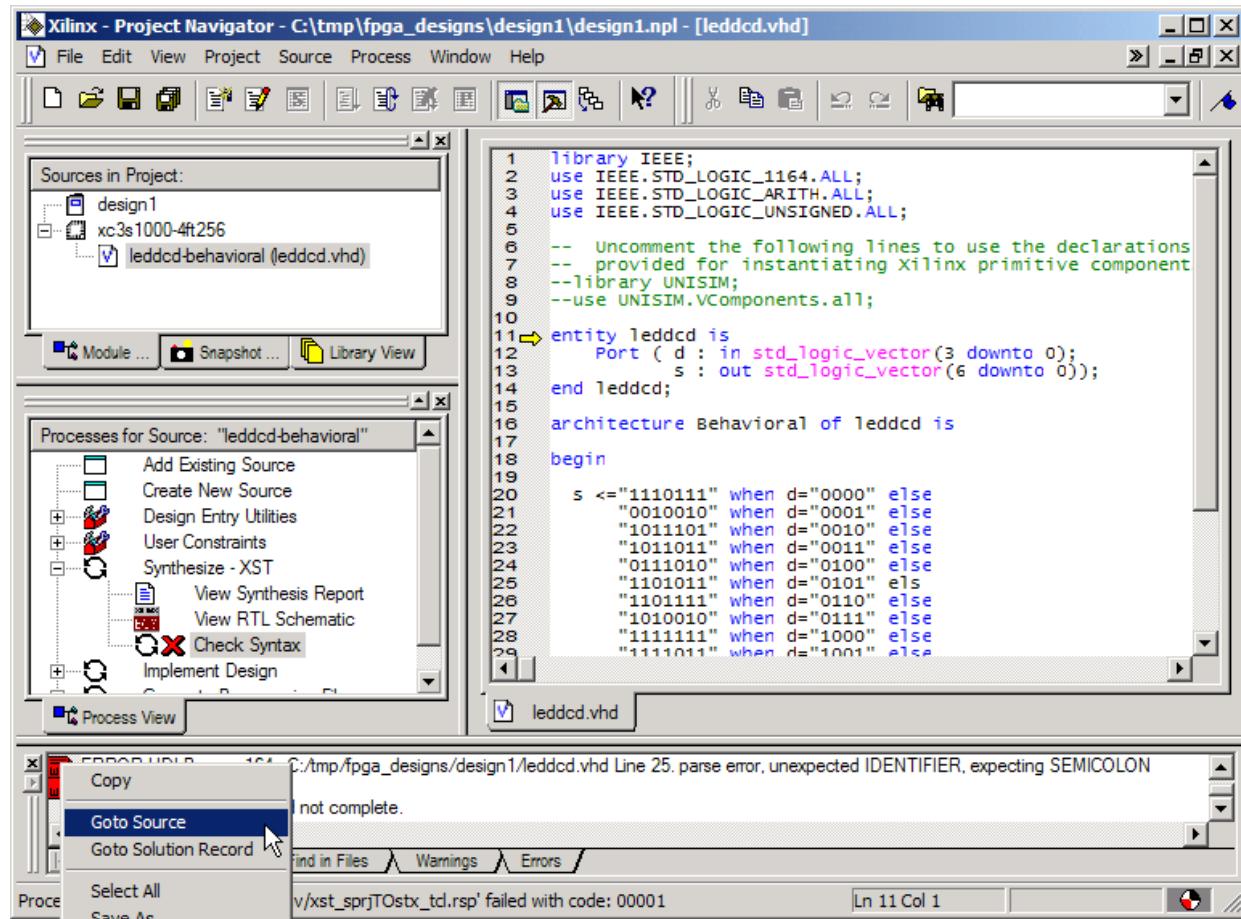
You can check for errors in our VHDL by highlighting the ledcd object in the Sources pane and then double-clicking on Check Syntax in the Process pane as shown below.



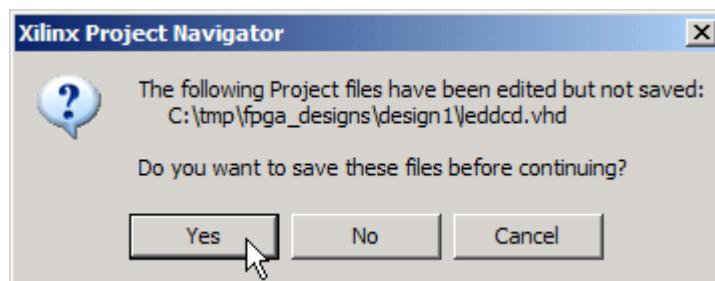
The syntax checking tool grinds away and then displays the result in the process window. In this case, an error was found as indicated by the **X** next to the Check Syntax process. But what is the error and where is it?

Fixing VHDL Errors

You can find the location of the error by scrolling the log pane at the bottom of the **Project Navigator** window until you find an error message. In this case, the error is located on line 25 and you can manually scroll there. You can also right-click on the error message in the log pane to go directly to the erroneous source. (This is most useful in more complicated projects consisting of multiple source files.)



On line 25, you can see that the 'e' was left off the end of the `else` keyword. After correcting this error, double-click the on `Check Syntax` in the Process pane to re-check the VHDL code. You will be asked to save the file before the syntax check proceeds. Click on Yes.



The syntax checker now finds another error on line 37 of the VHDL code.

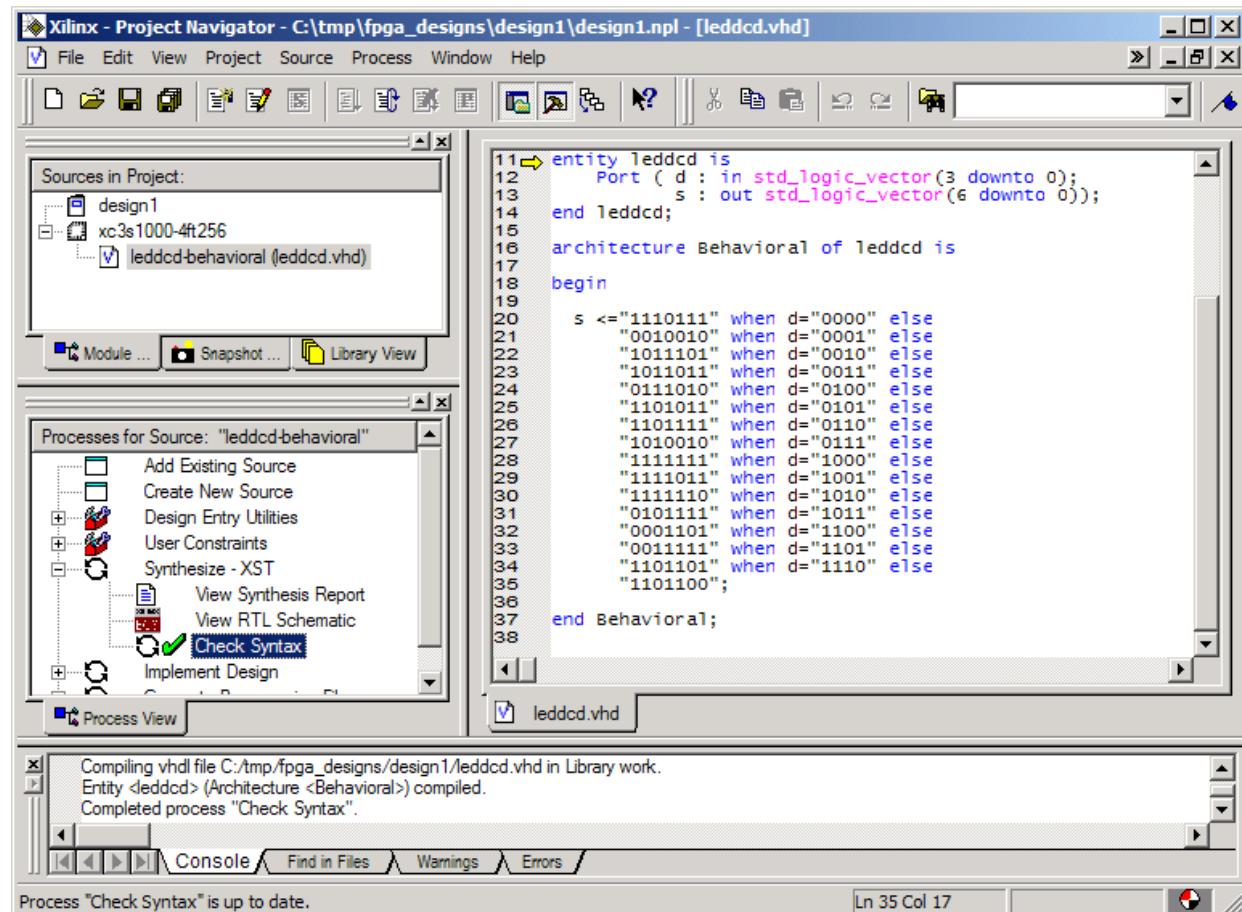
The screenshot shows the Xilinx Project Navigator interface. The top menu bar includes File, Edit, View, Project, Source, Process, Window, and Help. The left sidebar displays 'Sources in Project' with 'design1' and 'xc3s1000-4ft256' selected, and 'leddcd-behavioral (leddcd.vhd)' expanded. Below it is the 'Processes for Source: "leddcd-behavioral"' panel, which lists options like Add Existing Source, Create New Source, Design Entry Utilities, User Constraints, Synthesize - XST, View Synthesis Report, View RTL Schematic, Check Syntax (which is highlighted with a red X), Implement Design, and Process View. The main central area shows the VHDL code for 'leddcd.vhd'. Line 37 contains the error: 'end Behavioral;'. The bottom status bar indicates 'Process 'xst_sprjTOstx.tcl __projnav/xst_sprjTOstx_tcl.rsp' failed with code: 00001' and 'Ln 37 Col 1'.

```
entity leddcd is
    Port ( d : in std_logic_vector(3 downto 0);
           s : out std_logic_vector(6 downto 0));
end leddcd;
architecture Behavioral of leddcd is
begin
    s <="1110111" when d="0000" else
        "0010010" when d="0001" else
        "1011101" when d="0010" else
        "10111011" when d="0011" else
        "0111010" when d="0100" else
        "0111011" when d="0101" else
        "1101011" when d="0110" else
        "1101111" when d="0111" else
        "1010010" when d="1000" else
        "1111111" when d="1001" else
        "1111110" when d="1010" else
        "0101111" when d="1011" else
        "0001101" when d="1100" else
        "0011111" when d="1101" else
        "1101101" when d="1110" else
        "1101100";
end Behavioral;
```

Console / Find in Files / Warnings / Errors

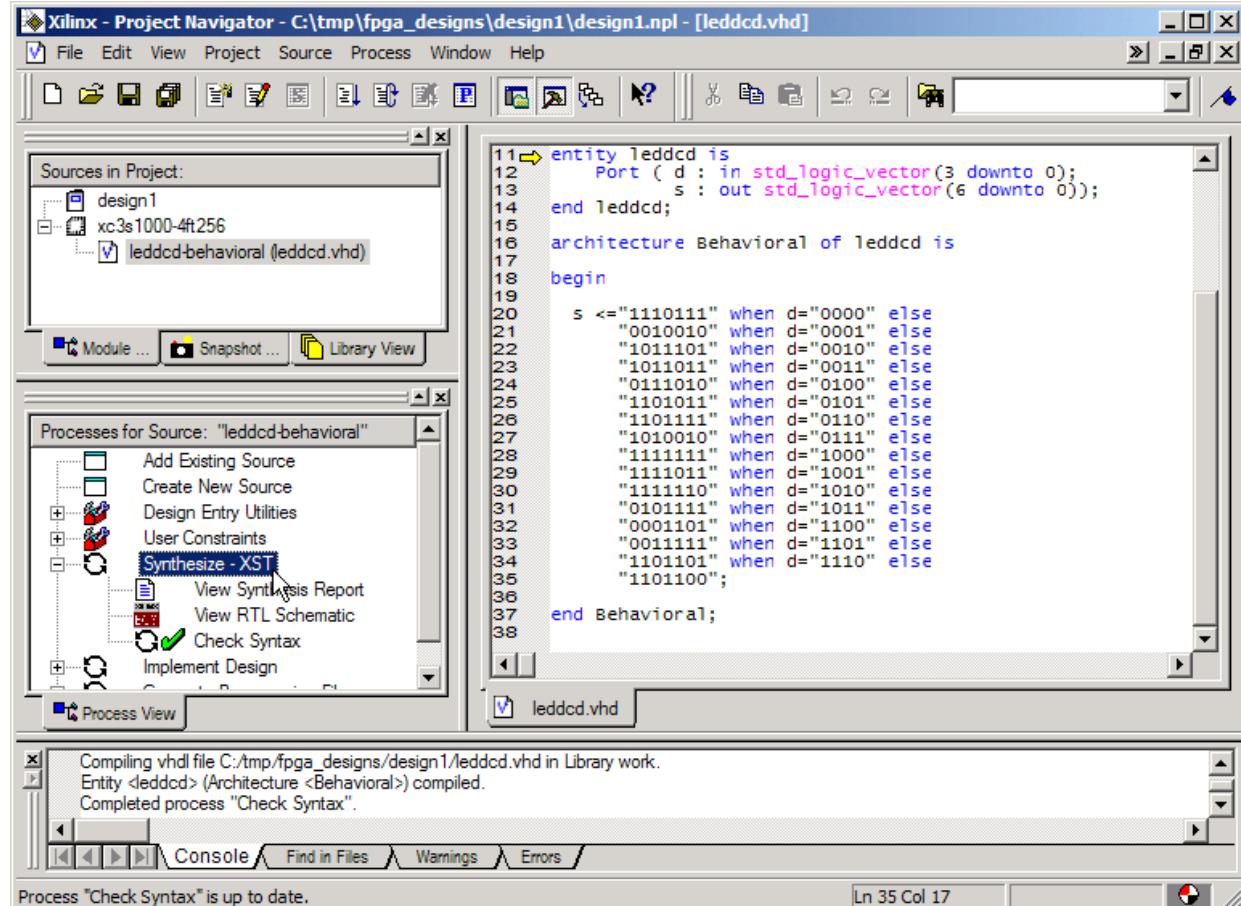
Process 'xst_sprjTOstx.tcl __projnav/xst_sprjTOstx_tcl.rsp' failed with code: 00001 Ln 37 Col 1

Examining line 37, you can see it is just the end statement for the architecture section. The VHDL syntax checker was expecting to find a ';' but it is missing from the end of line 35. Add the semicolon and save the file. Now when you double-click the Check Syntax process, it runs and then displays a to indicate there are no more errors.



Synthesizing the Logic circuitry for Your Design

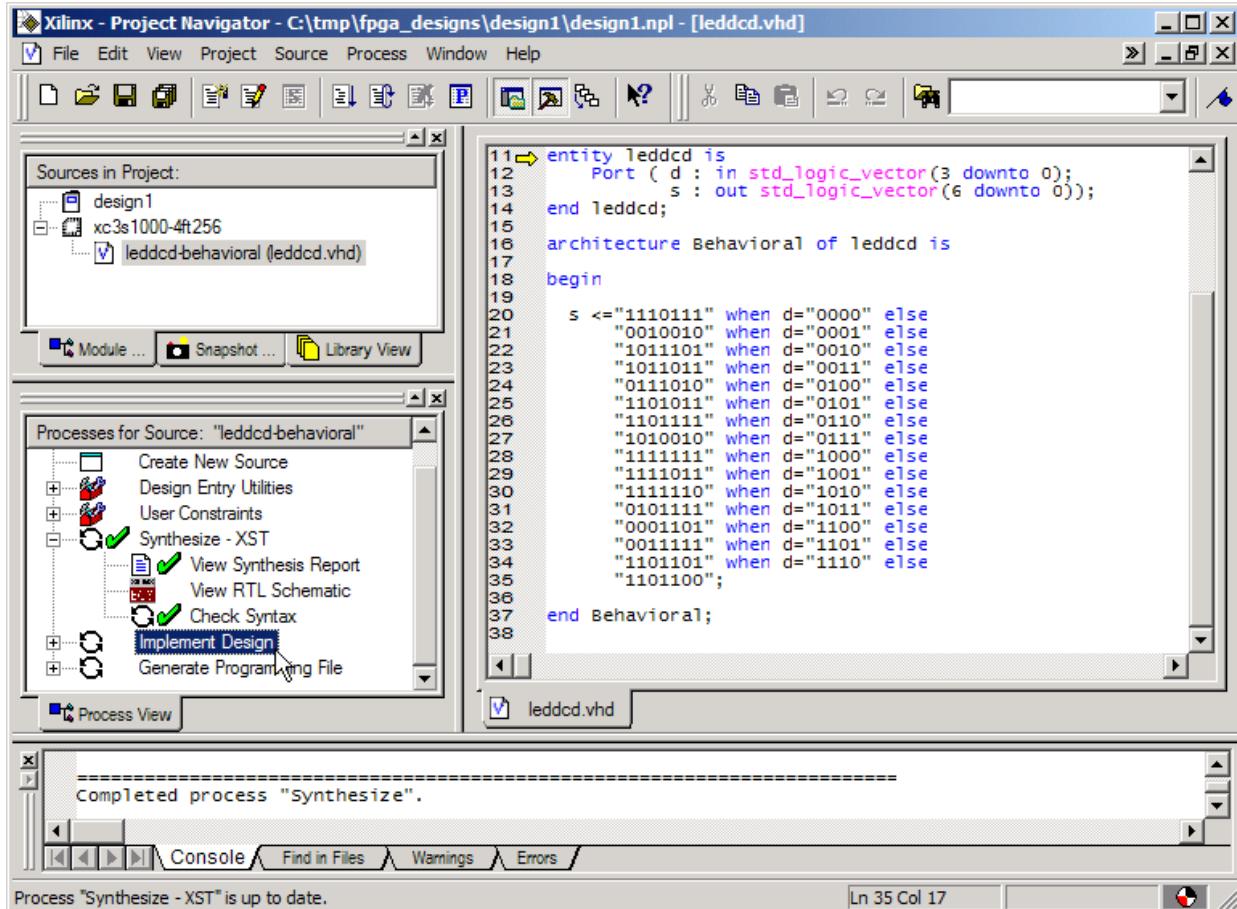
Now that you have valid VHDL for your design, you need to convert it into a logic circuit. This is done by highlighting the ledcd object in the Sources pane and then double-clicking on the Synthesize-XST process as shown below.



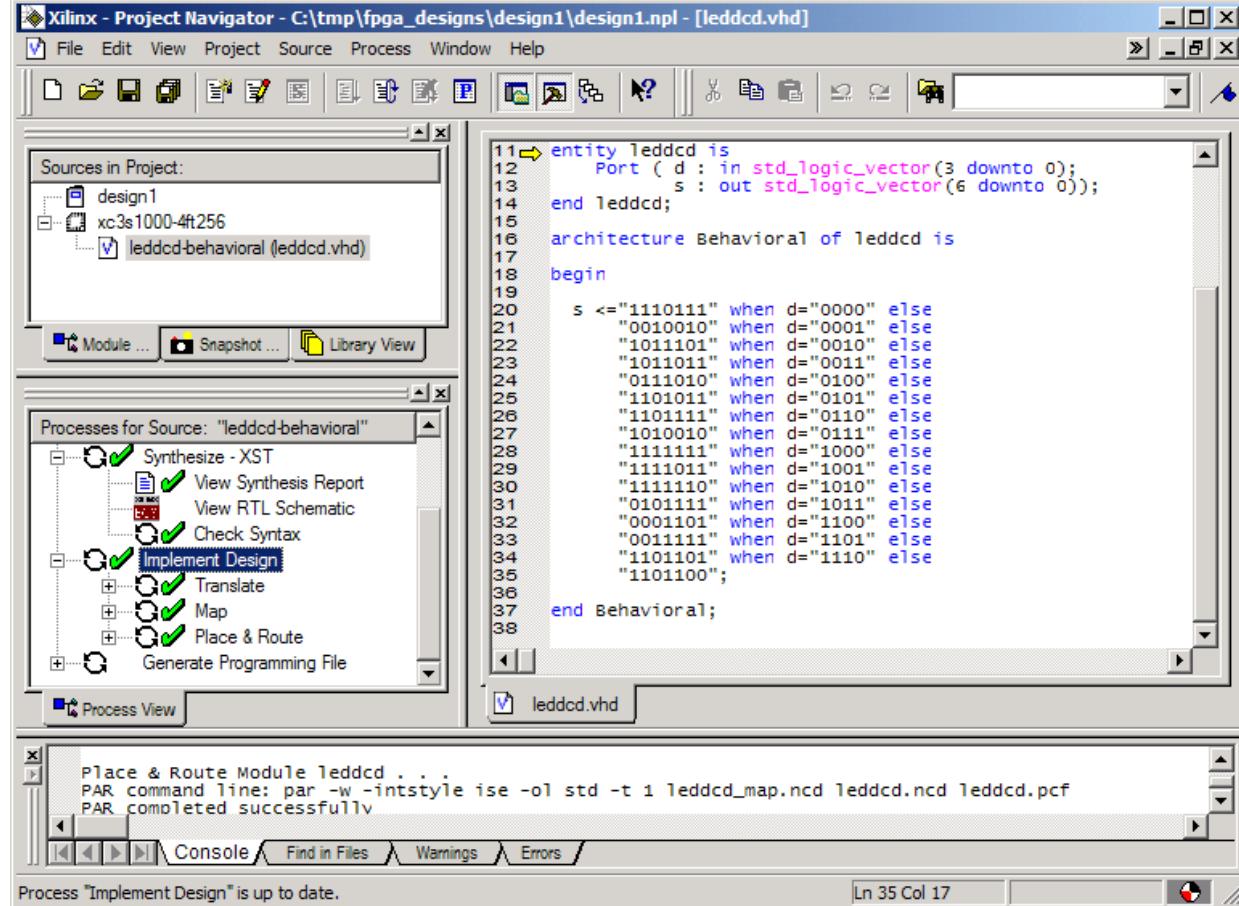
The synthesizer will read the VHDL code and transform it into a netlist of gates. This will take less than a minute. If no problems are detected, a will appear next to the Synthesize process. You can double-click on the View Synthesis Report to see the various synthesizer options that were enabled and some device utilization and timing statistics for the synthesized design. You can also double-click on View RTL Schematic to see the schematic that was derived from the VHDL source code, but it's not very interesting in this case.

Implementing the Logic Circuitry in the FPGA

You now have a synthesized logic circuit for the LED decoder, but you need to translate, map and place & route it into the logic resources of the FPGA in order to actually use it. Start this process by highlighting the ledcd object in the Sources pane and then double-click on the Implement Design process.

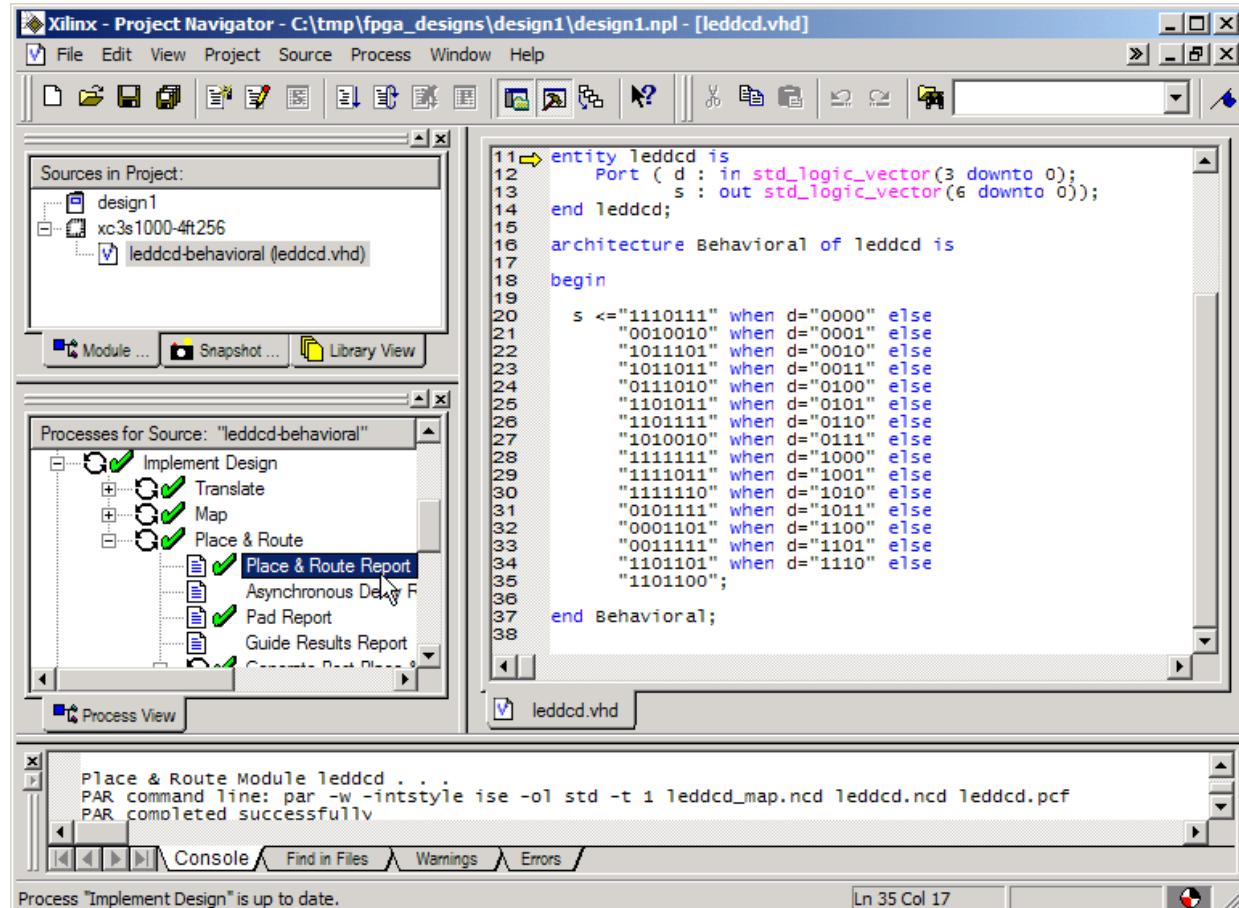


You can watch the progress of the implementation process in the status bar at the bottom of the **Project Navigator** window. For a simple design like the LED decoder, the implementation is completed in less than 30 seconds (on a 1.8 GHz Athlon PC with 512 Mbytes of RAM). A successful implementation is indicated by the next to the Implement Design process. You can expand the Implement Design process to see the subprocesses within it. The Translate process converts the netlist output by the synthesizer into a Xilinx-specific format and annotates it with any design constraints you may specify (more on that later). The Map process decomposes the netlist and rearranges it so it fits nicely into the circuitry elements contained in the FPGA device you selected. Then the Place & Route process assigns the mapped elements to specific locations in the FPGA and sets the switches to route the logic signals between them. If the Implement Design process had failed, a would appear next to the subprocess where the error occurred. You may also see a to indicate a successful completion but some warnings were issued or not all the subprocesses were enabled.



Checking the Implementation

You have your design fitted into the FPGA, but how much of the chip does it use? Which pins are the inputs and outputs assigned to? You can find answers to these questions by double-clicking on the Place & Route Report and the Pad Report in the Process pane.



The device utilization of the LED decoder circuit can be found near the top of the place & route report. The circuit only uses 4 of the 7680 available slices in the XC3S1000 FPGA. Each slice contains two CLBs and each CLB can compute the logic function for one LED segment output.

Device utilization summary:

Number of External IOBs	11	out of 173	6%
Number of LOCed External IOBs	0	out of 11	0%
Number of Slices	4	out of 7680	1%

The pad report shows what pins the inputs and outputs use to enter and exit the FPGA. (The pad report was edited to remove unused pins and fields so it would fit into this document.)

Pin Number	Signal Name	Pin Usage	Direction	IO Standard
M6	d<1>	IOB	INPUT	LVCMOS25
M7	d<3>	IOB	INPUT	LVCMOS25
N5	s<4>	IOB	OUTPUT	LVCMOS25
N6	s<1>	IOB	OUTPUT	LVCMOS25
N7	s<6>	IOB	OUTPUT	LVCMOS25
P5	s<5>	IOB	OUTPUT	LVCMOS25
P6	s<2>	IOB	OUTPUT	LVCMOS25
P7	d<0>	IOB	INPUT	LVCMOS25
R5	d<2>	IOB	INPUT	LVCMOS25
R6	s<3>	IOB	OUTPUT	LVCMOS25
R7	s<0>	IOB	OUTPUT	LVCMOS25

Assigning Pins with Constraints

The problem now is that the inputs and outputs for the LED decoder were assigned to pins picked by the implementation process, but these are not the pins you actually want to use on the FPGA. The FPGA on each XSA Board has eight inputs which are driven by the PC parallel port and you should assign the LED decoder inputs to four of these as follows:

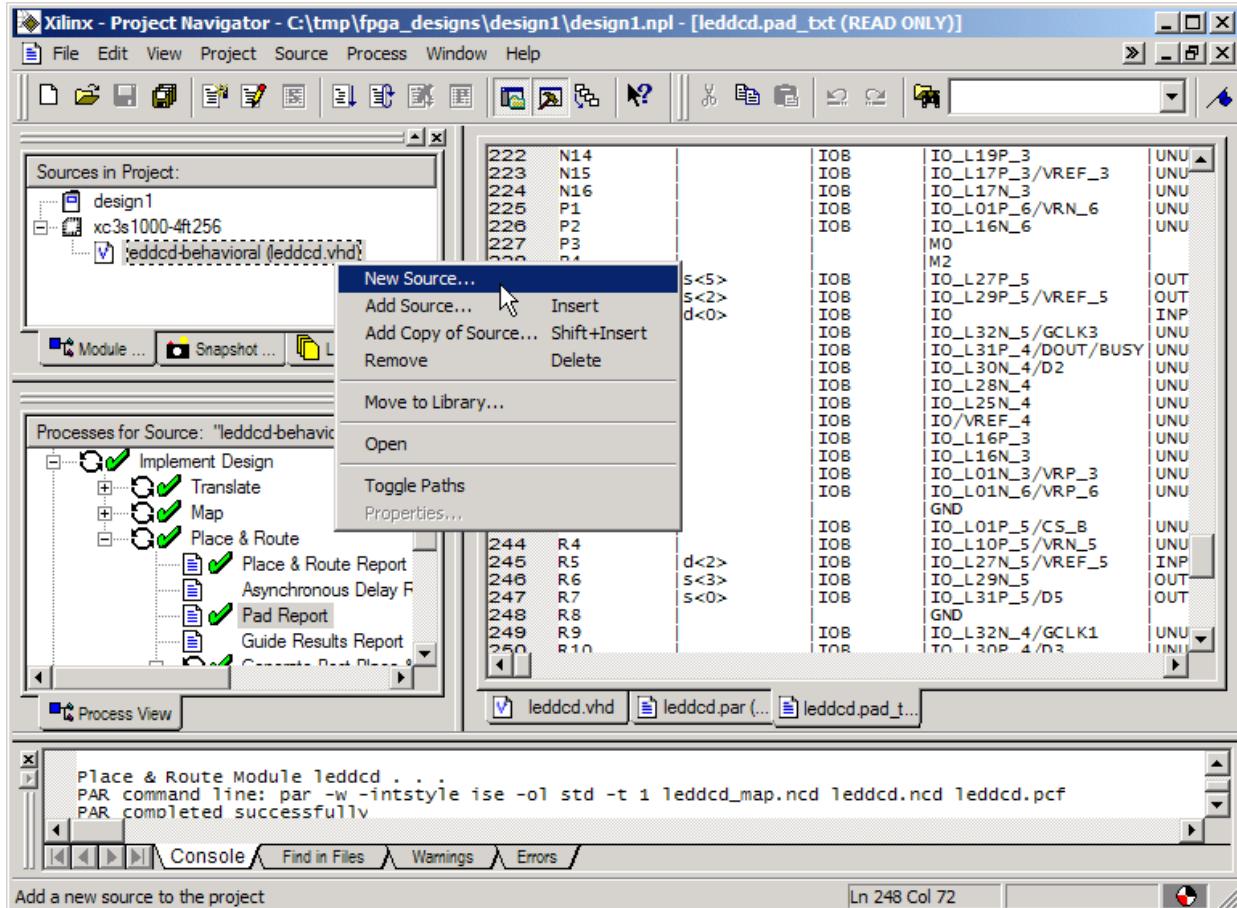
LED Decoder Input	XSA-50	XSA-100	XSA-200	XSA-3S1000
d0	P50	P50	E13	N14
d1	P48	P48	C16	P15
d2	P42	P42	E14	R16
d3	P47	P47	D16	P14

Likewise, each XSA Board has a seven-segment LED attached to the following pins of the FPGA:

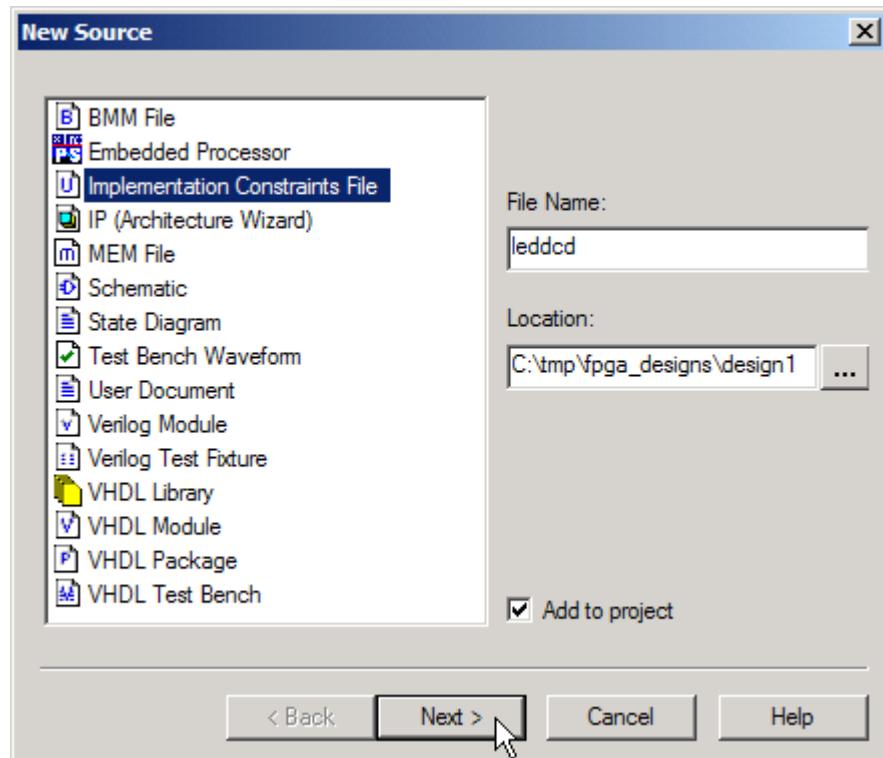
LED Decoder Output	XSA-50	XSA-100	XSA-200	XSA-3S1000
s0	P67	P67	N14	M6
s1	P39	P39	D14	M11
s2	P62	P62	N16	N6
s3	P60	P60	M16	R7
s4	P46	P46	F15	P10
s5	P57	P57	J16	T7
s6	P49	P49	G16	R10

How do you direct the implementation process so it assigns the inputs and outputs to the pins you want to use? This is done by using *constraints*. In this case, you would be constraining

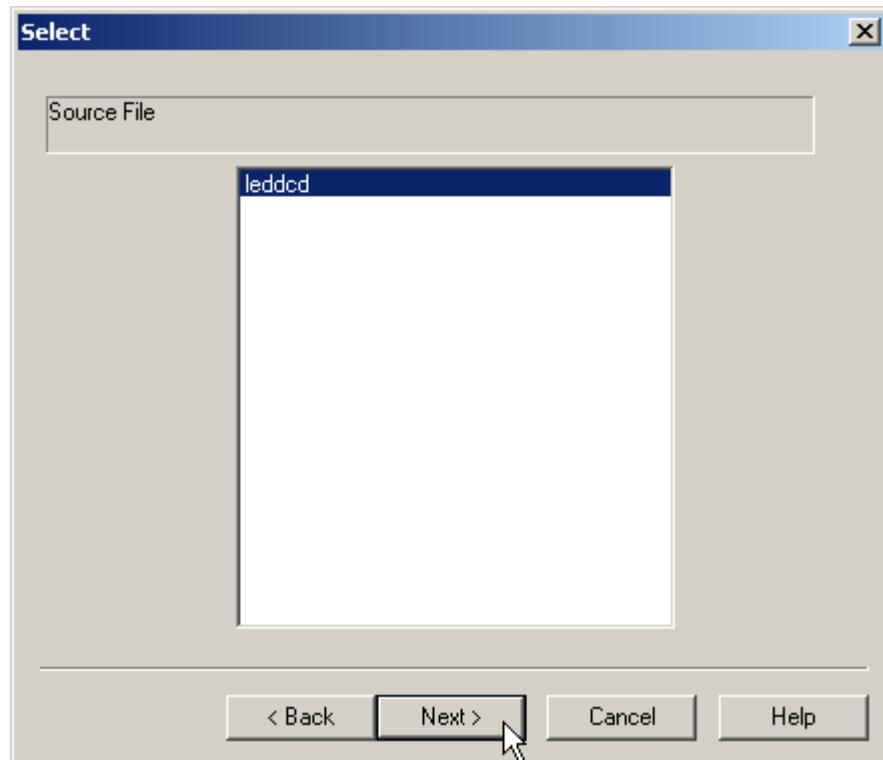
the implementation process so it assigns the inputs and outputs only to the pins shown in the previous tables. Start creating these constraints by right-clicking the ledcd object in the Sources pane and selecting New Source... from the pop-up menu.



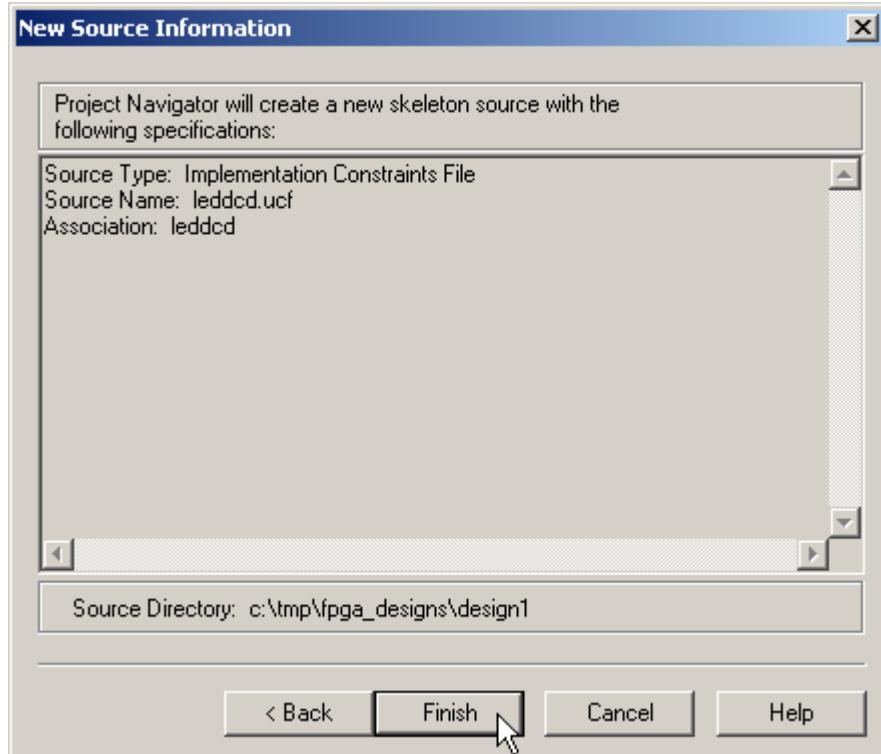
Select Implementation Constraints File as the type of source file you want to add and type ledcdc in the File Name field. Then click on the Next button.



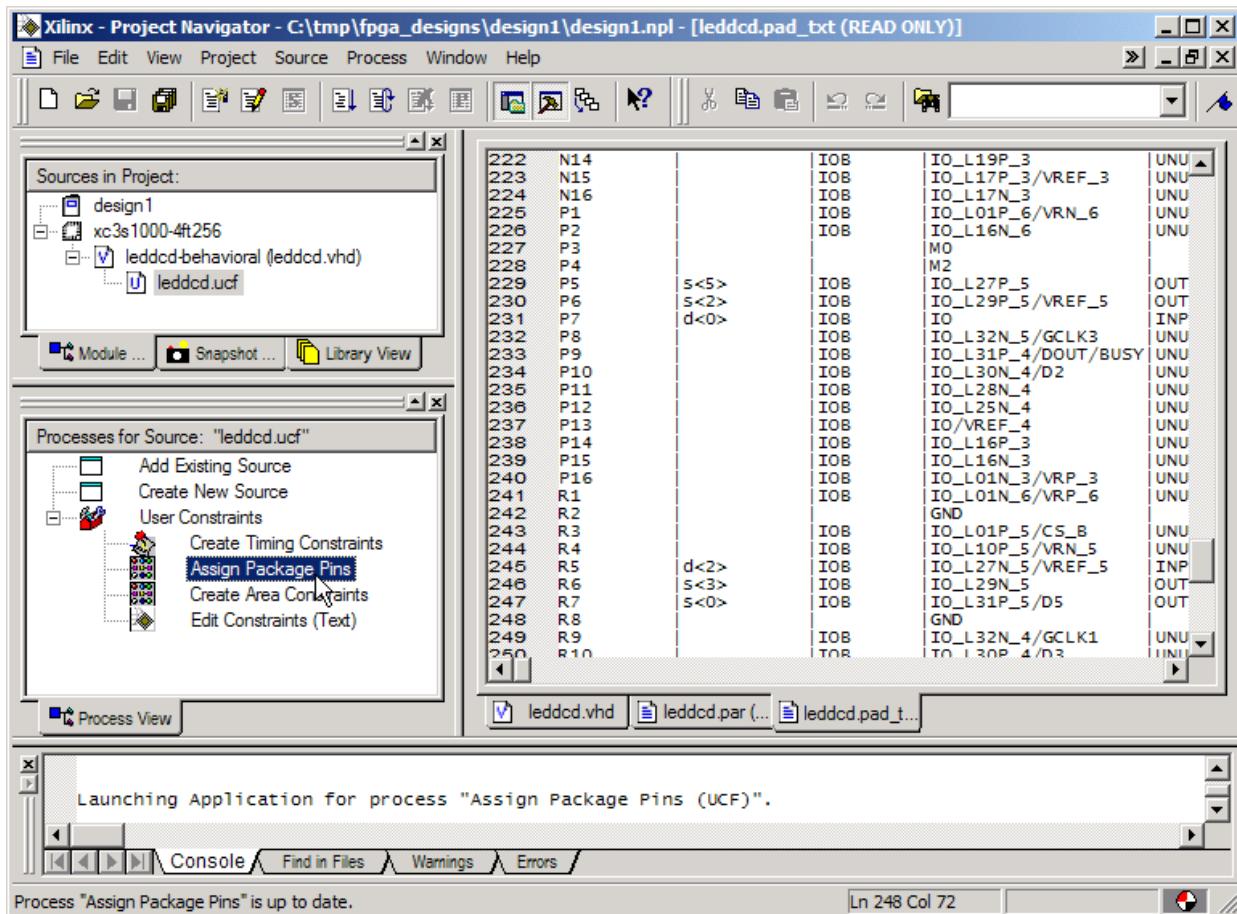
Then you are asked to pick the file that the constraints apply to. For this design there is only one choice, so click on the Next button and proceed.



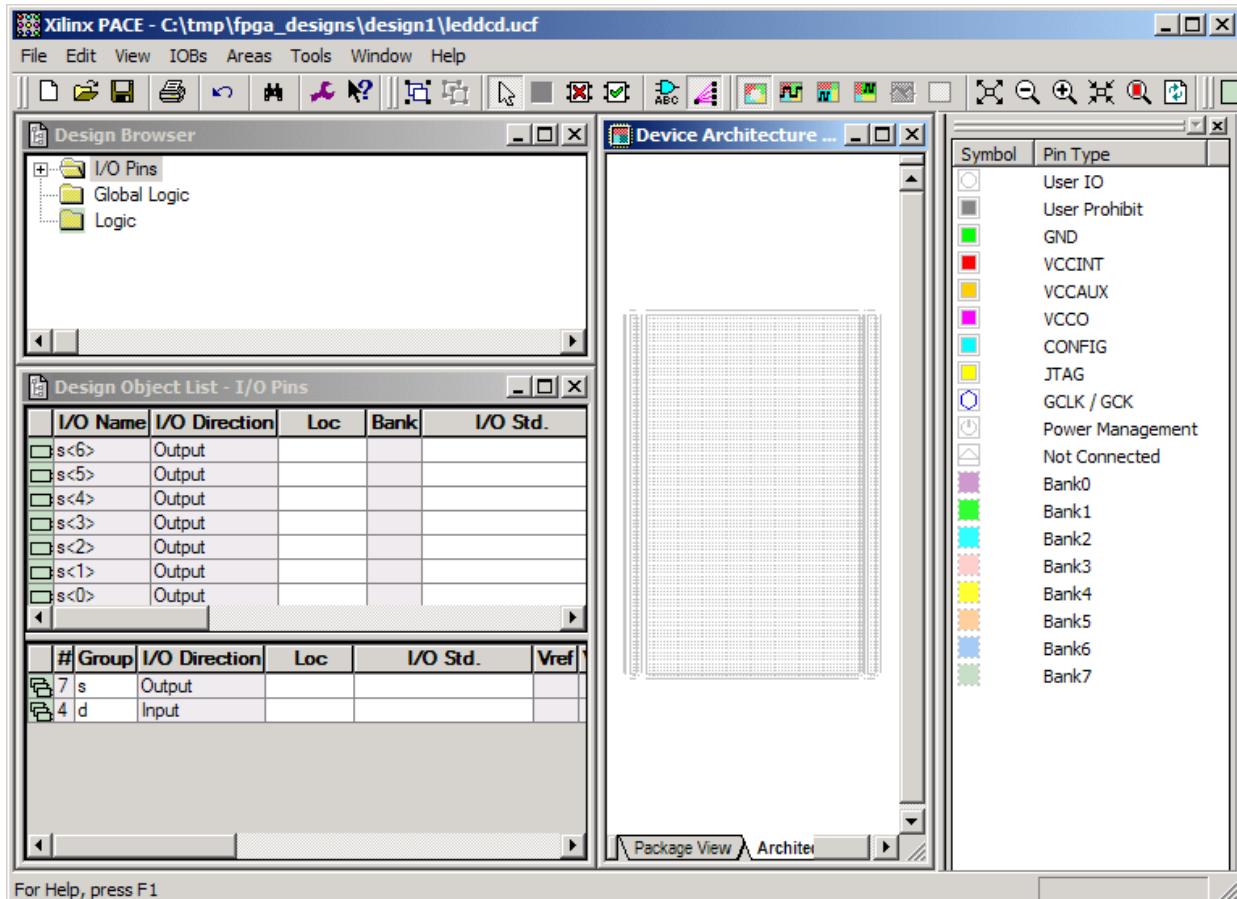
You will receive a feedback window that shows the name and type of the file you created and the file to which it is associated. Click on the Finish button to complete the addition of the ledcd.ucf constraint file to this project.



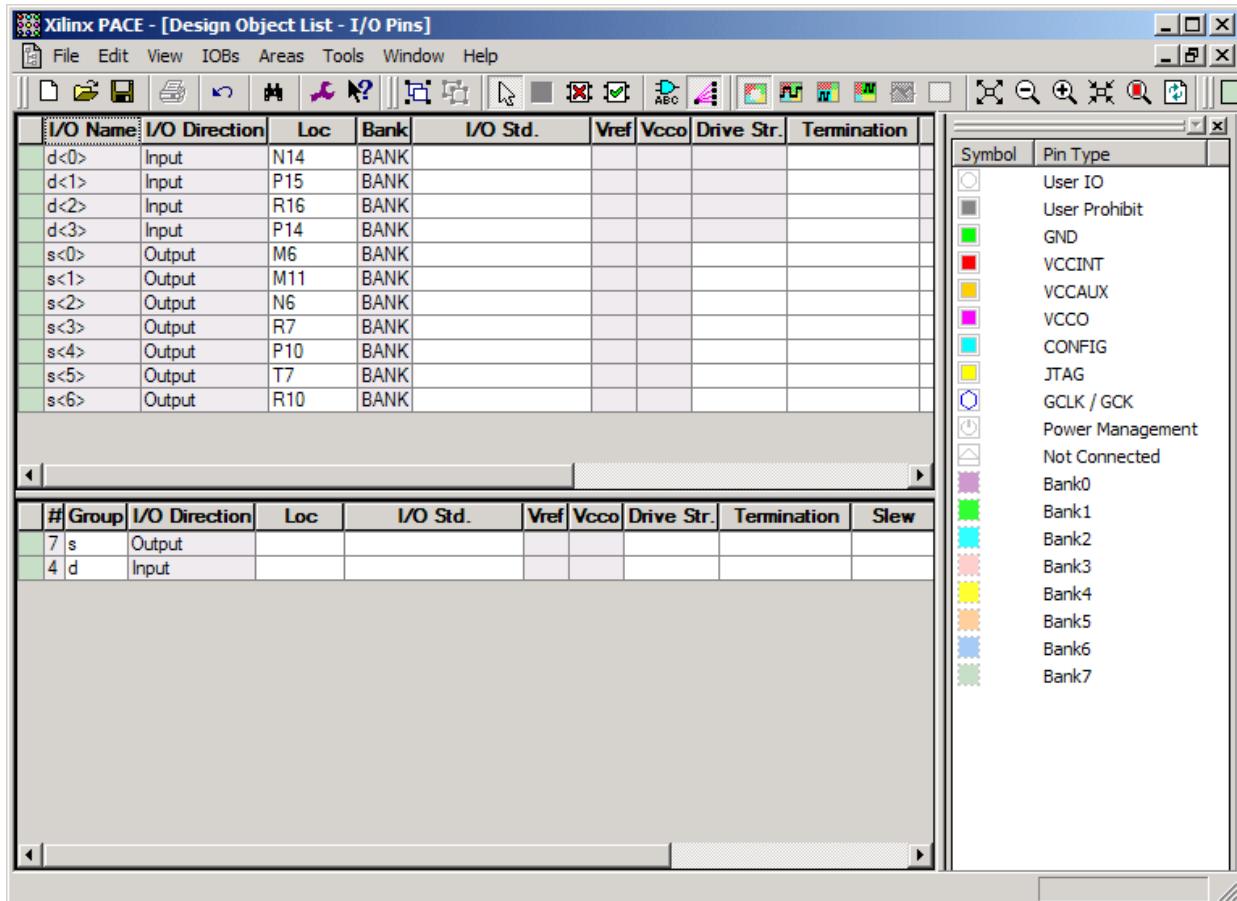
Now highlight the ledgcd.ucf object in the Sources pane and double-click the Assign Package Pins in the Process pane to begin adding pin assignment constraints to the design.



The **Xilinx PACE** window now appears. Click on the Ports tab in the upper pane. A list of the current inputs and outputs for the LED decoder will appear in the **Design Object List – I/O Pins** pane. You can change your pin assignments here.

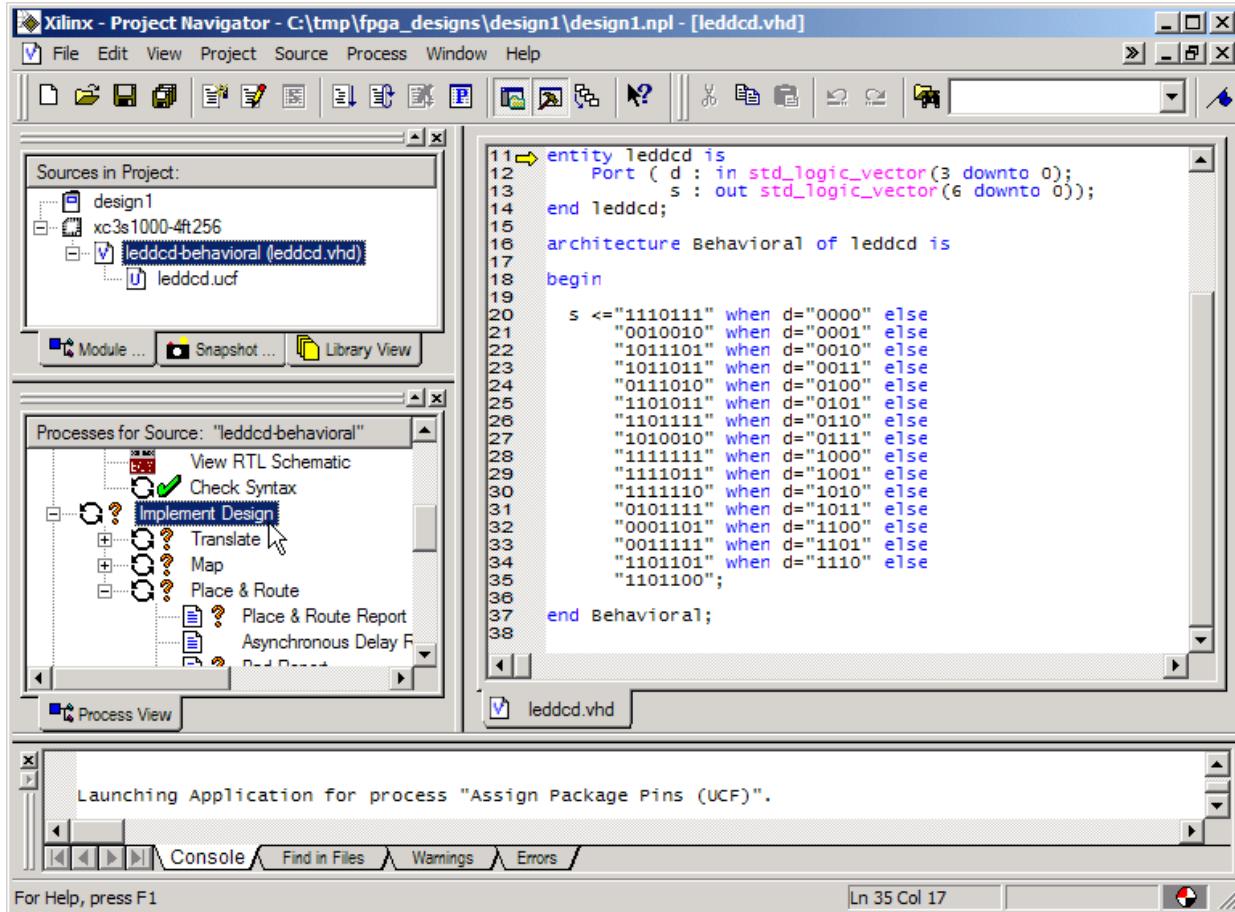


You start by clicking in the Location field for the **d<0>** input. Then just type in the pin assignment for this input: N14. Do this for all of the inputs and outputs using the pin assignments from the tables shown previously. The **Xilinx PACE** window now appears as follows.



After the pin assignments are entered, click on the button to save the pin assignment constraints. Then select File→Exit to close the **Xilinx PACE** window.

Now you can re-implement your design by highlighting the ledccd object in the Sources pane and double-clicking on the Implement Design process.



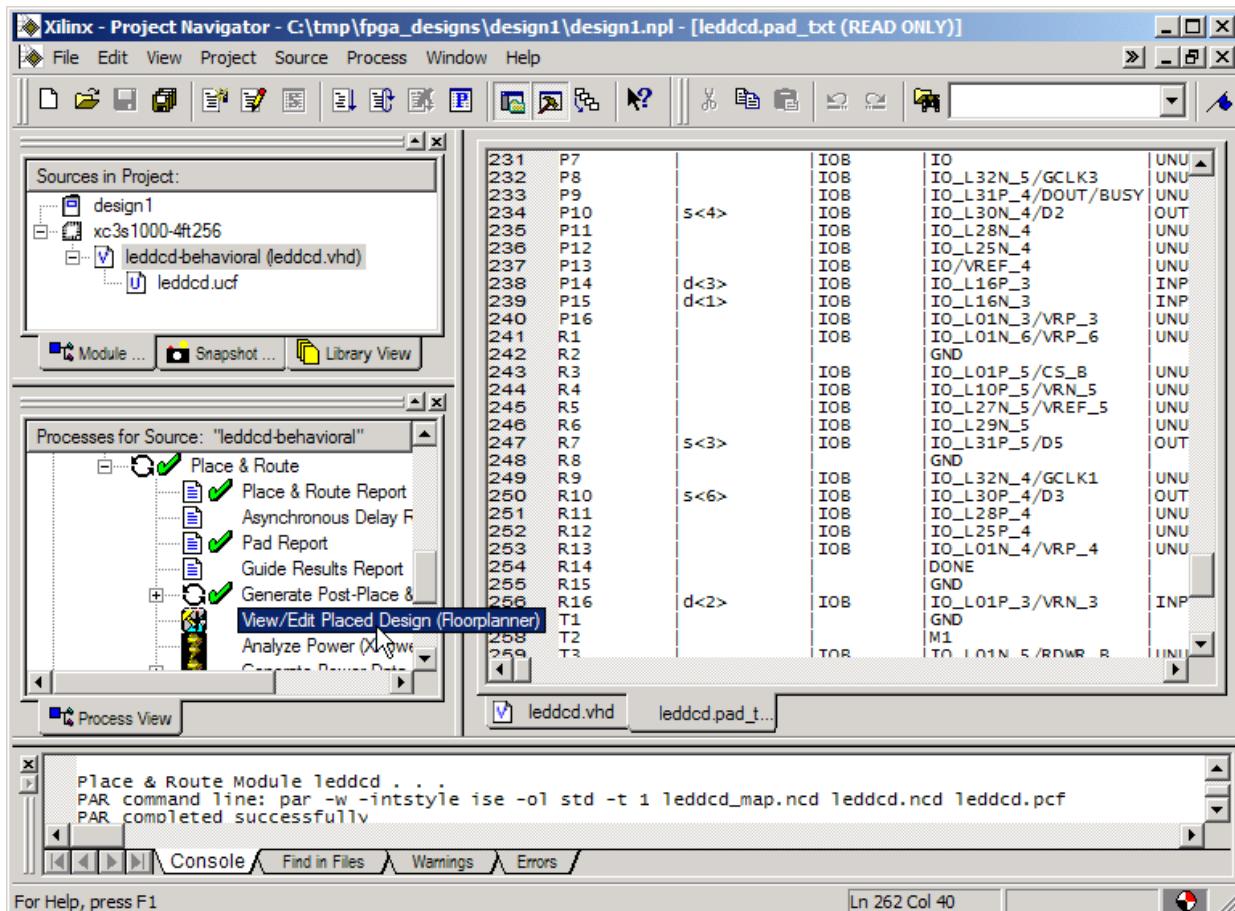
After the implementation process completes, double-click on Pad Report to view the pin assignments. Now the pad report shows the following pin assignments:

Pin Number	Signal Name	Pin Usage	Direction	IO Standard
M6	s<0>	IOB	OUTPUT	LVCMS25
M11	s<1>	IOB	OUTPUT	LVCMS25
N6	s<2>	IOB	OUTPUT	LVCMS25
N14	d<0>	IOB	INPUT	LVCMS25
P10	s<4>	IOB	OUTPUT	LVCMS25
P14	d<3>	IOB	INPUT	LVCMS25
P15	d<1>	IOB	INPUT	LVCMS25
R7	s<3>	IOB	OUTPUT	LVCMS25
R10	s<6>	IOB	OUTPUT	LVCMS25
R16	d<2>	IOB	INPUT	LVCMS25
T7	s<5>	IOB	OUTPUT	LVCMS25

The reported pin assignments match the assignments you made in the **Constraints Editor** window, so it appears you have constrained the I/O to the appropriate pins.

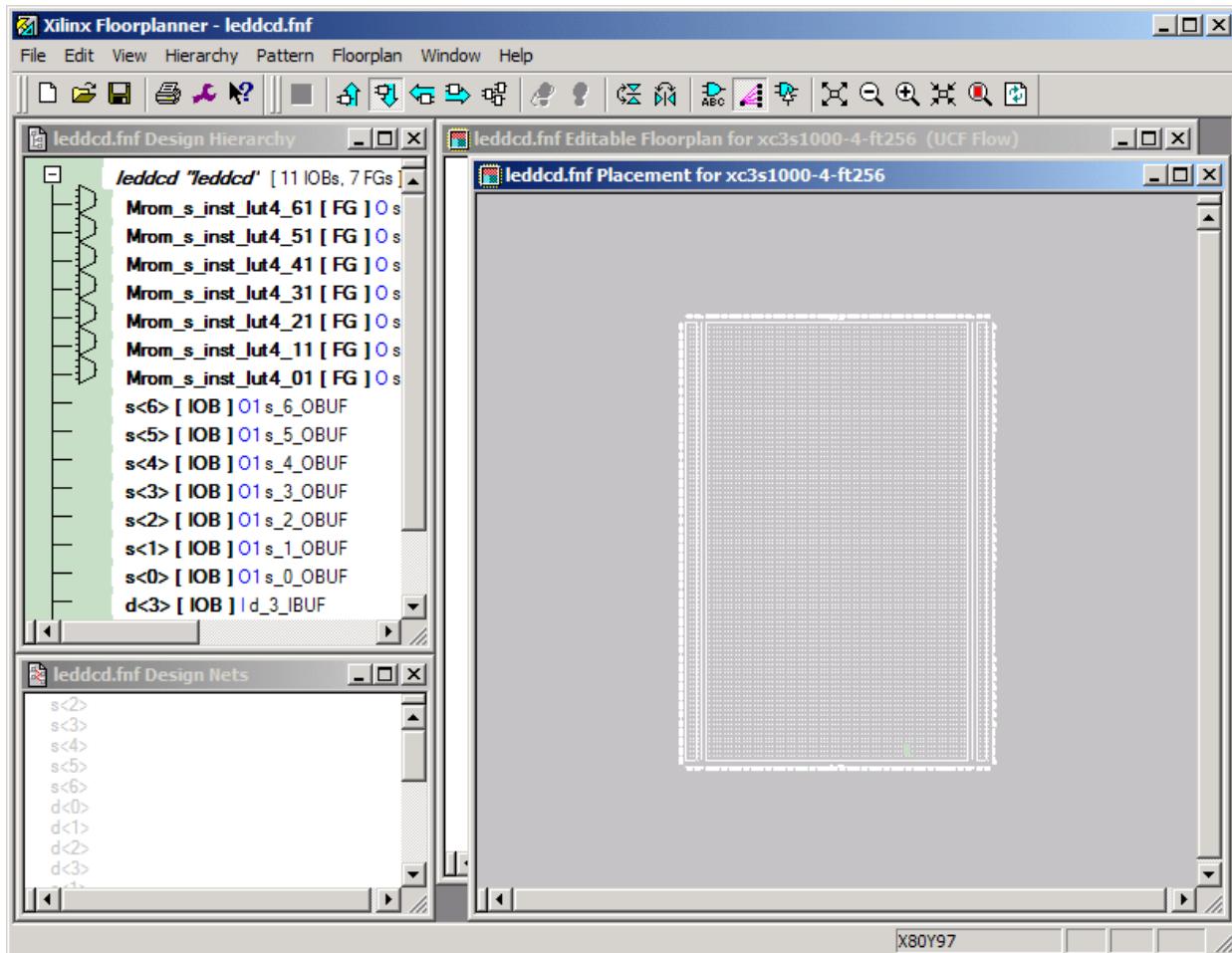
Viewing the Chip

After the implementation process completes, you can get a graphical depiction of how the logic circuitry and I/O are assigned to the FPGA CLBs and pins. Just highlight the ledcdc object in the Sources pane and then double-click the View/Edit Placed Design (FloorPlanner) process.

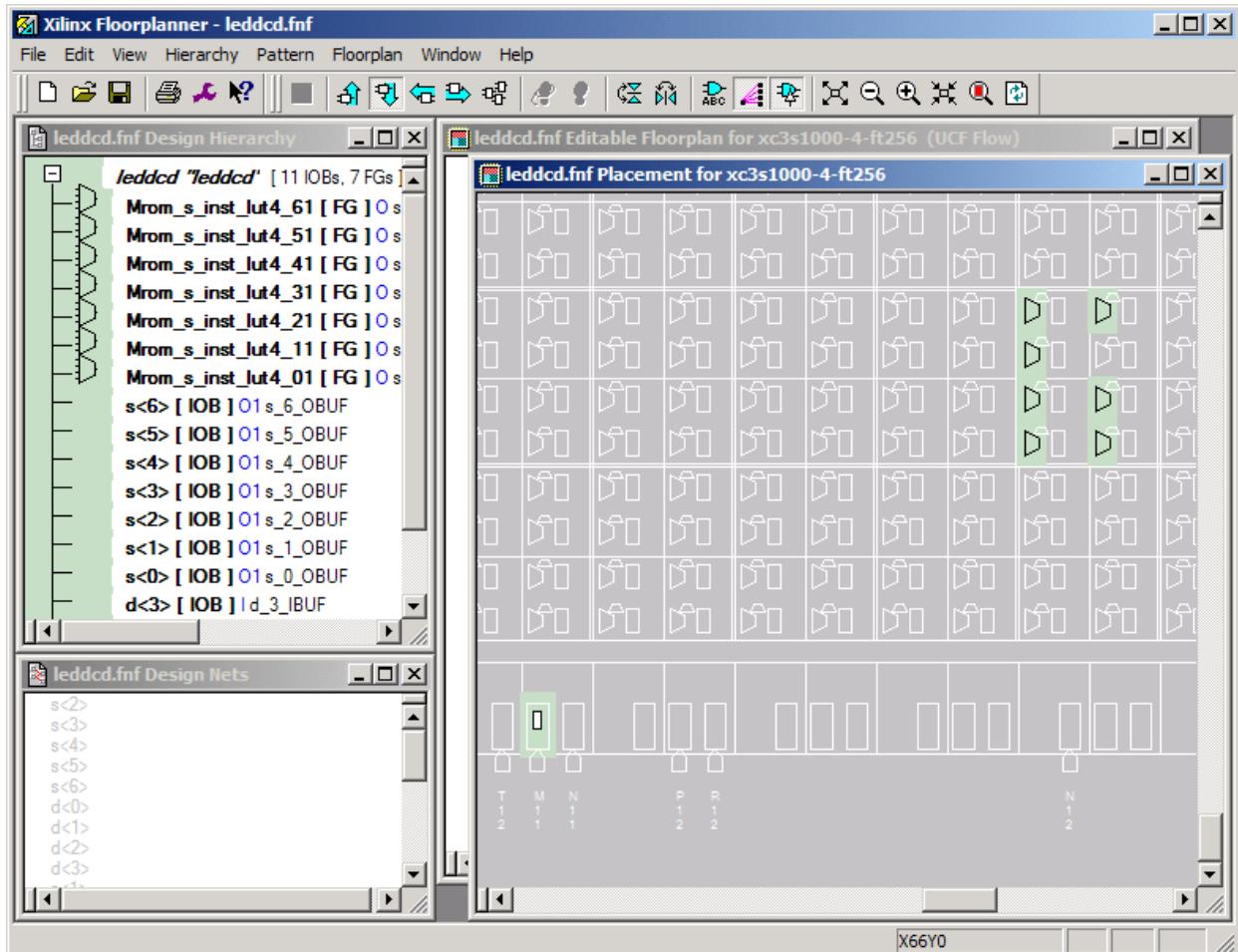


The **FloorPlanner** window will appear containing three panes:

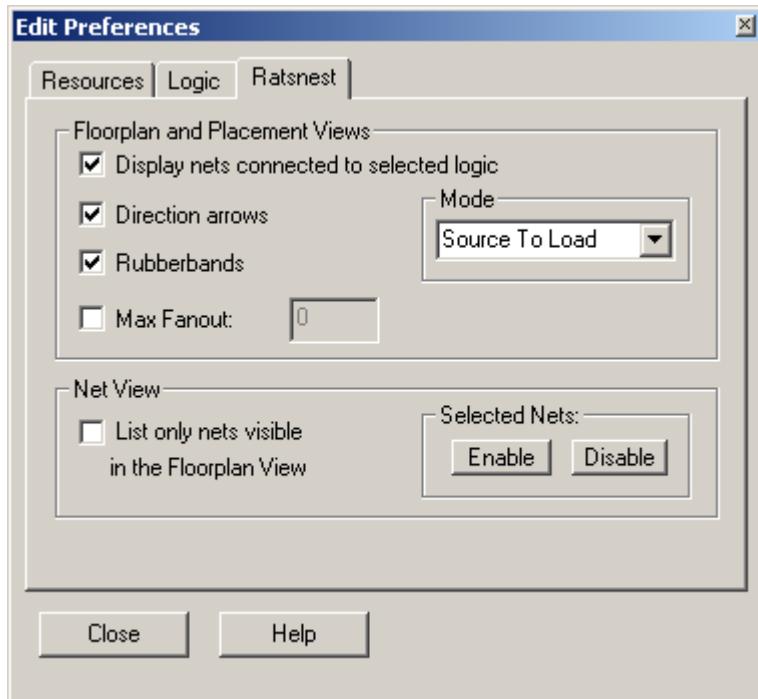
1. The **Design Hierarchy** pane lists the LED decoder inputs, outputs and LUTs assigned to the various CLBs in the FPGA.
2. The **Design Nets** pane lists the various signal nets in the LED decoder.
3. The **Placement** pane shows the array of CLBs in the FPGA. The I/O pins are also shown around the periphery. (The pins used for Vcc, GND, and programming are not shown.)



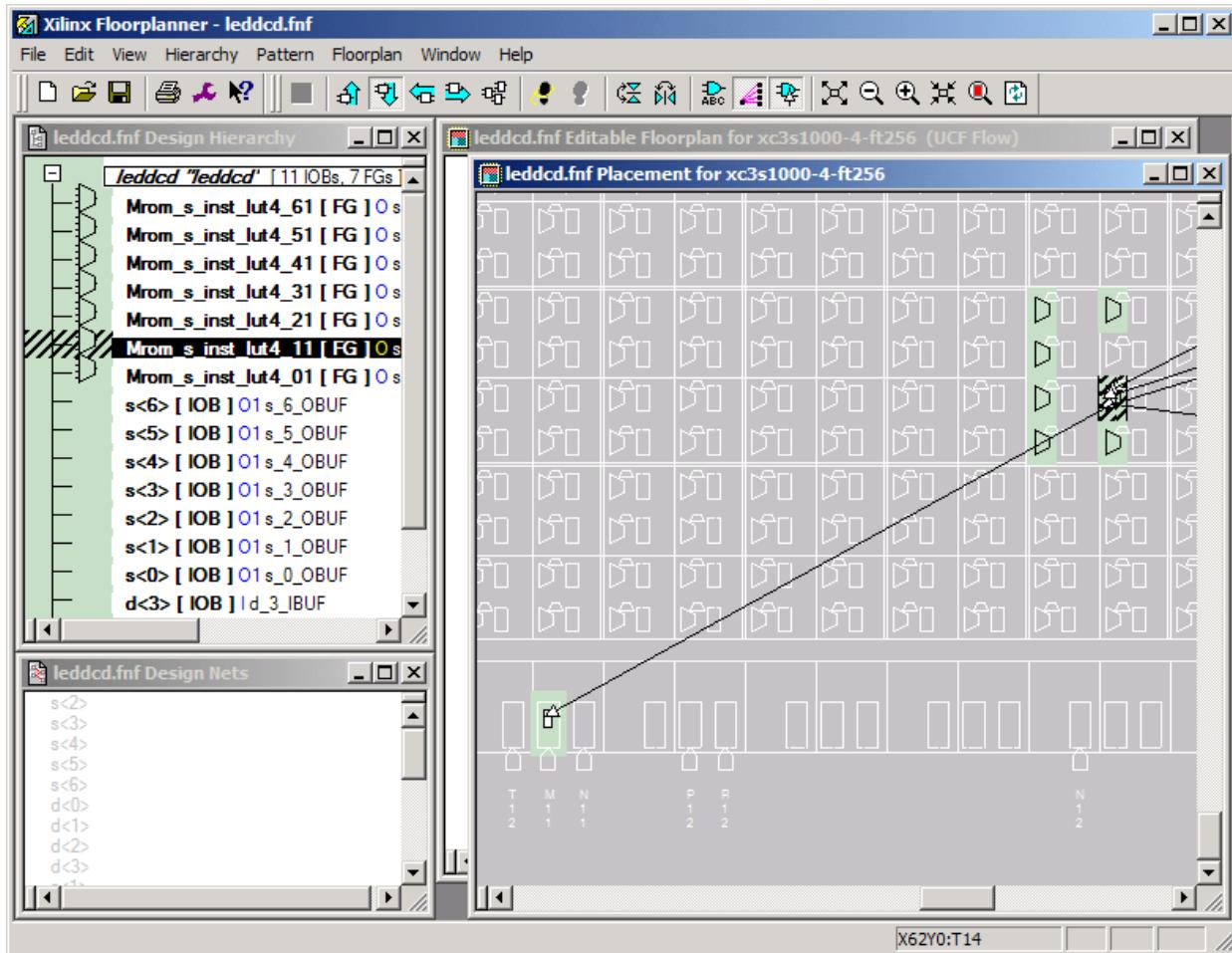
The CLBs used by the LED decoder circuit are highlighted in light-green and are clustered near the lower right-hand edge of the CLB array. To enlarge this region of the array, click on the button and then draw a rectangle around the highlighted CLBs in the **Placement** pane. The enlarged view of the CLBs used by the LED decoder will appear as shown below.



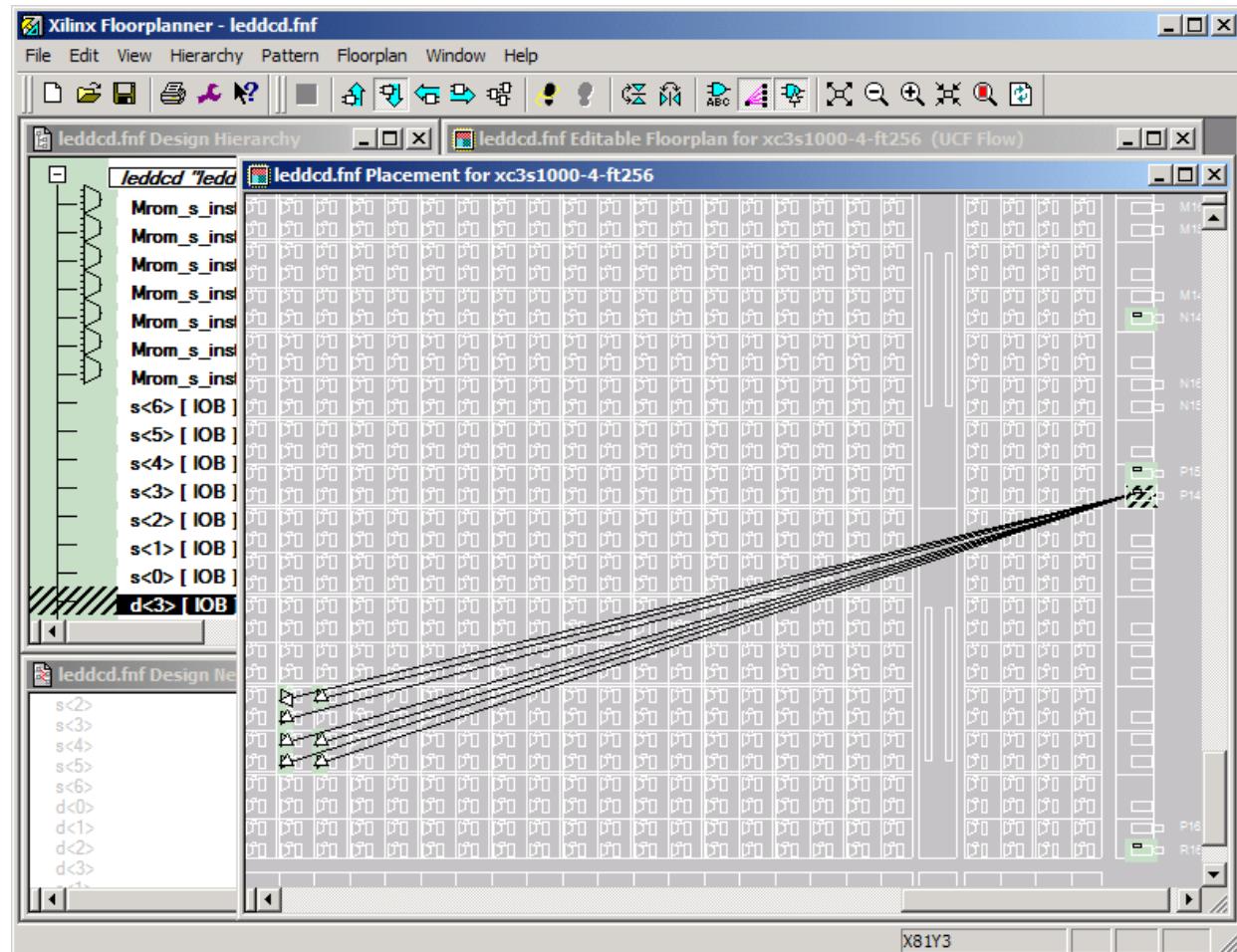
You can enable the display of the connections between I/O pins and CLBs by selecting the **Edit**→**Preferences** menu item and then checking the boxes in the Ratsnest tab of the **Edit Preferences** window as shown below.



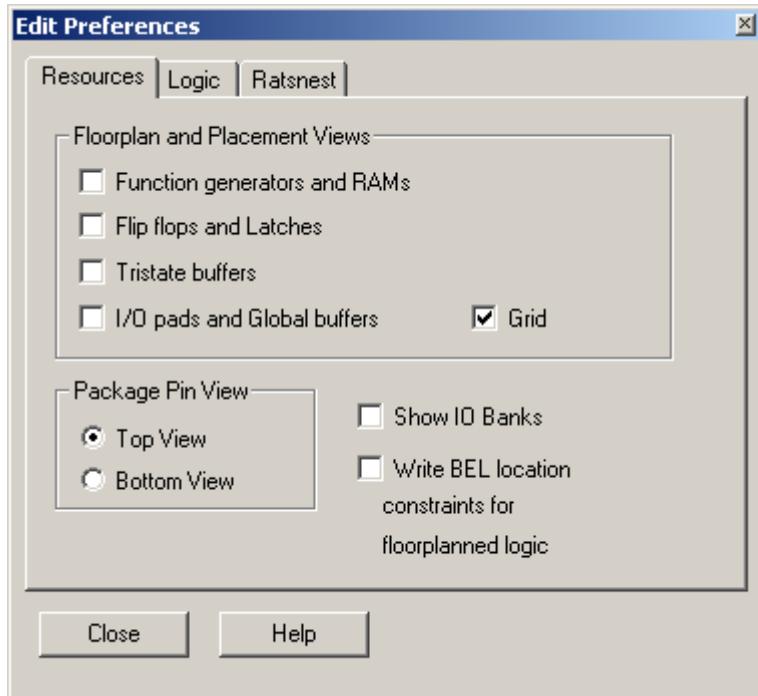
Now clicking on a CLB will highlight the nets connecting the inputs and output to the CLB.



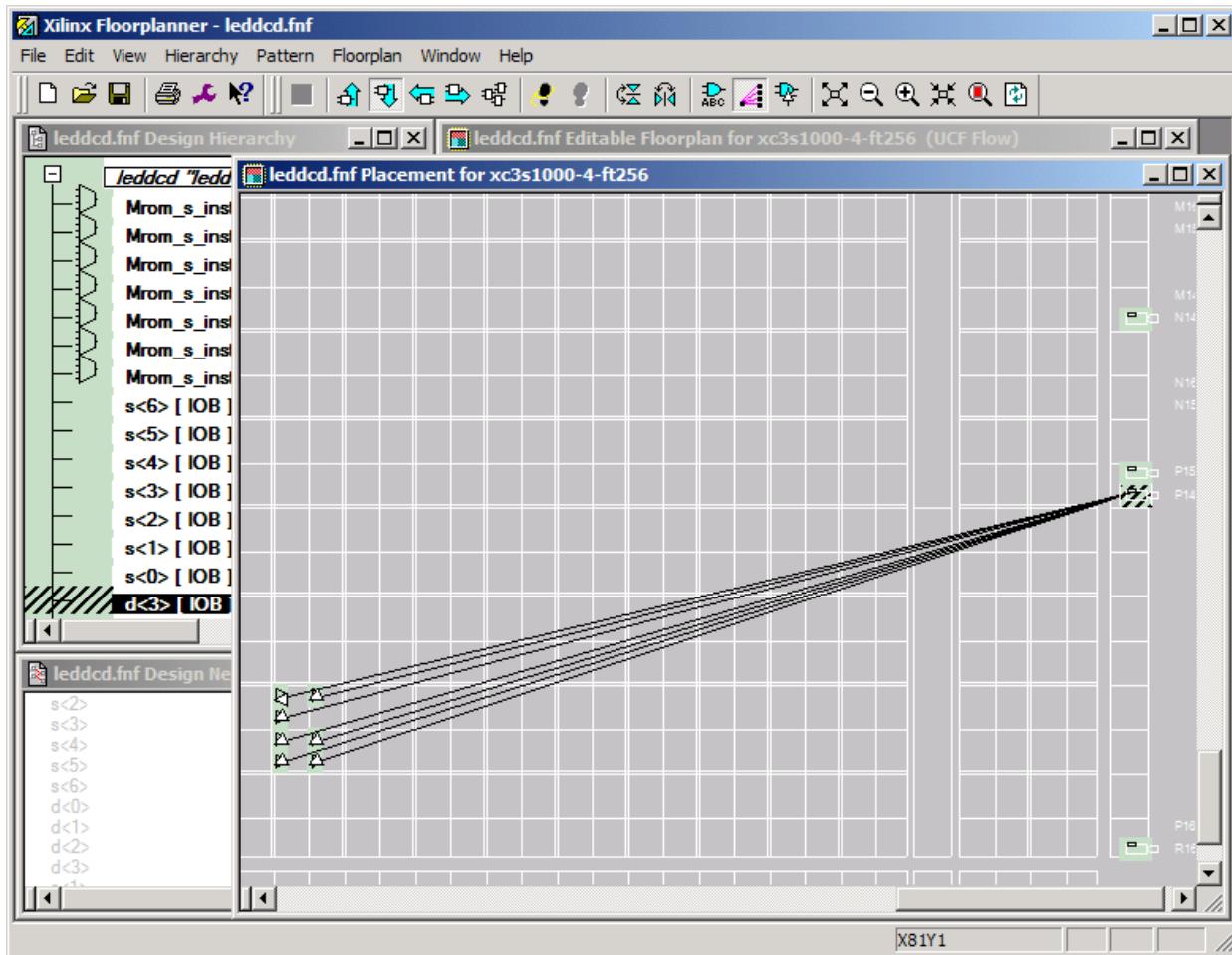
In an analogous manner, you can click on an input pin to highlight which CLBs are dependent on that input. (For this design, each input affects every CLB.)



The **Placement** pane may be showing too many details of the FPGA internal structure. To view only the FPGA resources that are used by the design, select **Edit→Preferences** and uncheck all the boxes in the Resources tab as shown below.



Now the **Placement** pane shows only the LUTs and I/O pins that are used in this design.

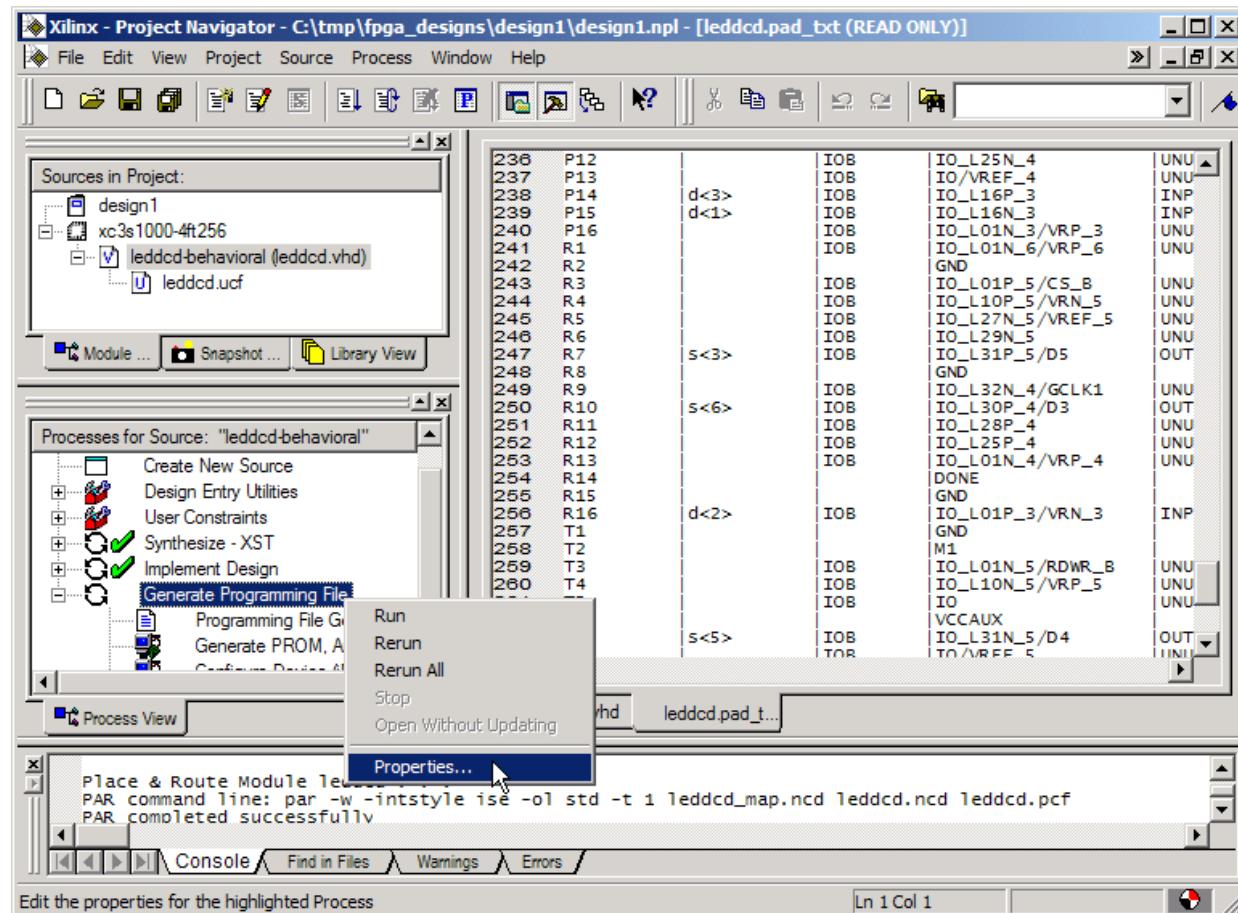


Viewing the placement of circuit elements after the place & route process can give you insights into the resource usage of certain VHDL language constructs. In addition to viewing the placement of the design, the Floorplanner can be used to re-arrange and optimize the placement. This is akin to the software technique of hand-optimizing assembly code output by a compiler. You won't do this here, but it is an option for designs which push at the limits of the capabilities of FPGAs.

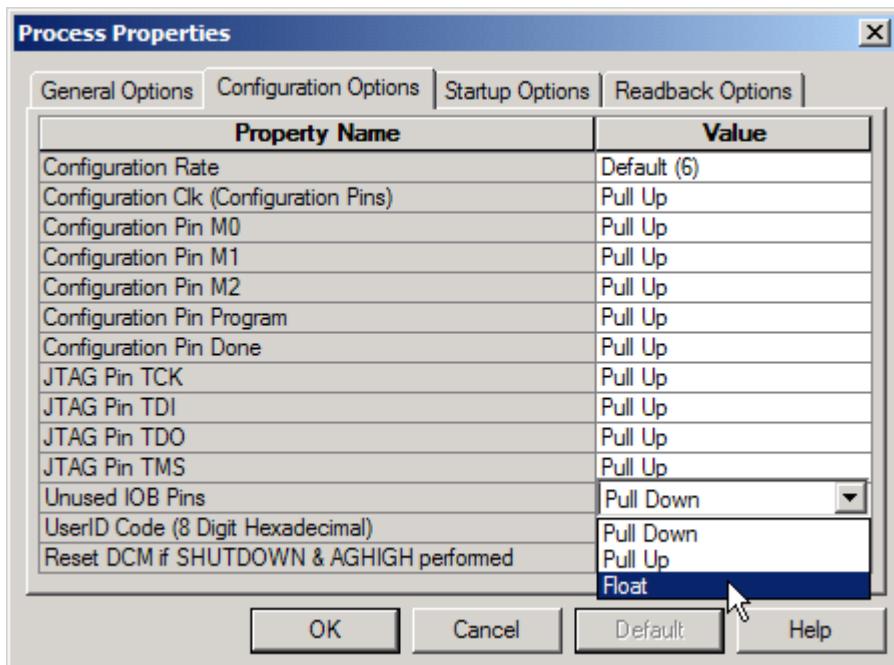
Generating the Bitstream

Now that you have synthesized our design and mapped it to the FPGA with the correct pin assignments, you are ready to generate the bitstream that is used to program the actual chip.

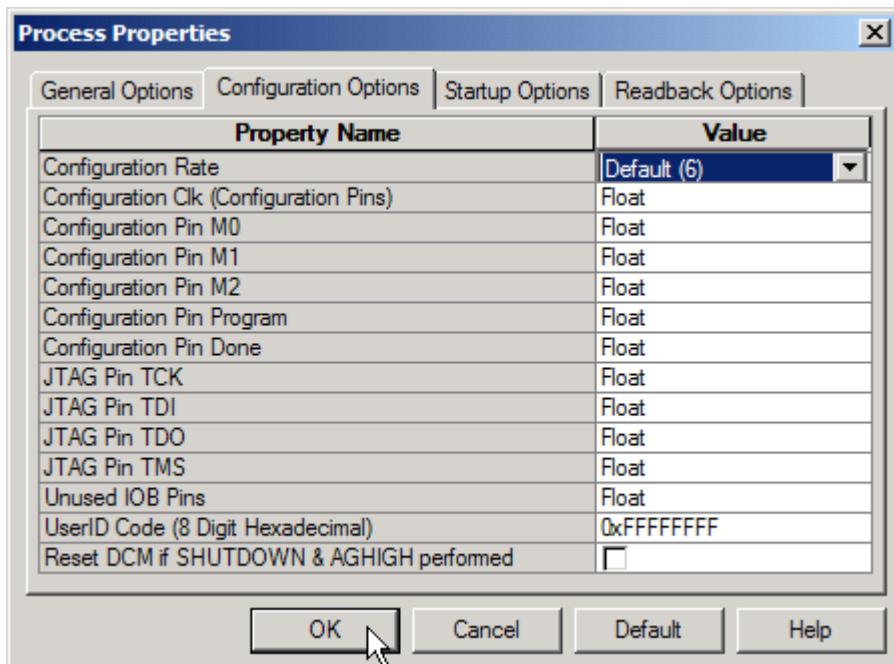
When using the XSA-3S1000 Board, you need to set some options before generating the bitstream. (This is not needed if you are using the XSA-50, XSA-100 or XSA-200 Board, but it wouldn't hurt, either.) Right-click on the Generate Programming File process and select Properties... from the pop-up menu.



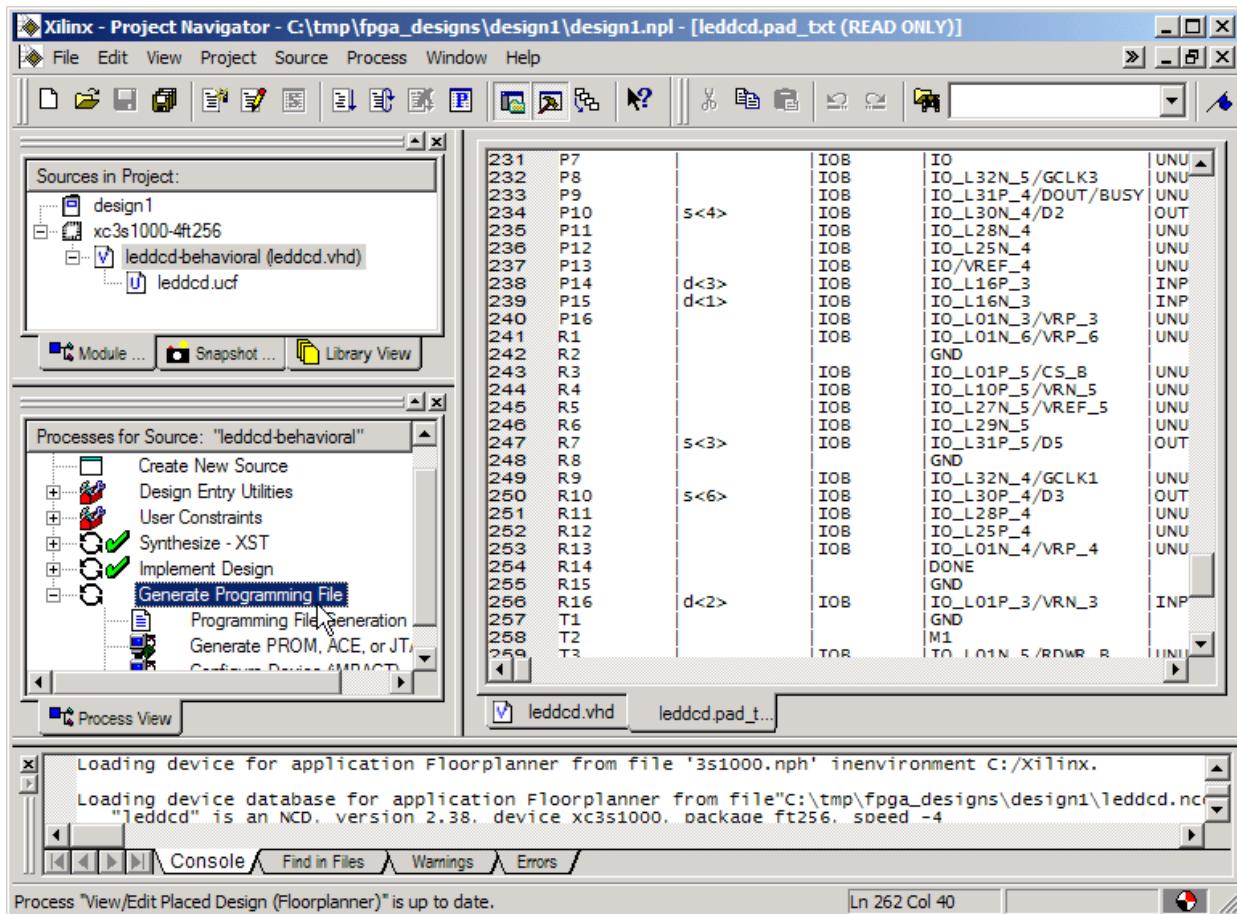
Now select the Configuration Options tab in the **Process Properties** window and set all the Pull Up and Pull Down values to Float to disable the internal resistors of the FPGA. (At the minimum, the Unused IOB Pins value must be set to Float, but it is best to set them all to Float.) If they are not disabled, the strong internal pull-up and pull-down resistors in the Spartan3 FPGA will overpower the external resistors on the XSA Board.



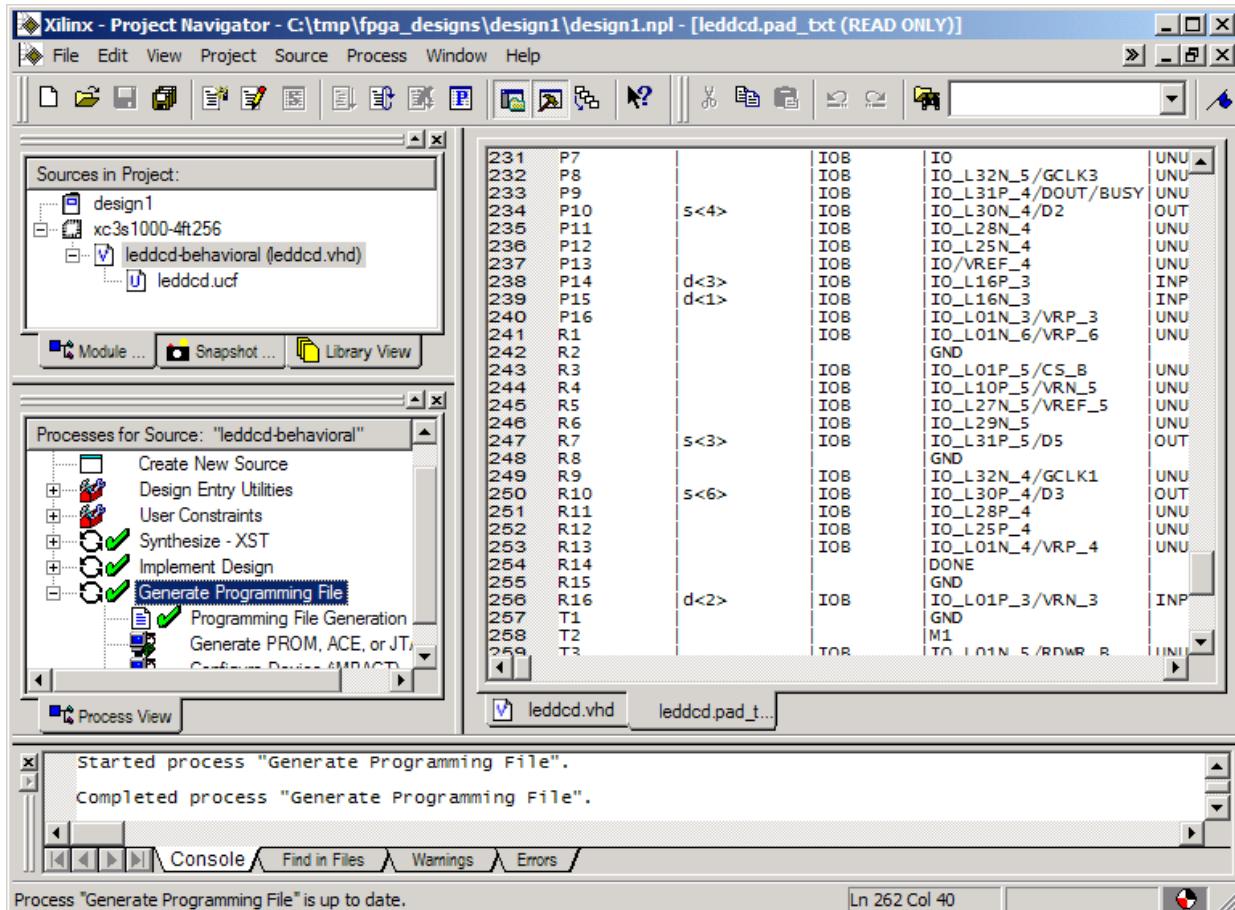
After setting all the values as shown below, click on OK.



Once you have set the bitstream generation options, highlight the ledgcd object in the Sources pane and double-click on the Generate Programming File process.

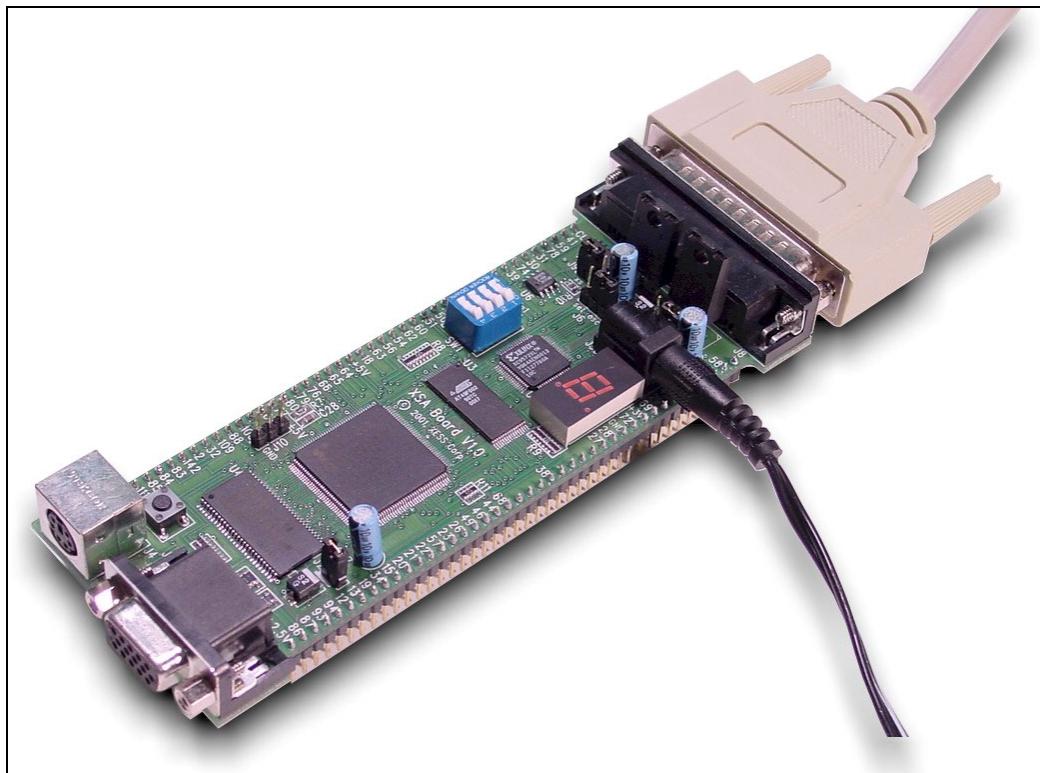


Within a few seconds, a  will appear next to the Generate Programming File process and a file detailing the bitstream generation process will be created. A bitstream file named ledgcd.bit can now be found in the design1 folder.

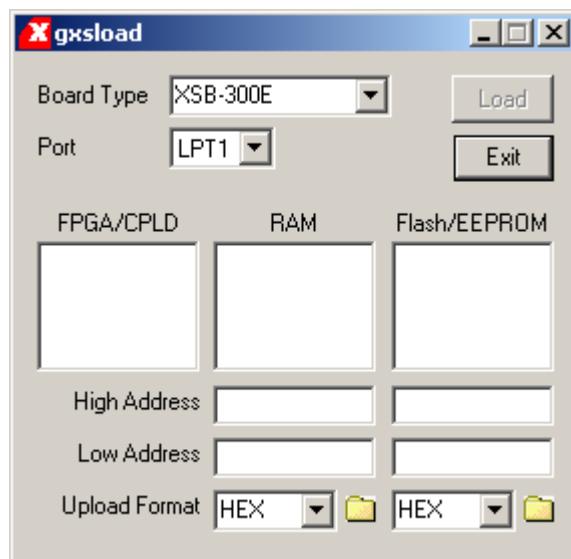


Downloading the Bitstream

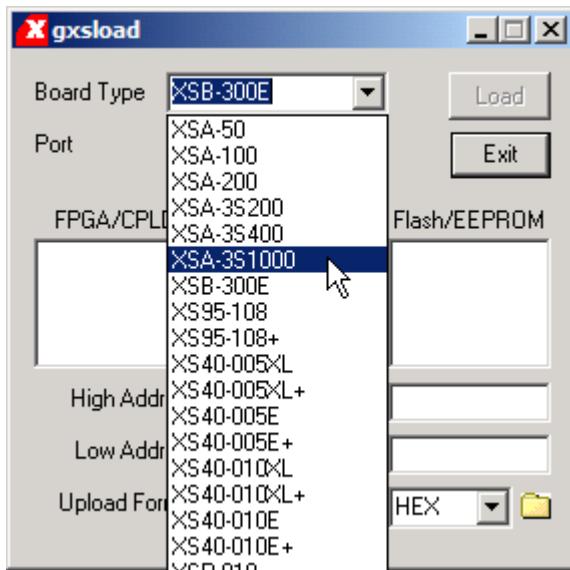
Now you have to get the bitstream file programmed into the FPGA on the XSA Board. The XSA Board is powered with a DC power supply and is attached to the PC parallel port with a standard 25-wire cable as shown below.



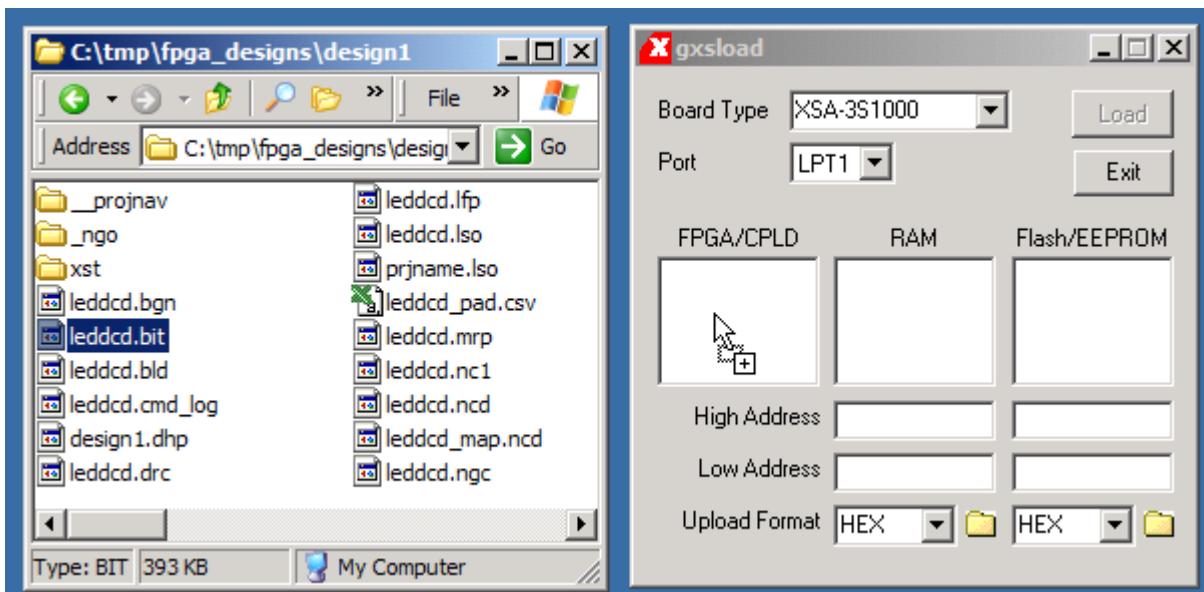
The XSA Boards are programmed using the gxsload utility. Double click the **GXSLOAD** icon to bring up the **gxsload** window:



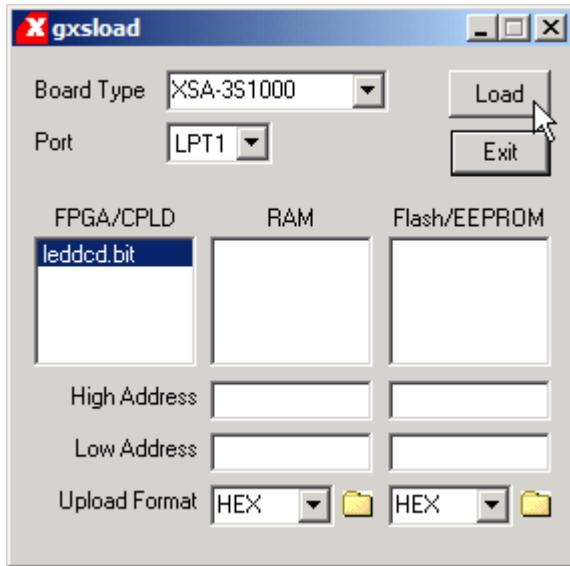
Then click in the Board Type field and select XSA-3S1000 from the drop-down menu since this is the board you are going to load with the bitstream.



Then open a window that shows the contents of the folder where you stored our LED decoder design (C:\tmp\fpga_designs\design1 in this case). You just drag-and-drop the leddcd.bit file from the **design1** window into the FPGA/CPLD pane of the **gxsload** window.



Then you click on the Load button to initiate the programming of the FPGA. Downloading the ledcd.bit file to the XSA Board takes only a few seconds.

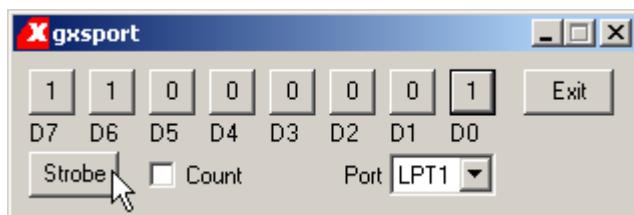


Testing the Circuit

Once the FPGA on the XSA Board is programmed, you can begin testing the LED decoder. The eight data pins of the PC parallel port connect to the FPGA through the downloading cable. You have assigned the inputs of the LED decoder to pins which are connected to the parallel port data pins. The gxsport utility lets you control the logic values on these pins. By placing different bit patterns on the pins, you can observe the outputs of the LED decoder through the seven-segment LED on the XSA Board.



Double-clicking the **gxsport** icon initiates the gxsport utility. The **d0**, **d1**, **d2**, and **d3** inputs of the LED decoder are assigned to the pins controlled by the D0, D1, D2, and D3 buttons of the **gxsport** window. To apply a given input bit pattern to the LED decoder, click on the D buttons to toggle their values. Then click on the Strobe button to send the new bit pattern to the pins of the parallel port and on to the FPGA. For example, setting (D3,D2,D1,D0) = (1,1,1,0) will cause E to appear on the seven-segment LED of the XSA Board.



If you check the Count box in the **gxsport** window, then each click on the Strobe button increments the eight-bit value represented by D7-D0. This makes it easy to check all sixteen input combinations.

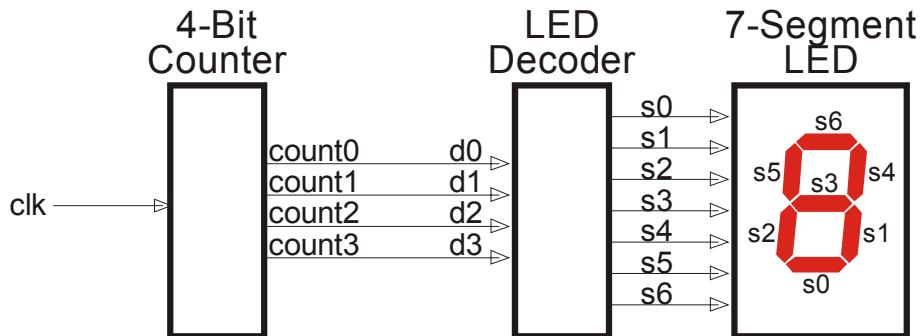
NOTE: Bit D7 of the parallel port controls the /PROGRAM pin of the FPGA. Do not set D7 to 0 or you will erase the configuration of the FPGA. Then you will have to download the bitstream again to continue testing your design.

4

Hierarchical Design

A Displayable Counter

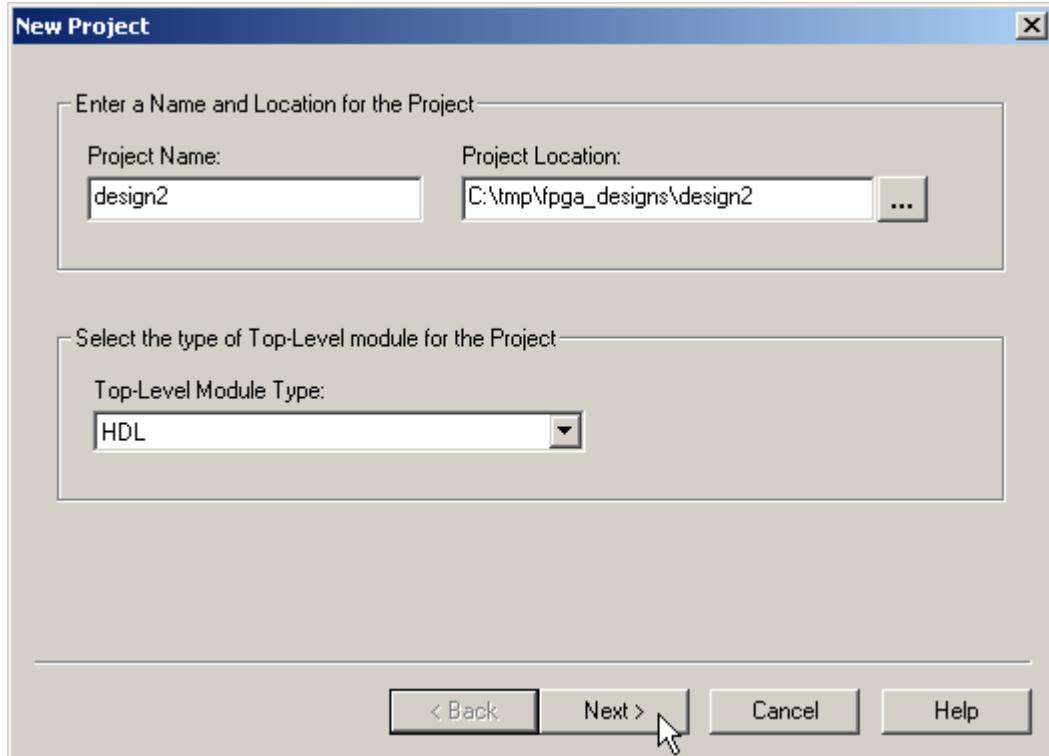
You went through a lot of work for your first FPGA design, so you will reuse it in this design: a four-bit counter whose value is displayed on a seven-segment display. The counter will increment on the falling edge of the clock. The four-bit output from the counter enters the LED decoder whereupon the counter value is displayed on the seven-segment LED. A high-level diagram of the displayable counter looks like this:



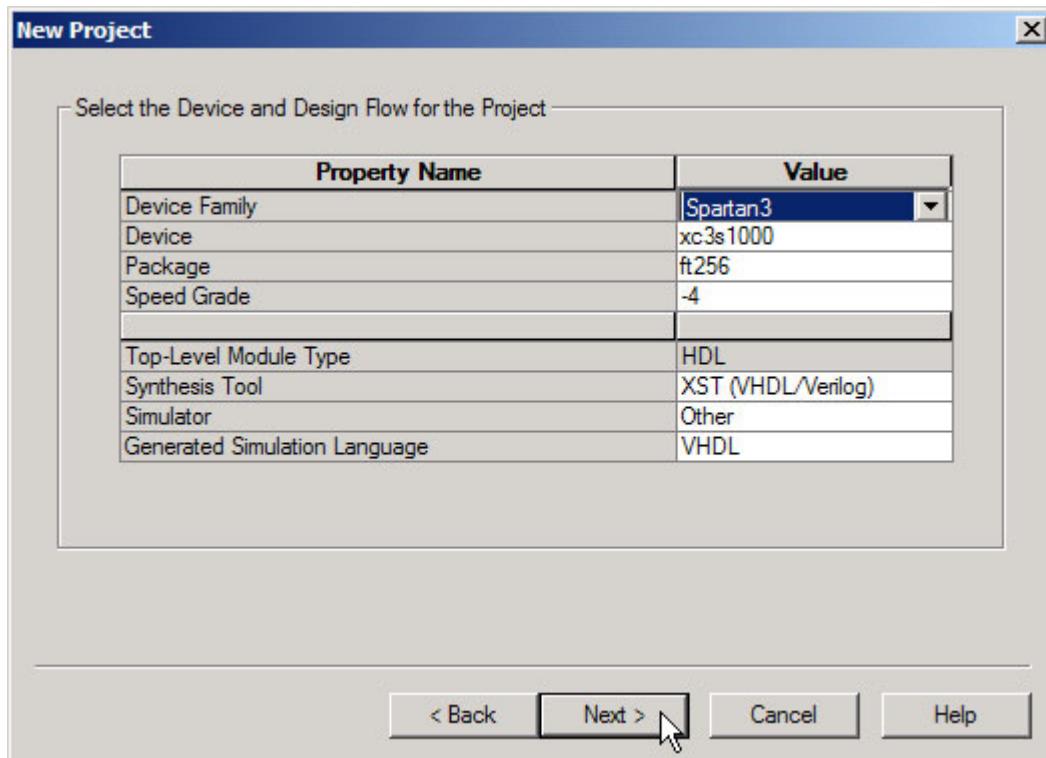
This design is hierarchical in nature. The LED decoder and counter are modules which are interconnected within a top-level module.

Starting a New Design

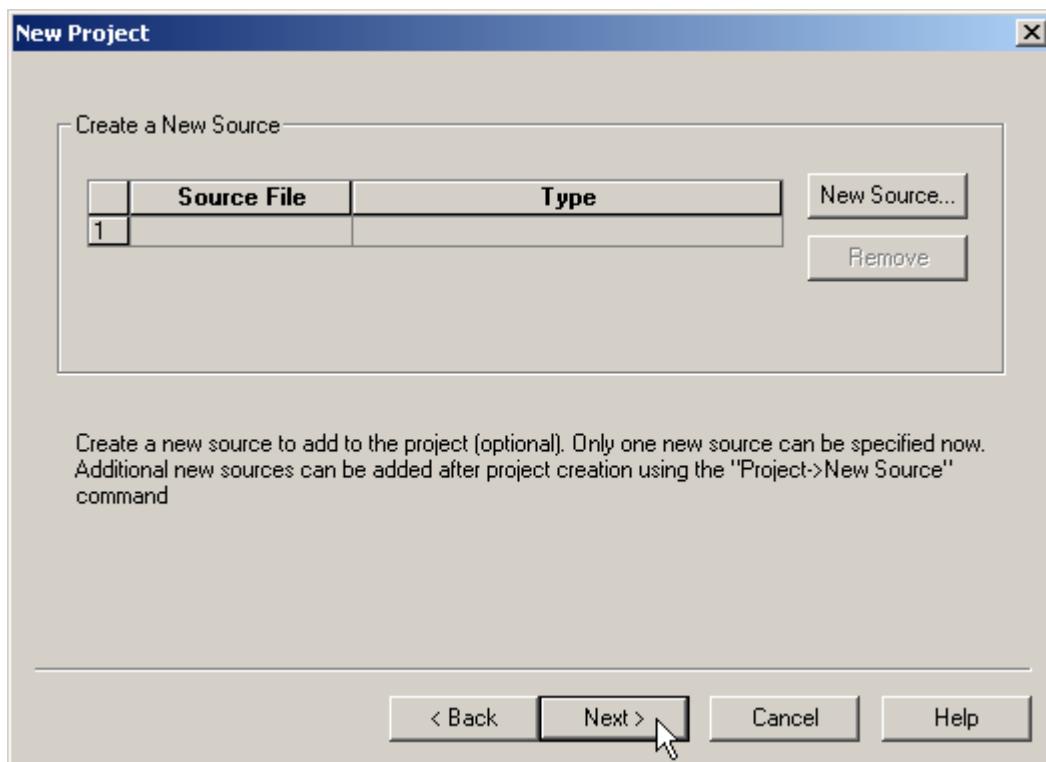
You can start a new project using the **File→New Project...** menu item. Name the project **design2** and store it in the same folder as the previous design: C:\tmp\fpga_designs. Then click on the Next button.



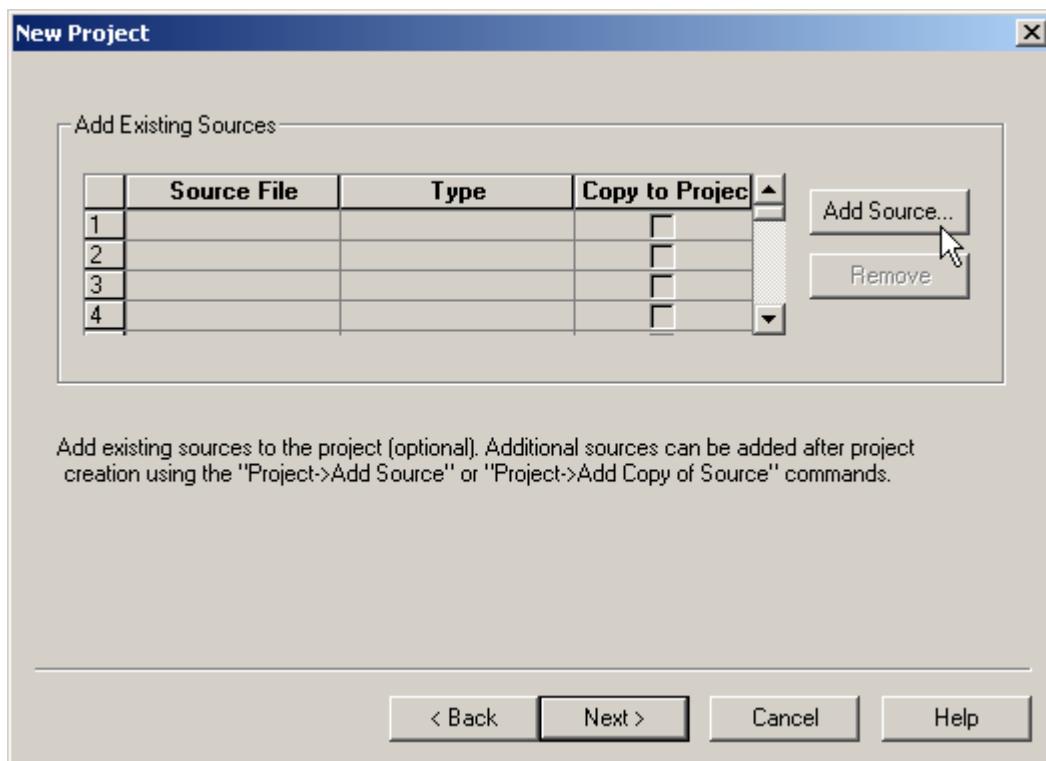
You will target the same FPGA on the XSA Board, so the other properties in the **New Project** window retain the same values you set in the previous project.



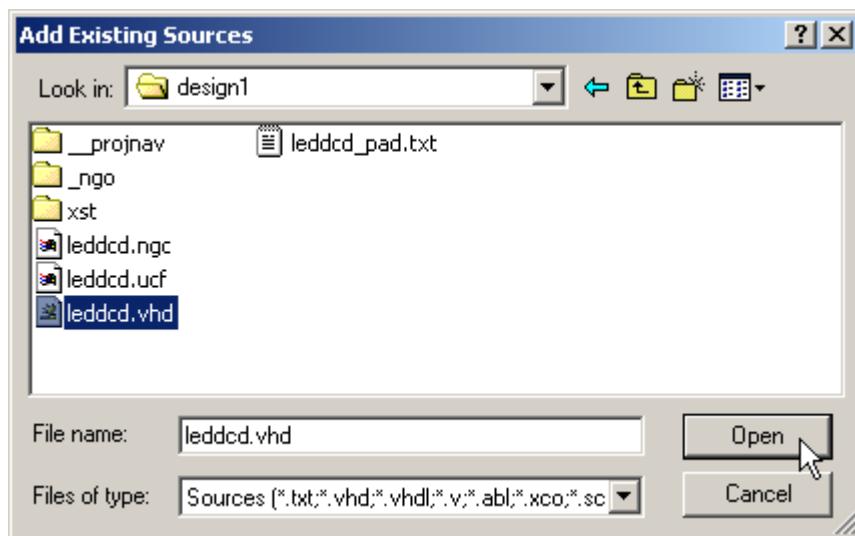
You won't add any new source files at the moment, so just click on the Next button.



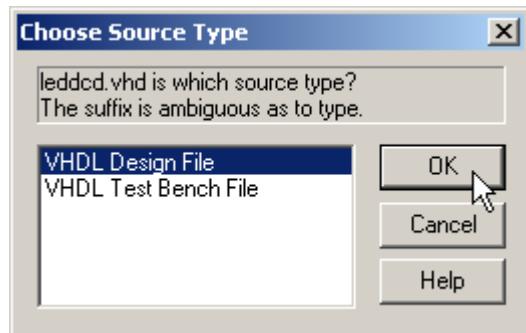
The next window allows you to add existing source files to your new project. It will save time if you re-use the LED decoder from your previous design, so click on the Add Source... button.



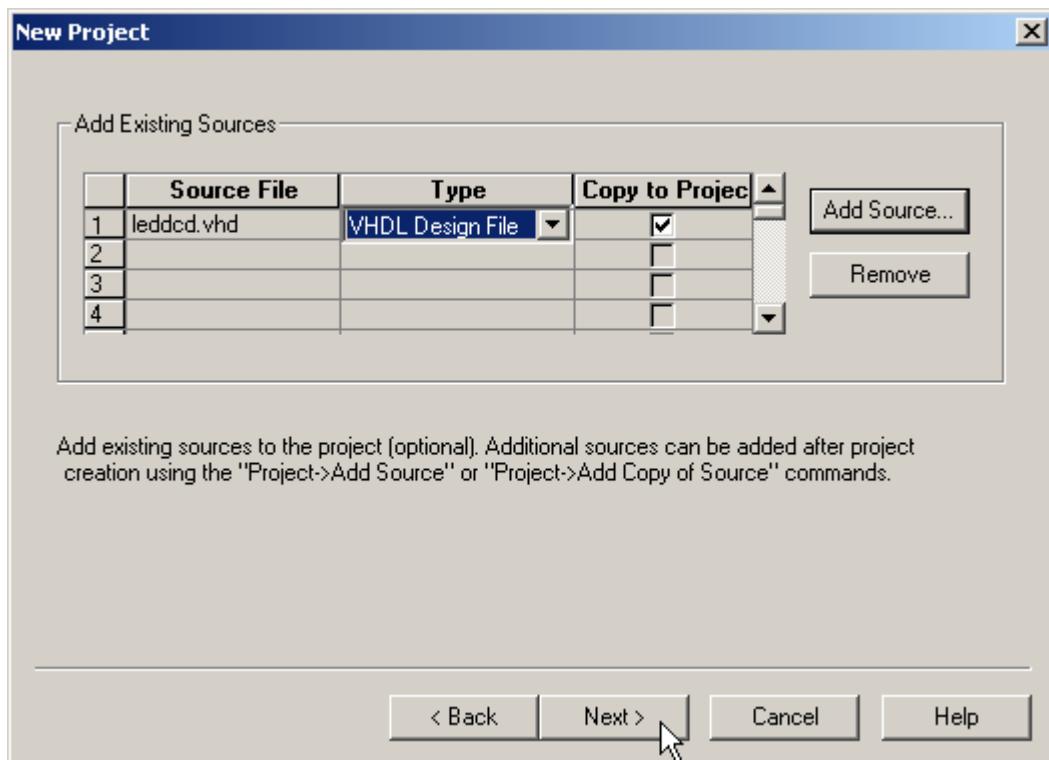
The **Add Existing Sources** window appears. Move to the C:\tmp\fpga_designs\design1 folder and highlight the leddcd.vhd file that contains the VHDL source code for the LED decoder.



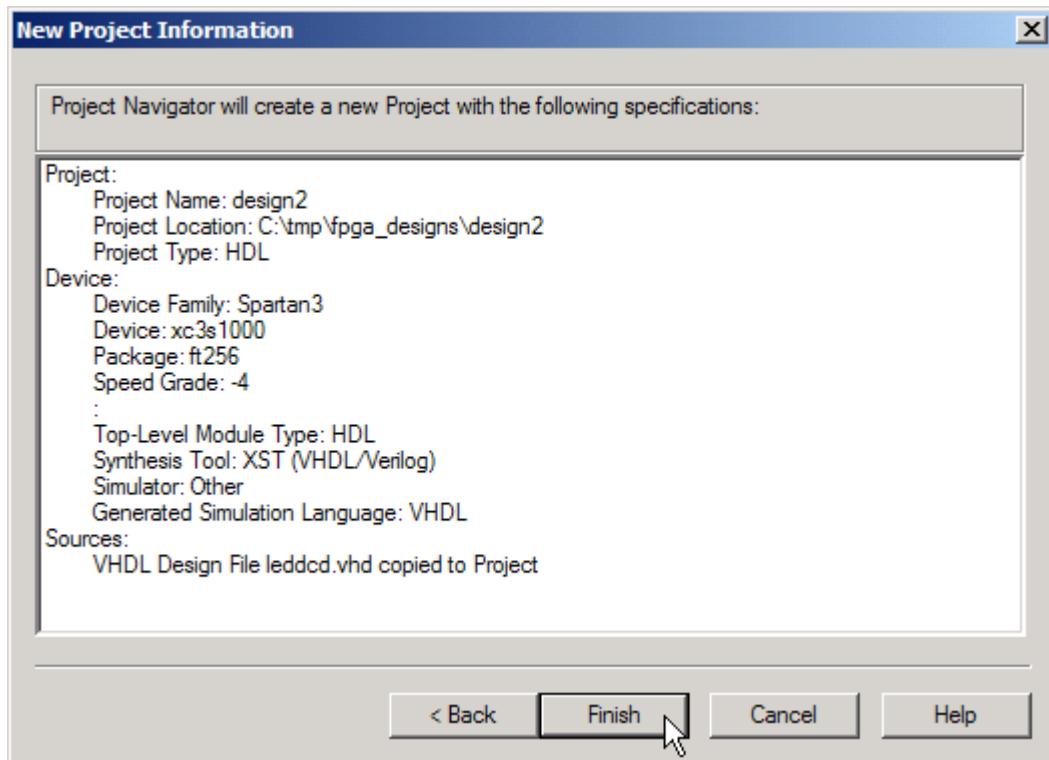
After clicking on Open, a window appears that asks for the type of file you are adding to the project. Select VHDL Design File and click the OK button.



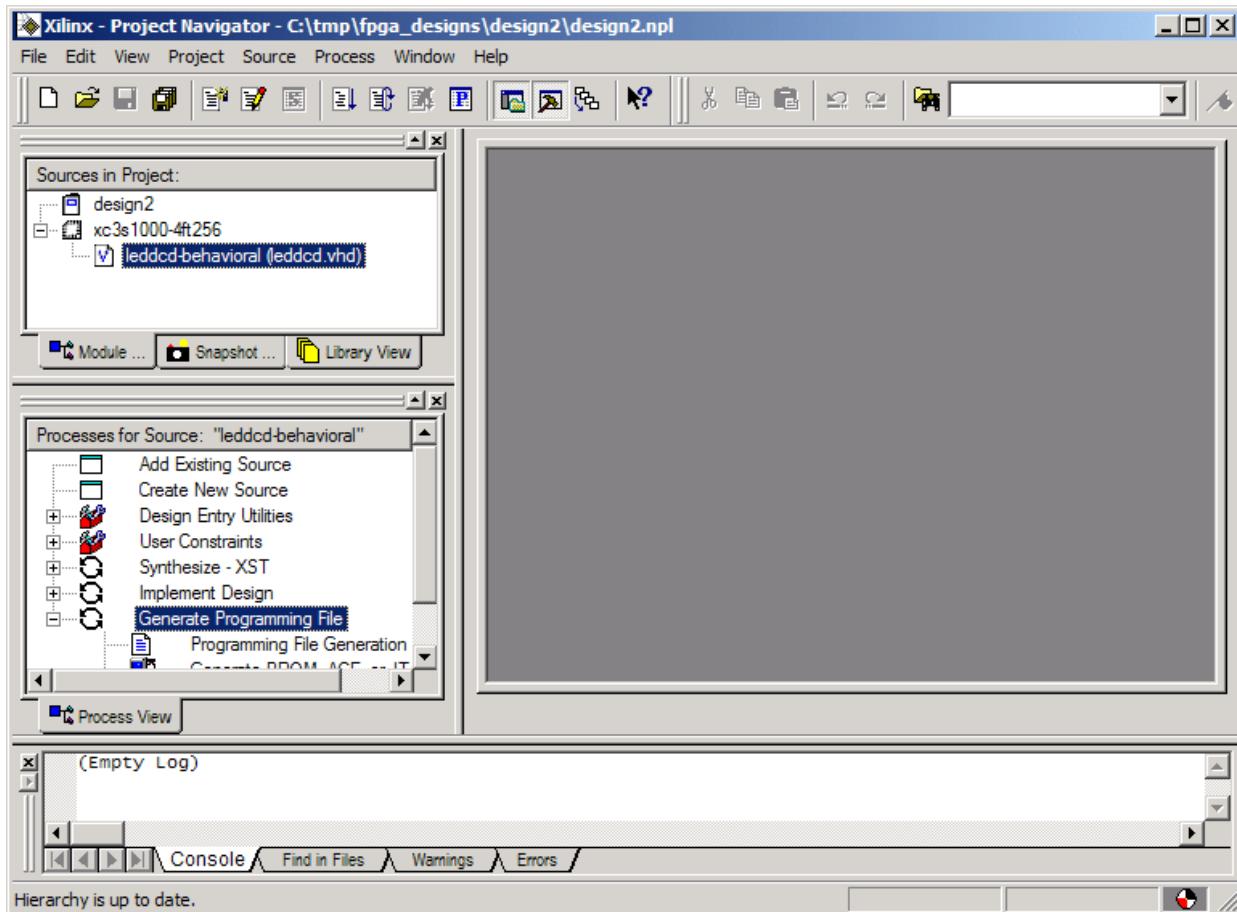
The **New Project** window now shows that a copy of the leddcd.vhd file will be added to the project. This is the only existing file you need to add, so click on the Next button to move on to the next window.



The final screen shows the pertinent information for the new project. Click on the Finish button to complete the creation of the project.

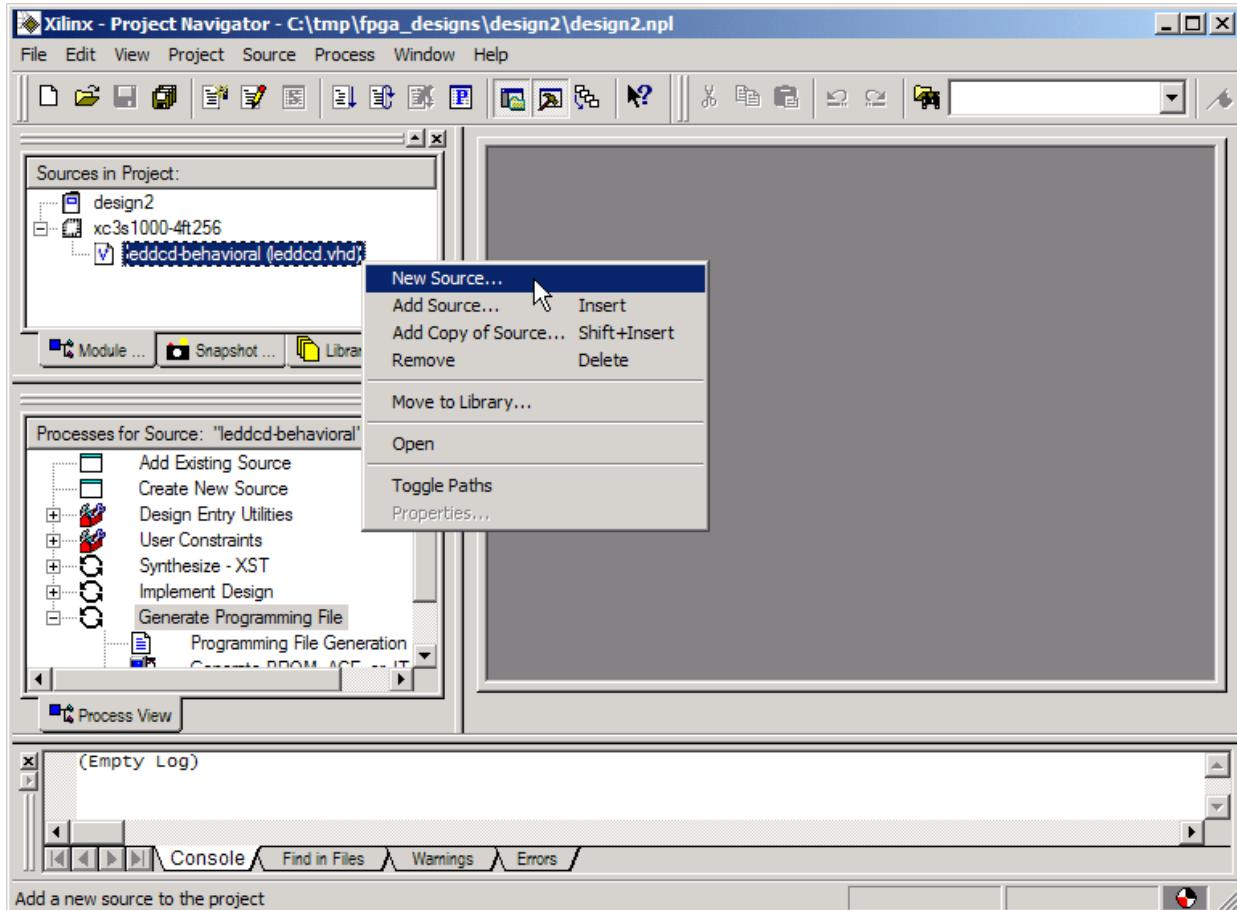


Once you click on Finish in the **New Project** window, the **Project Navigator** window appears as shown below. The project currently contains only the single ledcd.vhd source file.

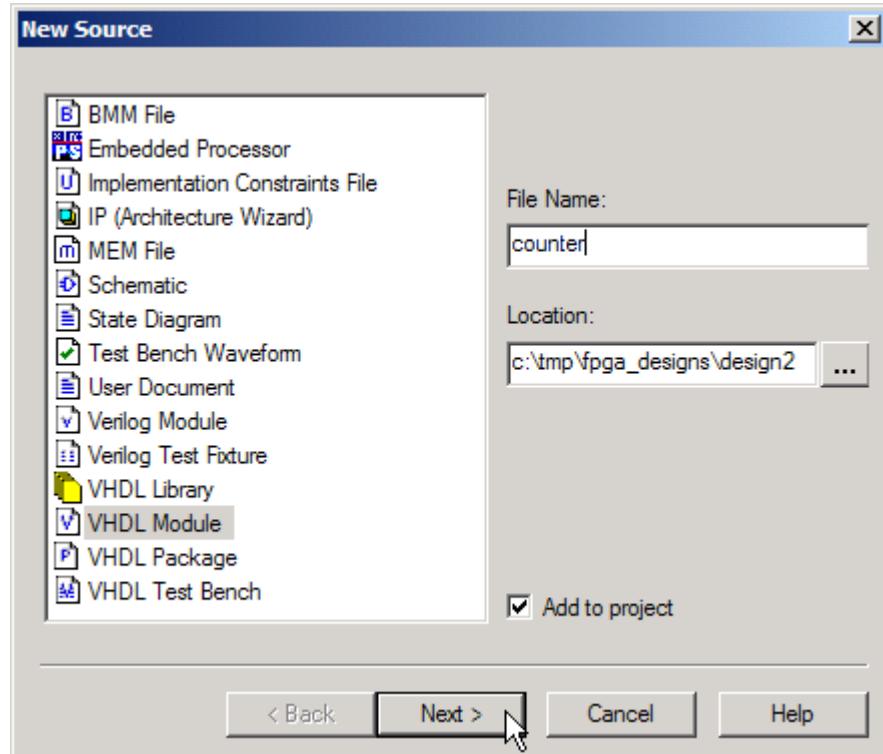


Adding a Counter

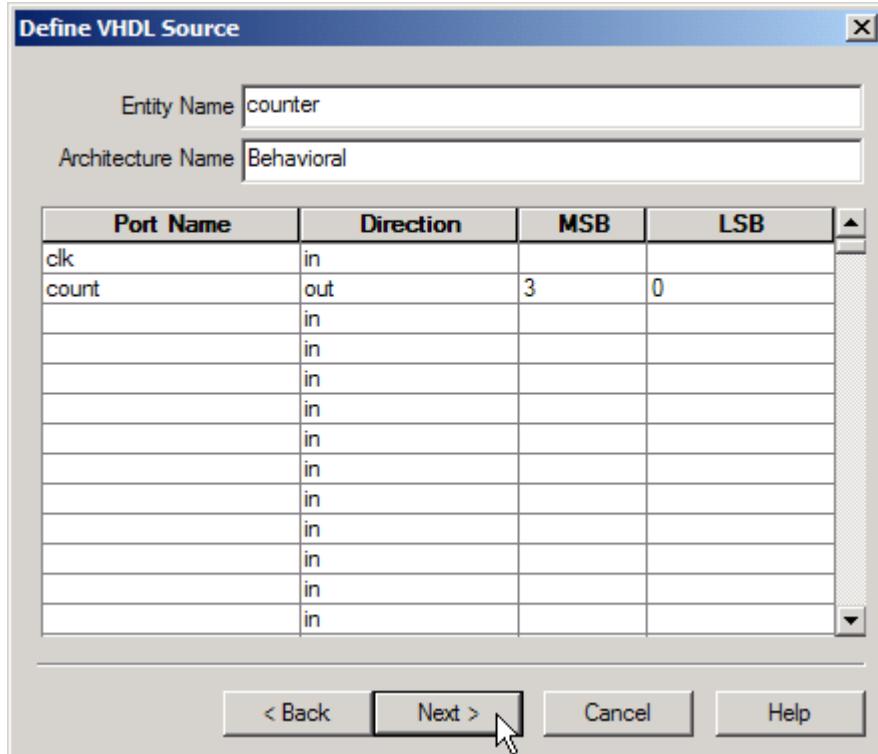
Now you have to add the counter to our design. There is no counter module yet, so you have to build one with VHDL. Right-click on the xc3s1000-4ft256 object and select New Source... from the pop-up menu.



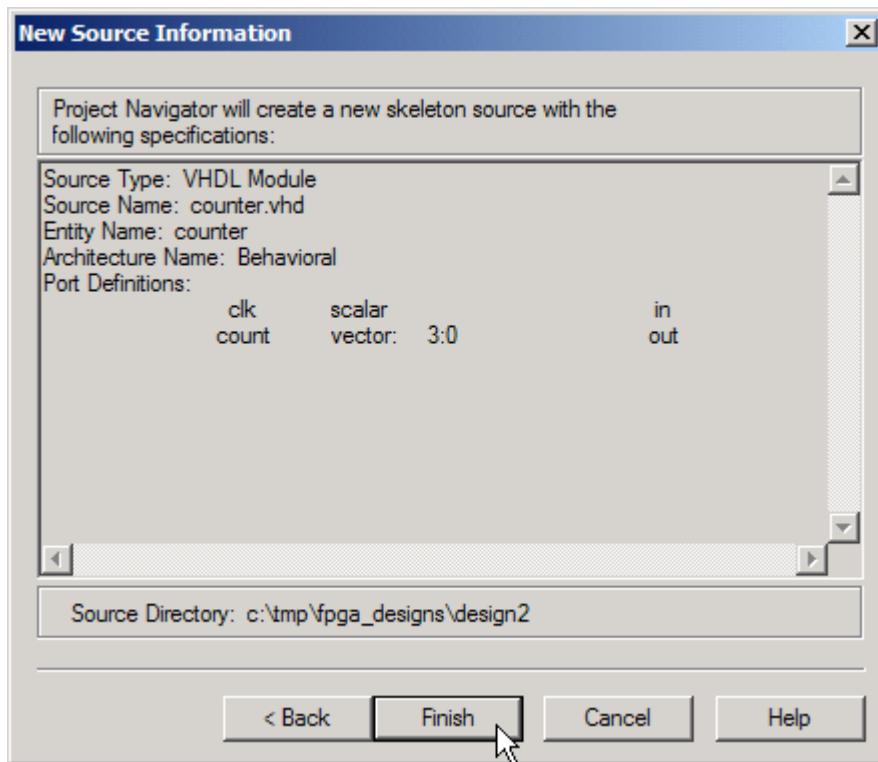
As in the previous example, you are prompted for the type of file to add to the project. Once again, select the VHDL Module menu item. Then type `counter` into the File Name field and click on the Next button.



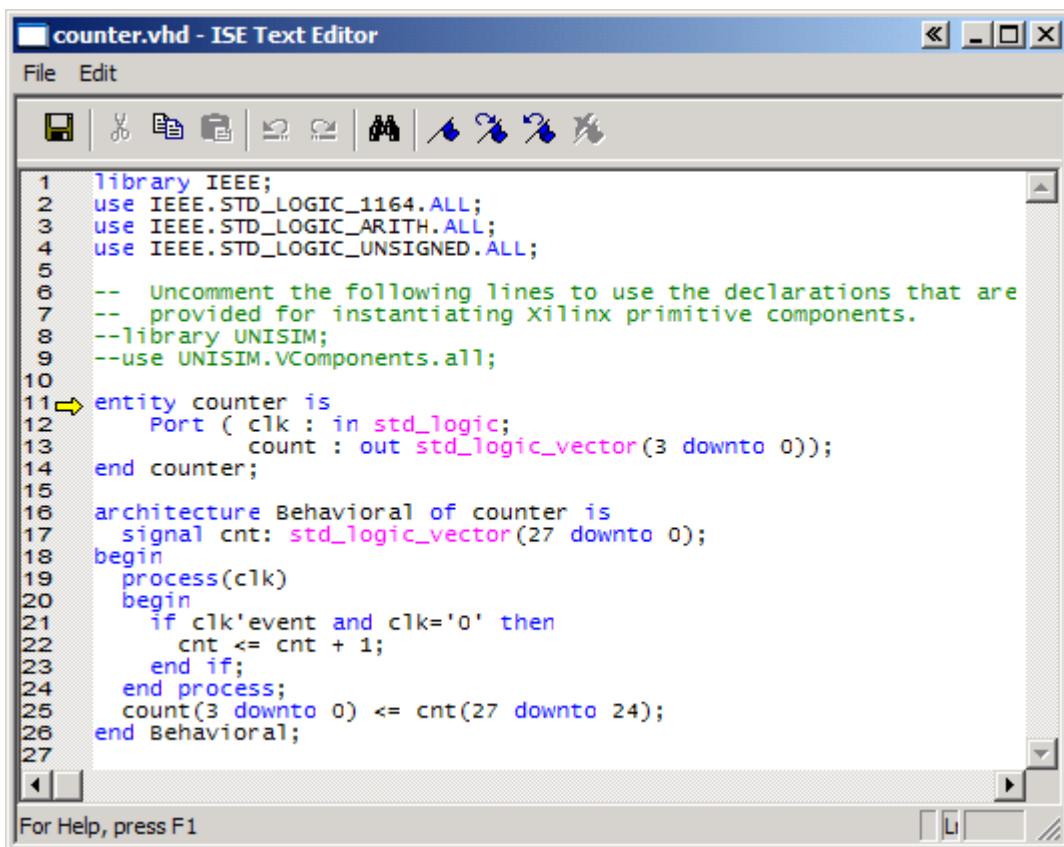
Now you can declare the inputs and outputs for the counter in the **Define VHDL Source** window as shown below. The **counter** module receives a single input, **clk**, and has a four-bit output bus, **count**, which outputs the current counter value.



Click on Next and check the information about the module.



After clicking Finish in the **New Source Information** window, you are presented with a VHDL skeleton for the counter. Flesh-out the skeleton as follows:



```

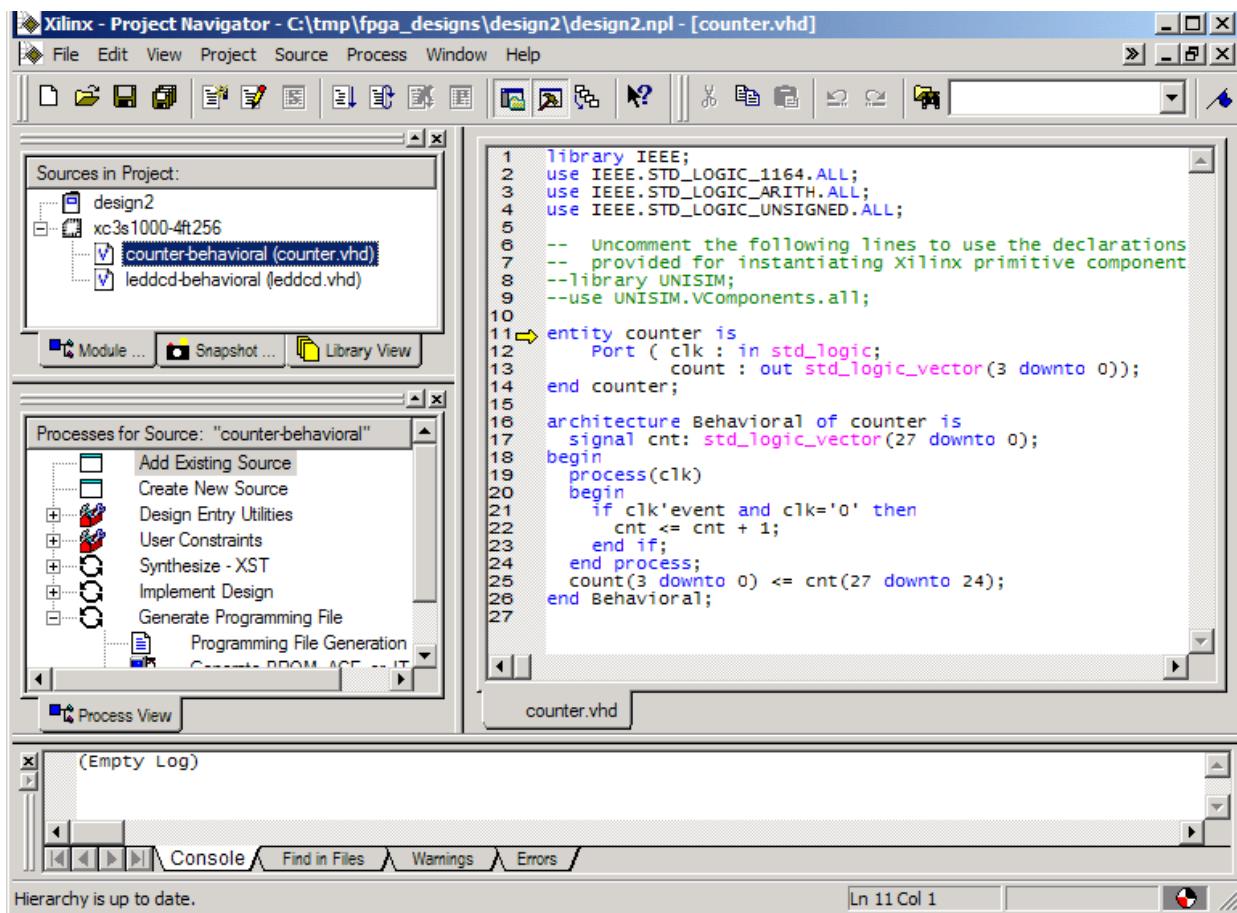
1  library IEEE;
2  use IEEE.STD_LOGIC_1164.ALL;
3  use IEEE.STD_LOGIC_UNSIGNED.ALL;
4
5
6  -- Uncomment the following lines to use the declarations that are
7  -- provided for instantiating Xilinx primitive components.
8  --library UNISIM;
9  --use UNISIM.VComponents.all;
10
11 entity counter is
12     Port ( clk : in std_logic;
13            count : out std_logic_vector(3 downto 0));
14 end counter;
15
16 architecture Behavioral of counter is
17     signal cnt: std_logic_vector(27 downto 0);
18 begin
19     process(clk)
20     begin
21         if clk'event and clk='0' then
22             cnt <= cnt + 1;
23         end if;
24     end process;
25     count(3 downto 0) <= cnt(27 downto 24);
26 end Behavioral;
27

```

Line 17 declares a 28-bit signal, **cnt**, that is the current value of the counter. The process on lines 19-24 controls when the counter increments. The condition clause of line 21 is only true when the value on the **clk** input goes from 1 to 0. Then the statement on line 22 replaces the value in **cnt** with its incremented value. (You can use the high-level addition operator instead of having to describe a 28-bit adder because on line 4 we have linked into the `ieee.std_logic_unsigned.all` package that supports unsigned arithmetic.) Finally, line 25 places the upper four bits of the current counter value onto the outputs of the module.

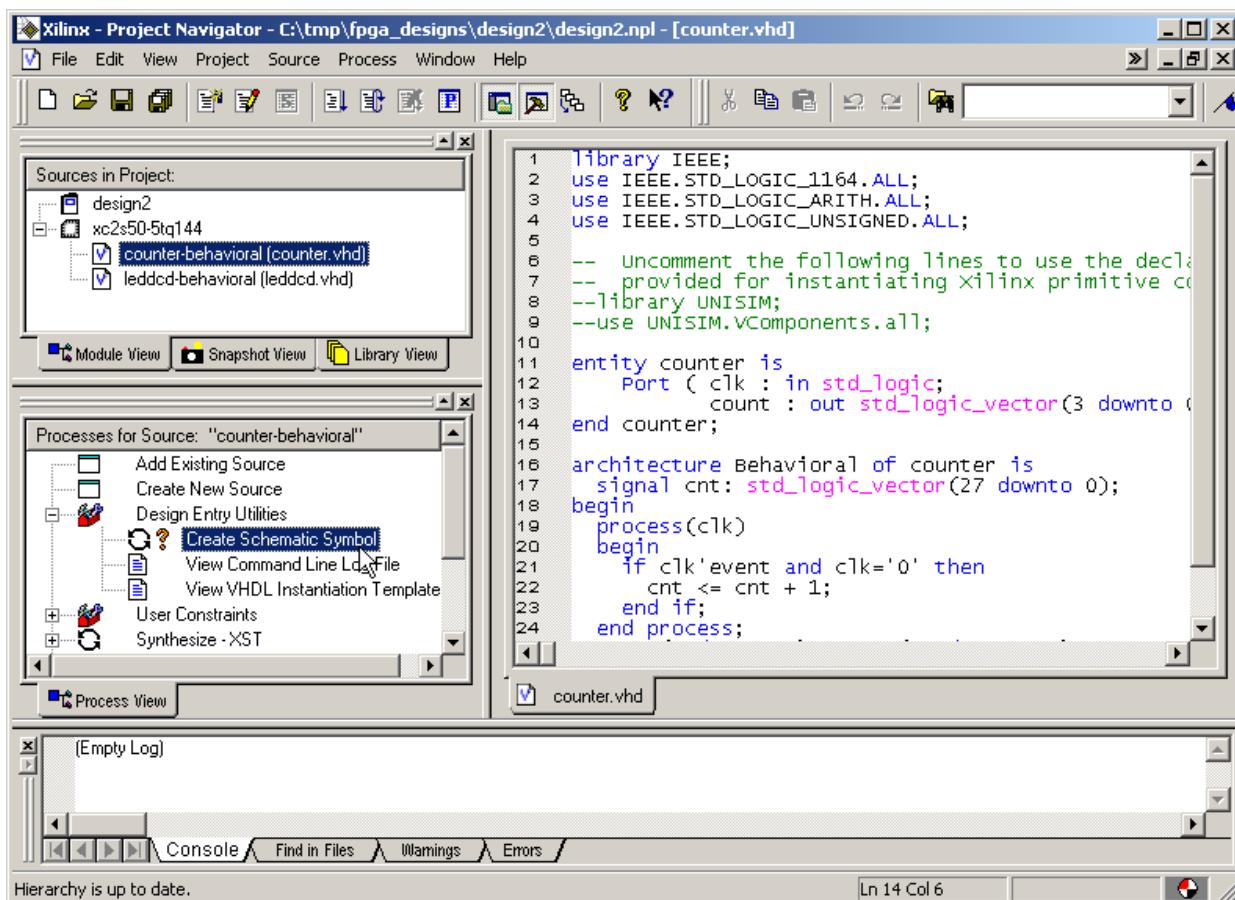
Why are you building a 28-bit counter and using only the upper four bits? The counter will be driven by a clock signal on the XSA Board that has a frequency of 50 MHz. The LED display would be changing much too quickly to see at this frequency. By connecting the LED decoder to the upper four bits of the 28-bit counter, the display will only change once in every 2^{24} clock cycles. So the LED display will change every $2^{24} / (50 \times 10^6) = 0.336$ seconds which is slow enough to read.

After entering the VHDL shown above and saving it, you can see that the counter module has been added to the Sources pane of the **Project Navigator** window.

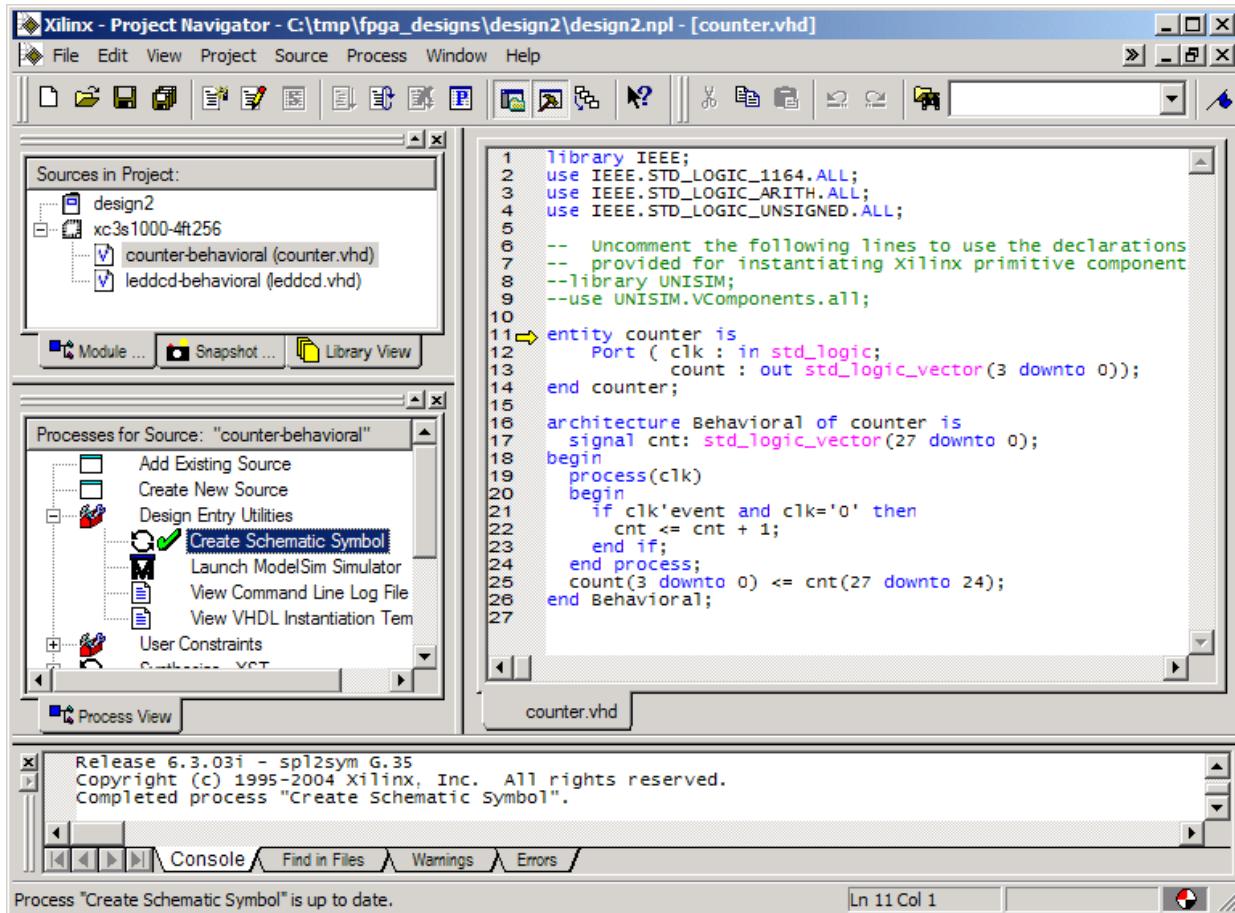


Tying Them Together

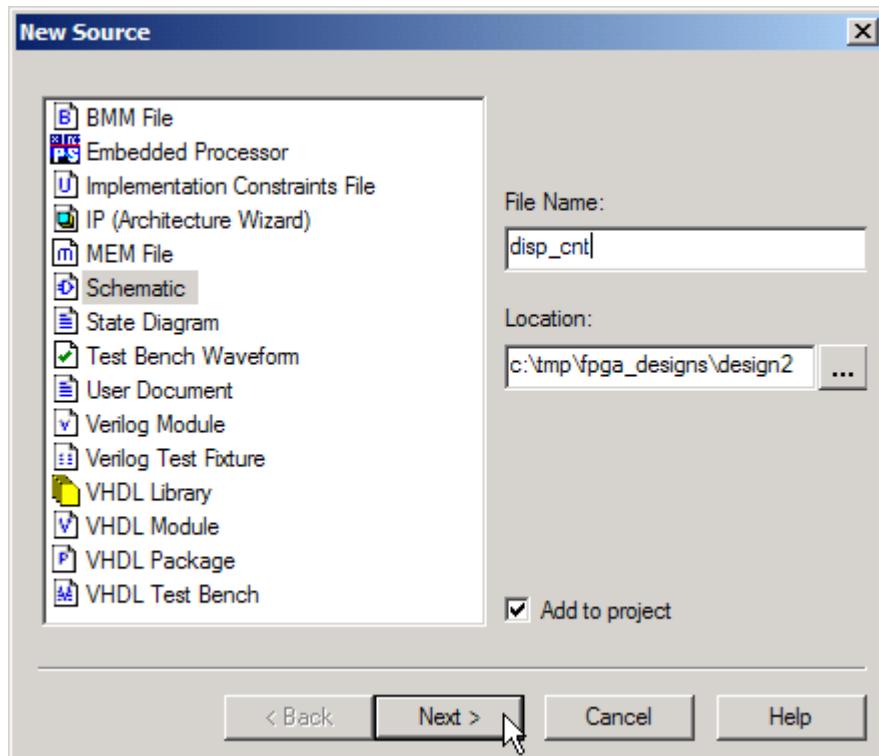
You have the LED decoder and the counter, but now you need to tie them together to build the displayable counter. You will do this by connecting the counter to the LED decoder in a top-level schematic. Before you can do this, you have to create schematic symbols for both the counter and LED decoder VHDL modules. To create the counter schematic symbol, highlight the counter object in the Sources pane and then double-click the Create Schematic Symbol process.



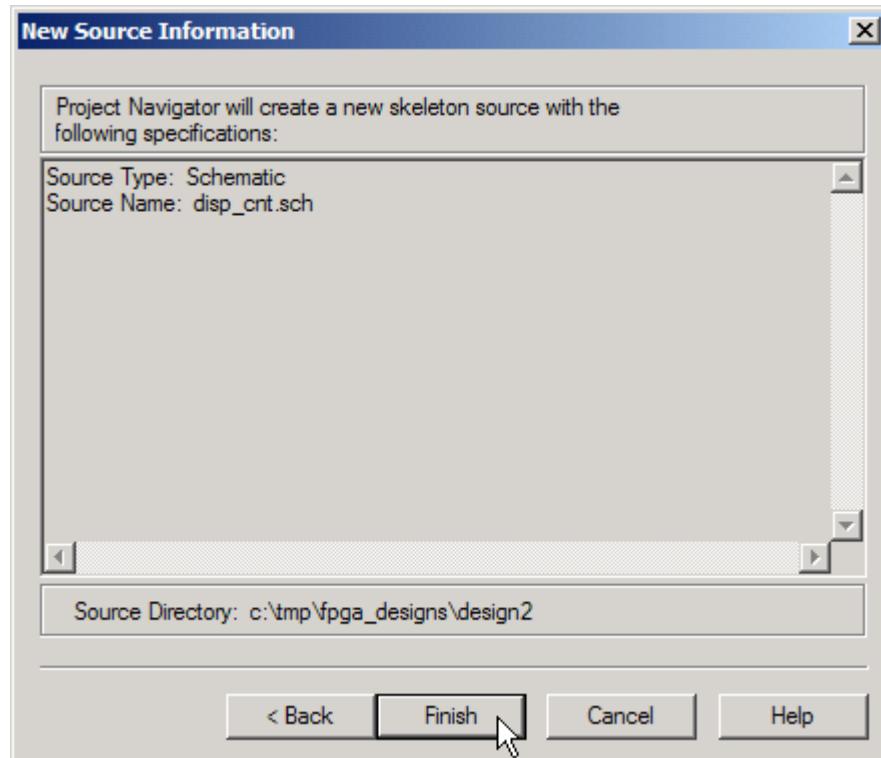
A will appear next to the Create Schematic Symbol process after the counter symbol is created. Repeat this procedure to create the schematic symbol for the LED decoder.



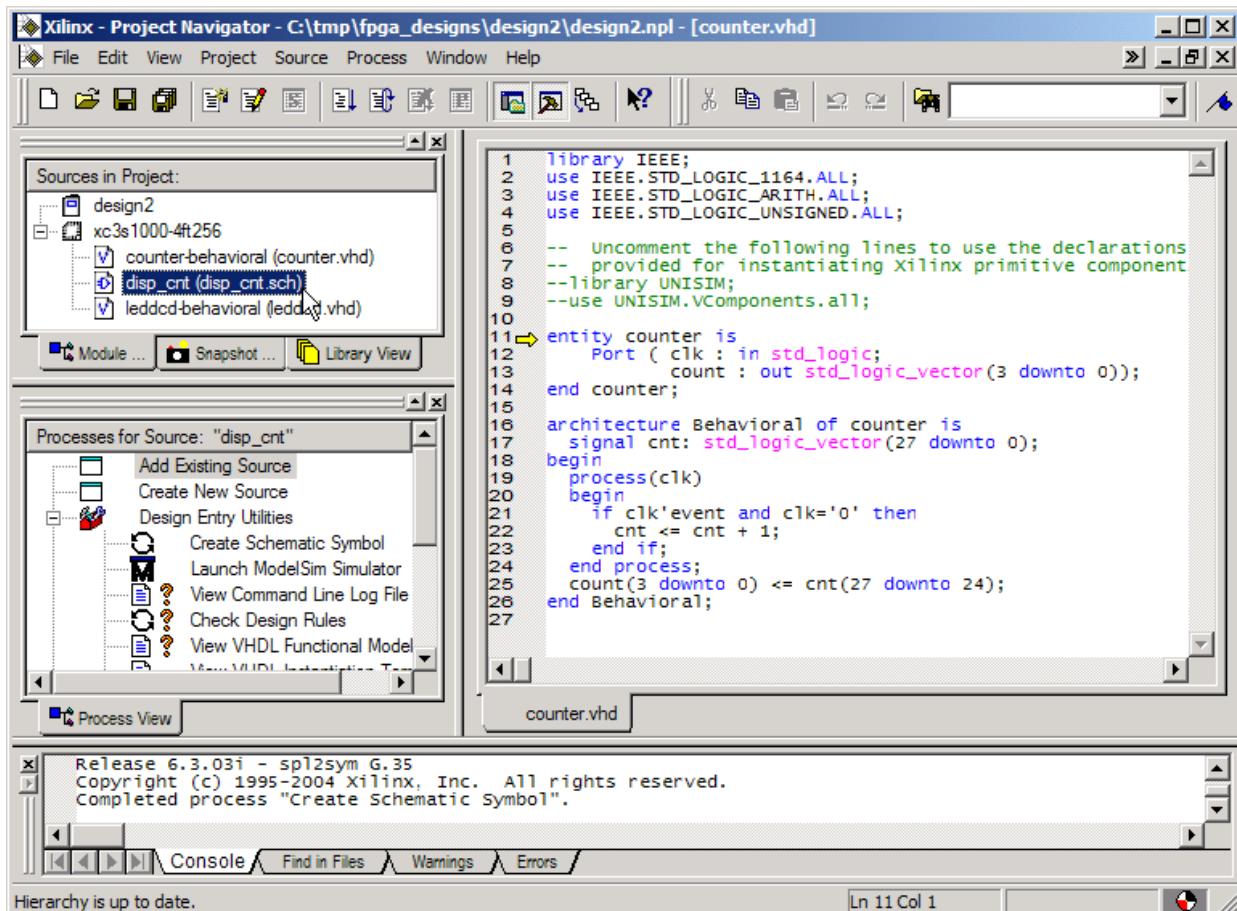
Once the schematic symbols for the lower-level modules are built, you can add the top-level schematic to the project. Right-click on the xc3s1000-4ft256 object and select New Source... from the pop-up menu. Then highlight the Schematic entry in the **New Source** window and name the schematic **disp_cnt**. Then click on Next.



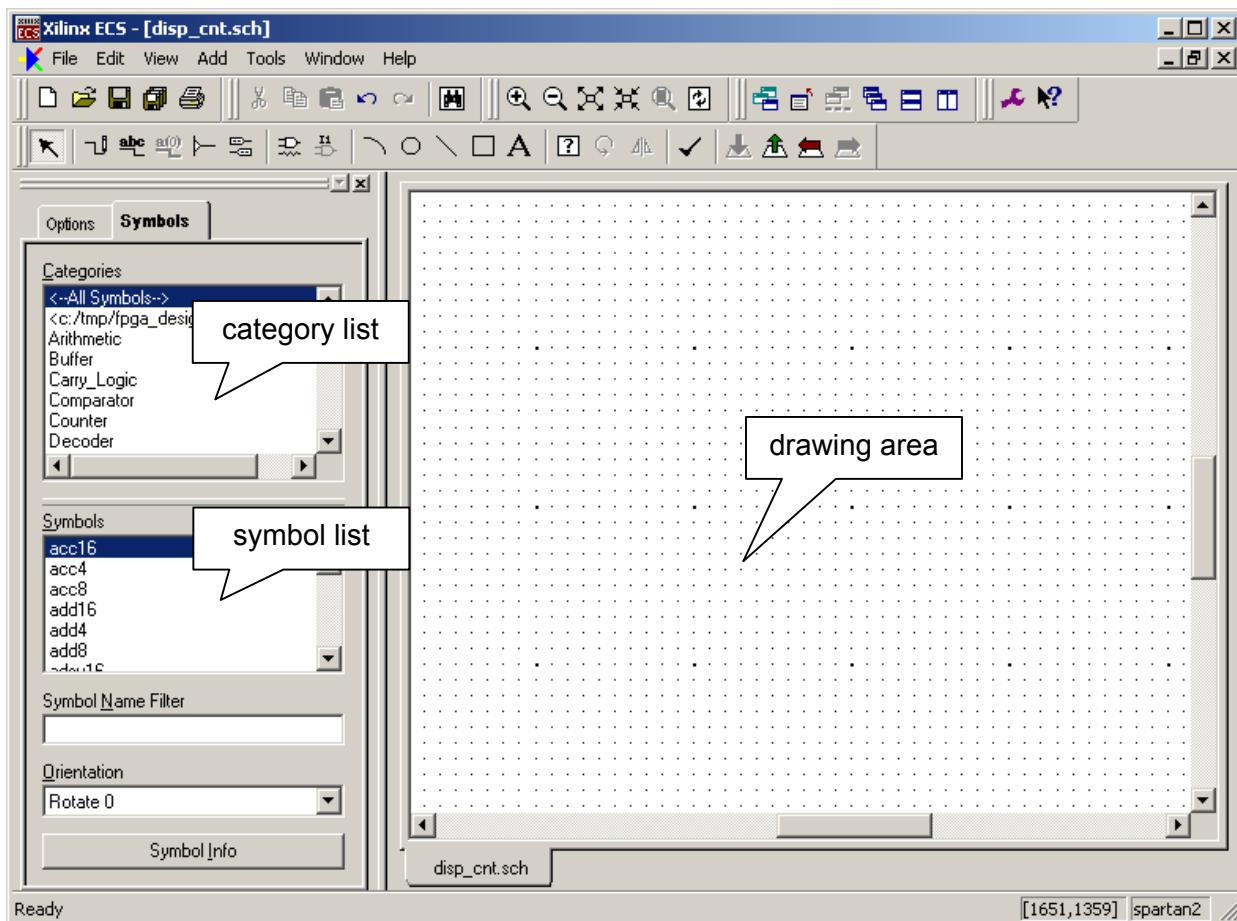
There is very little to do when initializing a schematic, so just click on the Finish button in the **New Source Information** window that appears.



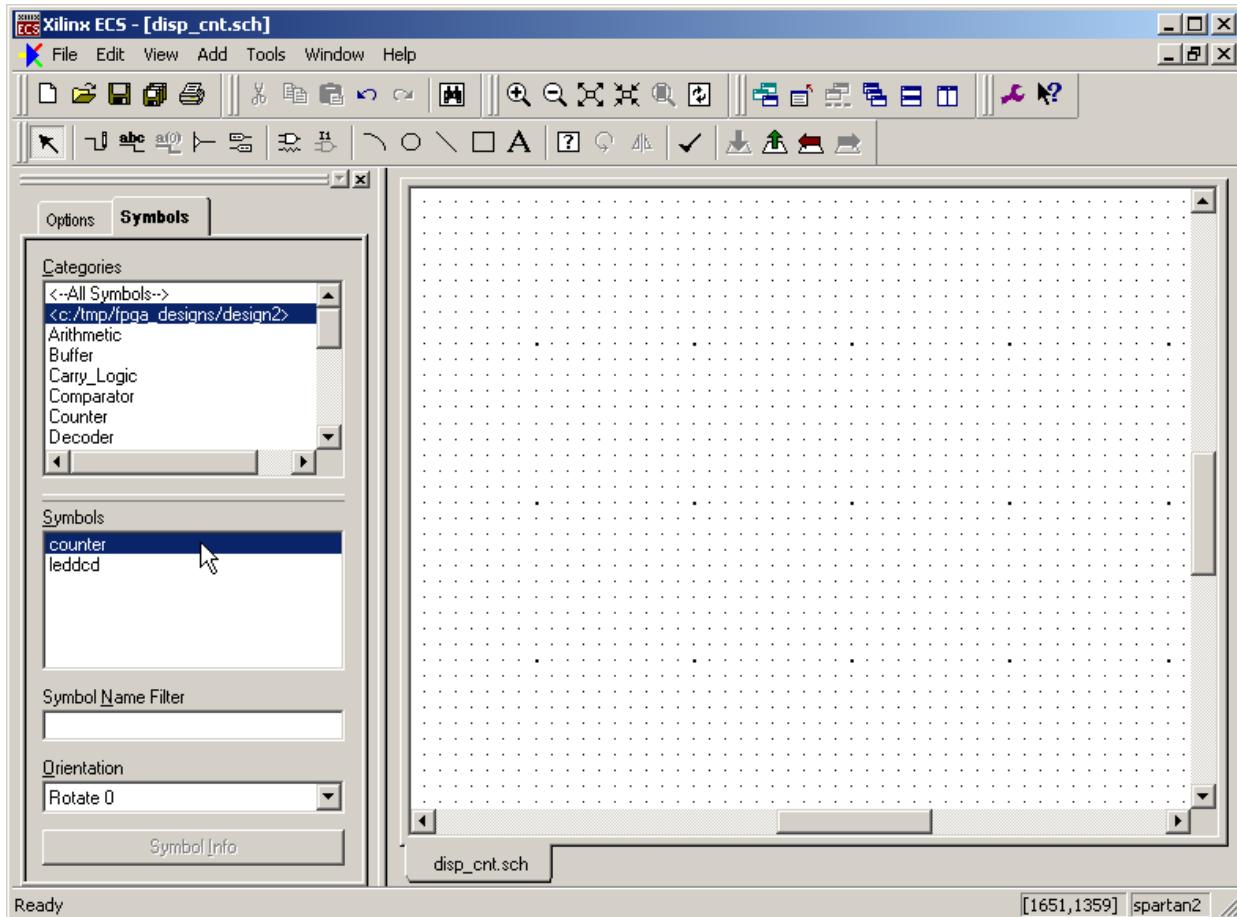
Now the disp_cnt schematic object has been added to the Sources pane. You can double-click it to begin creating the schematic, but a schematic editor window should open automatically once the file is created.



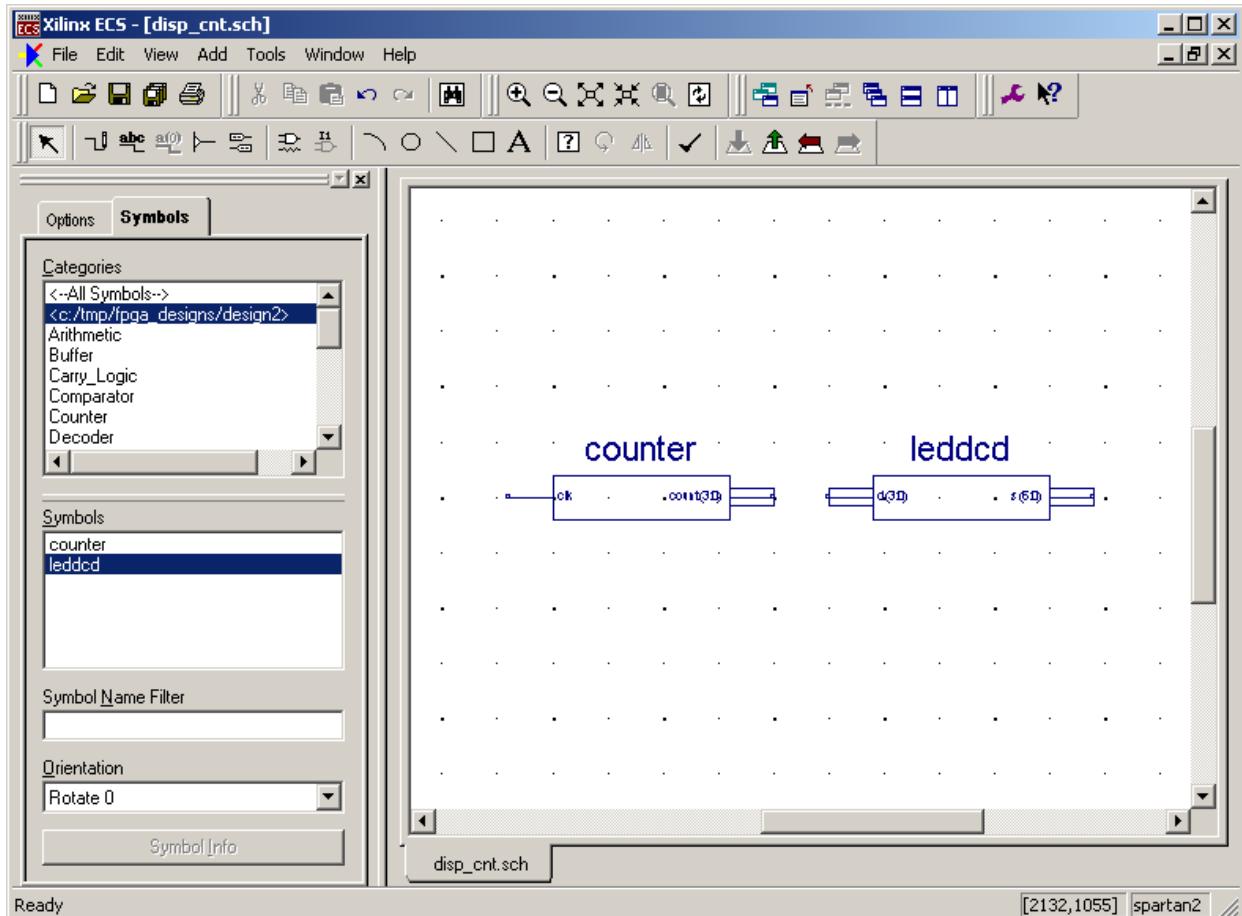
The schematic editor window has a drawing area, and the Symbols tab has a list of categories for various logic circuit elements that can be used in a schematic. Below that is the list of symbols for circuit elements in the highlighted category.



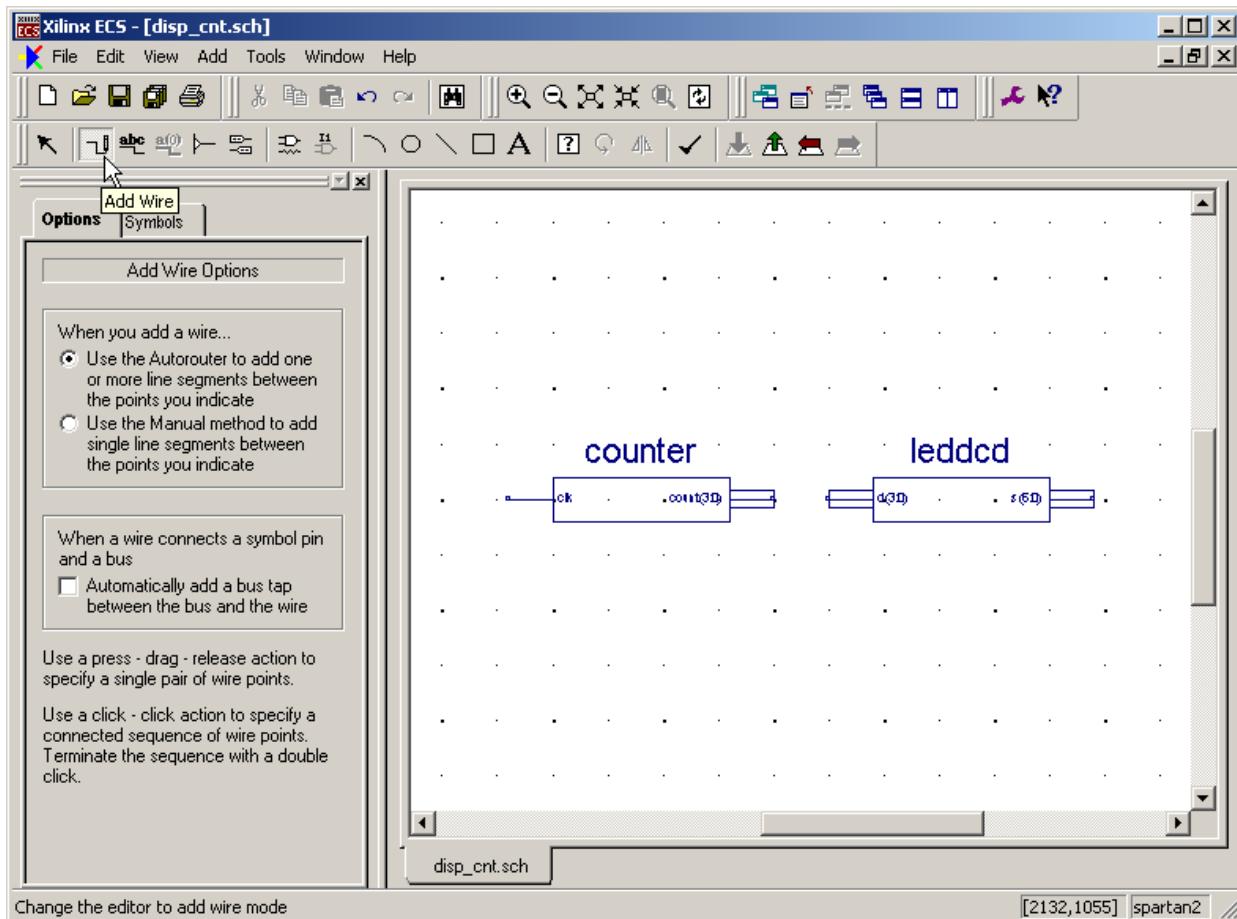
To start creating the top-level schematic, highlight the second entry in the category list. The c:/tmp/fpga_designs/design2 category contains the schematic symbols for the **design2** project's counter and LED decoder modules. You can see the names of these modules in the symbol list.



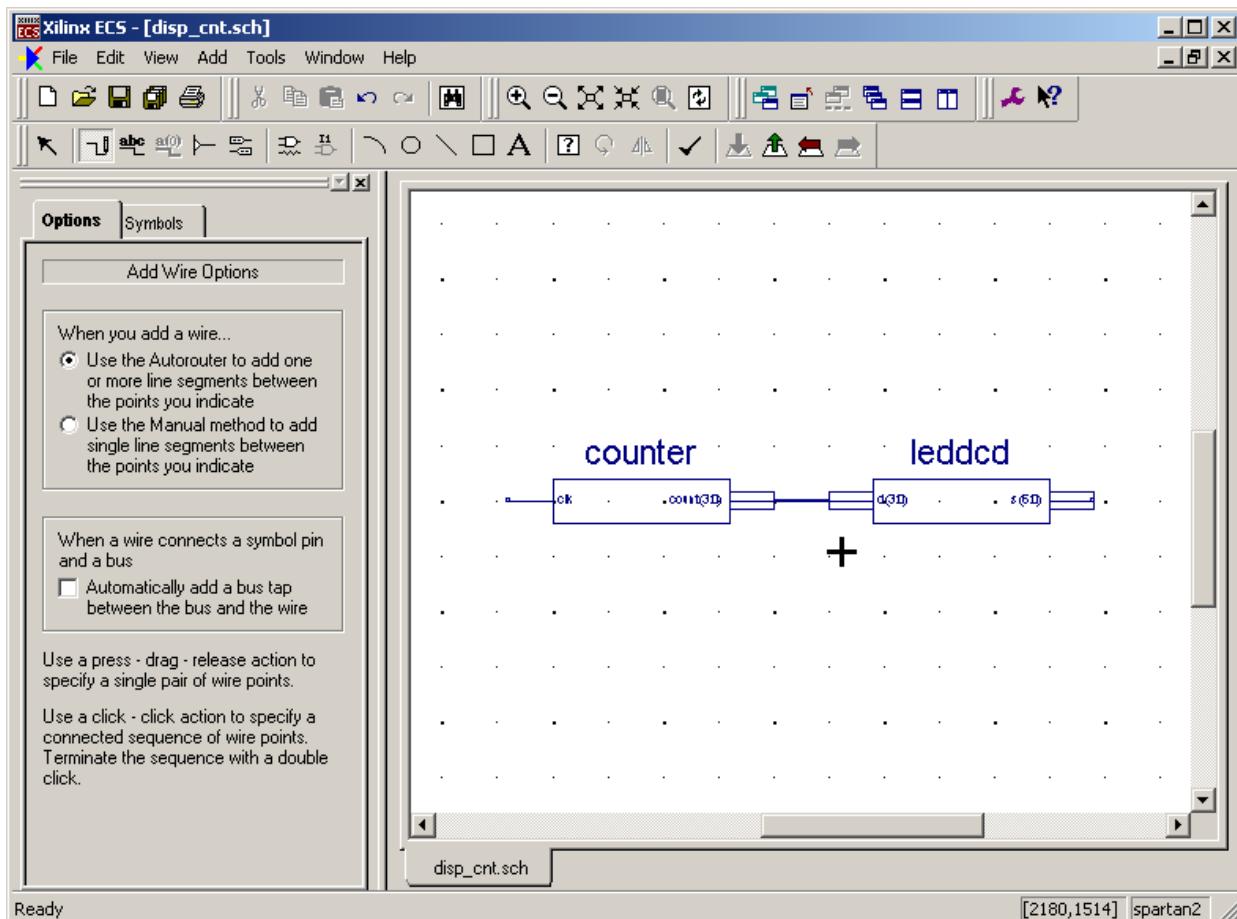
Click on the counter entry in the Symbols list. Then move the mouse cursor into the drawing area and left-click to place an instance of the counter into the schematic. Repeat this process with the ledcd module to arrive at the arrangement shown below.



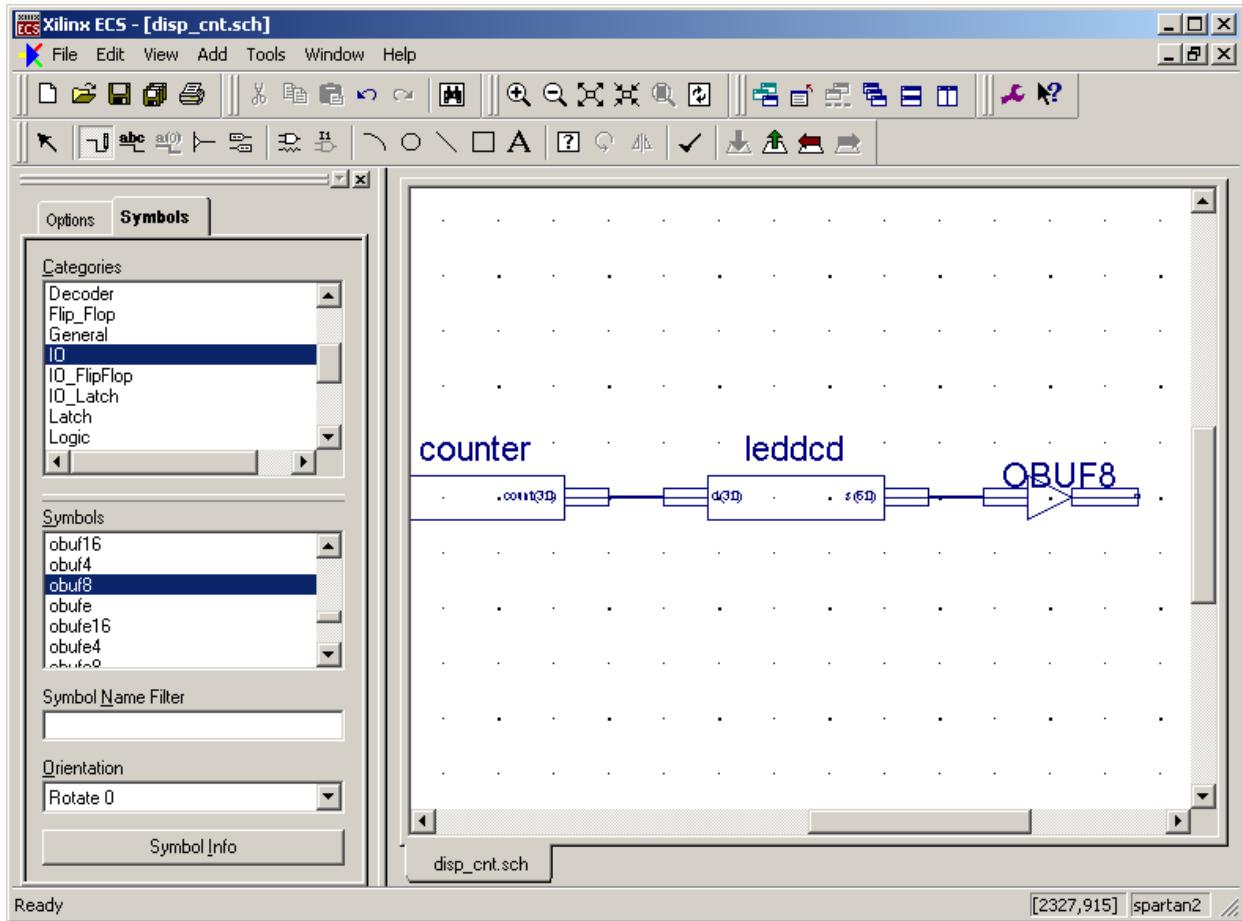
Next, click on the  button to begin adding wires to the schematic.



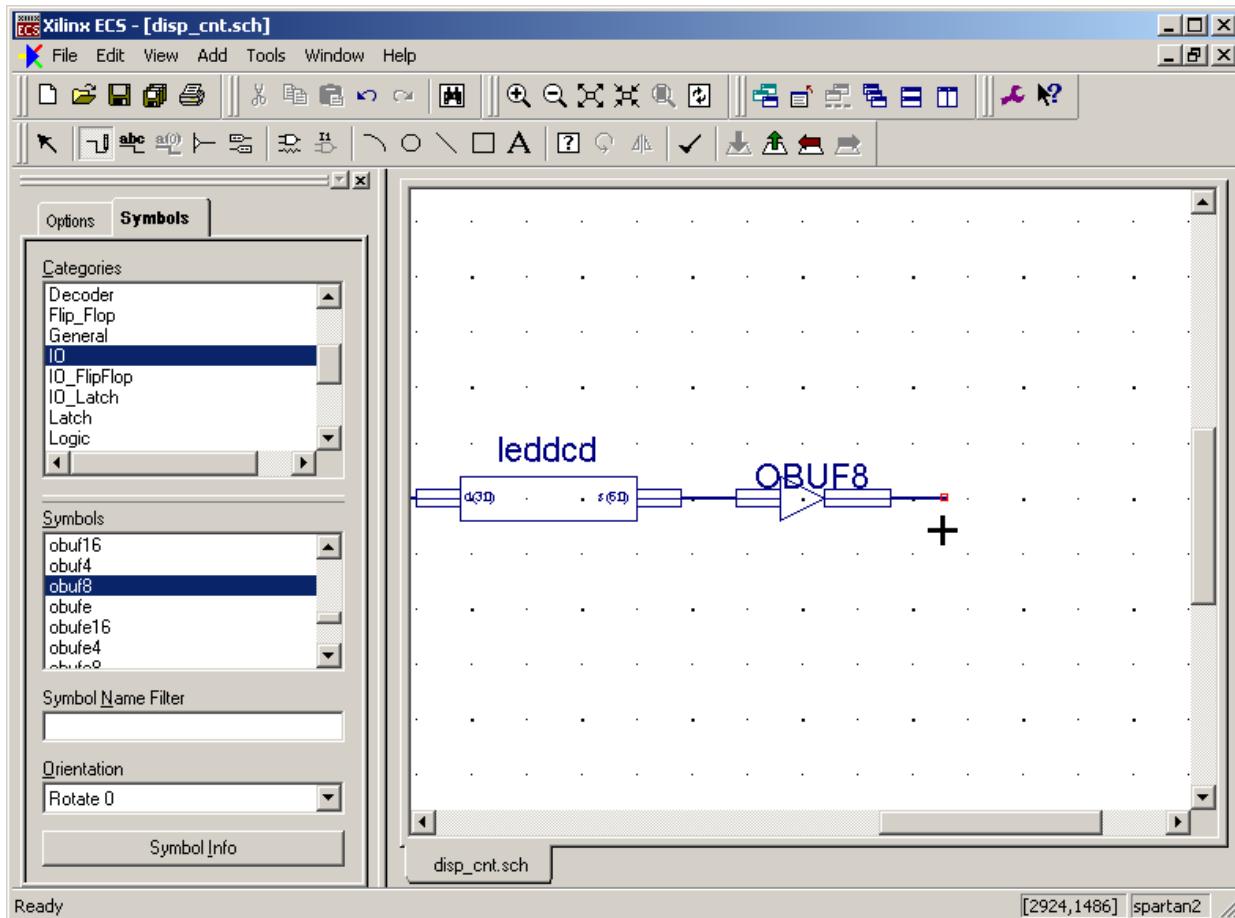
Left-click the mouse on the **count(3:0)** bus on the right-hand edge of the **counter** module. Then left-click on the **d(3:0)** bus on the left-hand edge of the **leddcd** module. This creates a four-bit bus between the output of the counter module and the input of the LED decoder module.



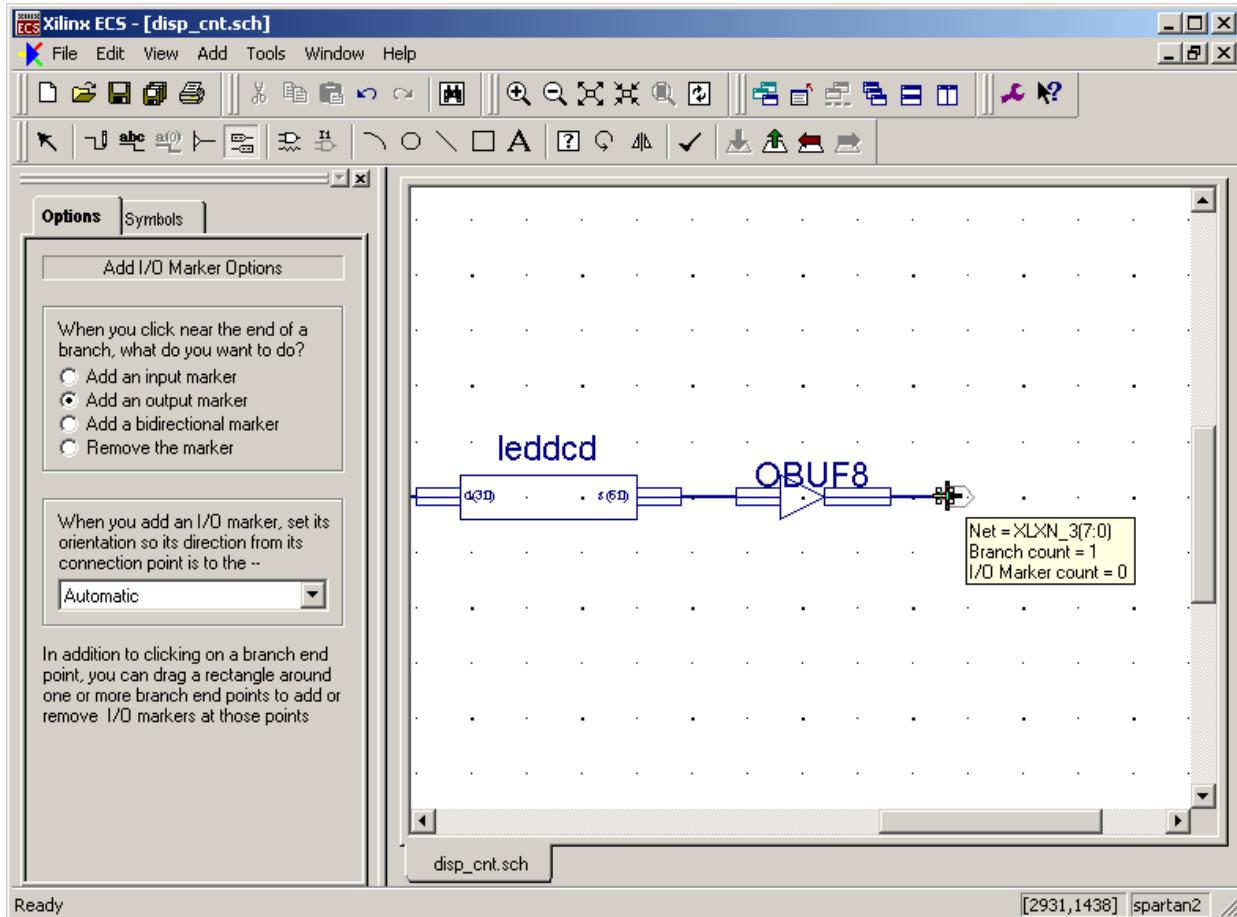
Now highlight the IO category and select a byte-wide output buffer (OBUF8) from the list of symbols. Attach the output buffer to the output of the LED decoder as shown below.



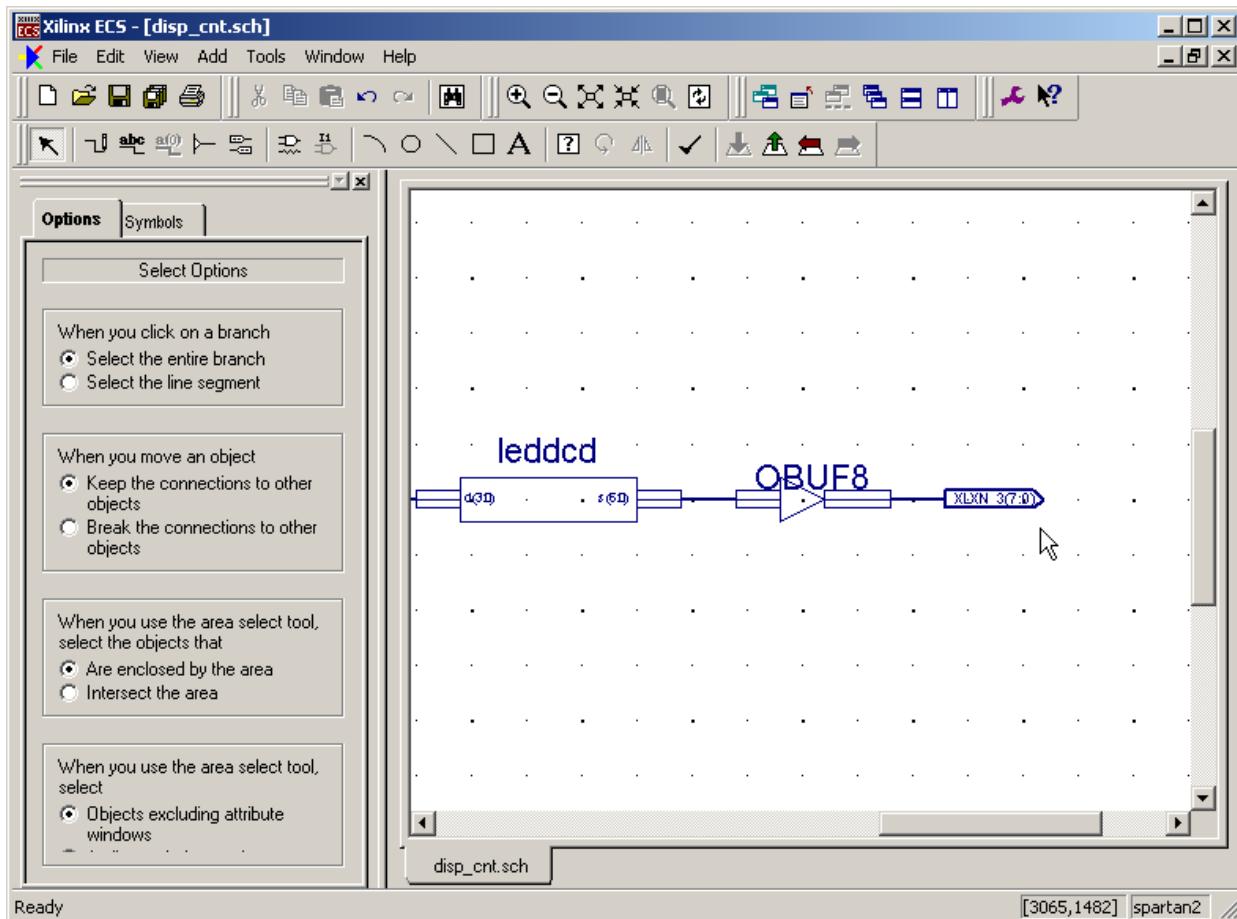
Next attach a short bus segment to the output of the byte-wide buffer. Do this by selecting the  wiring tool, clicking on the output of the byte-wide buffer, and then moving the cursor slightly to the right and double-clicking to create a stub.



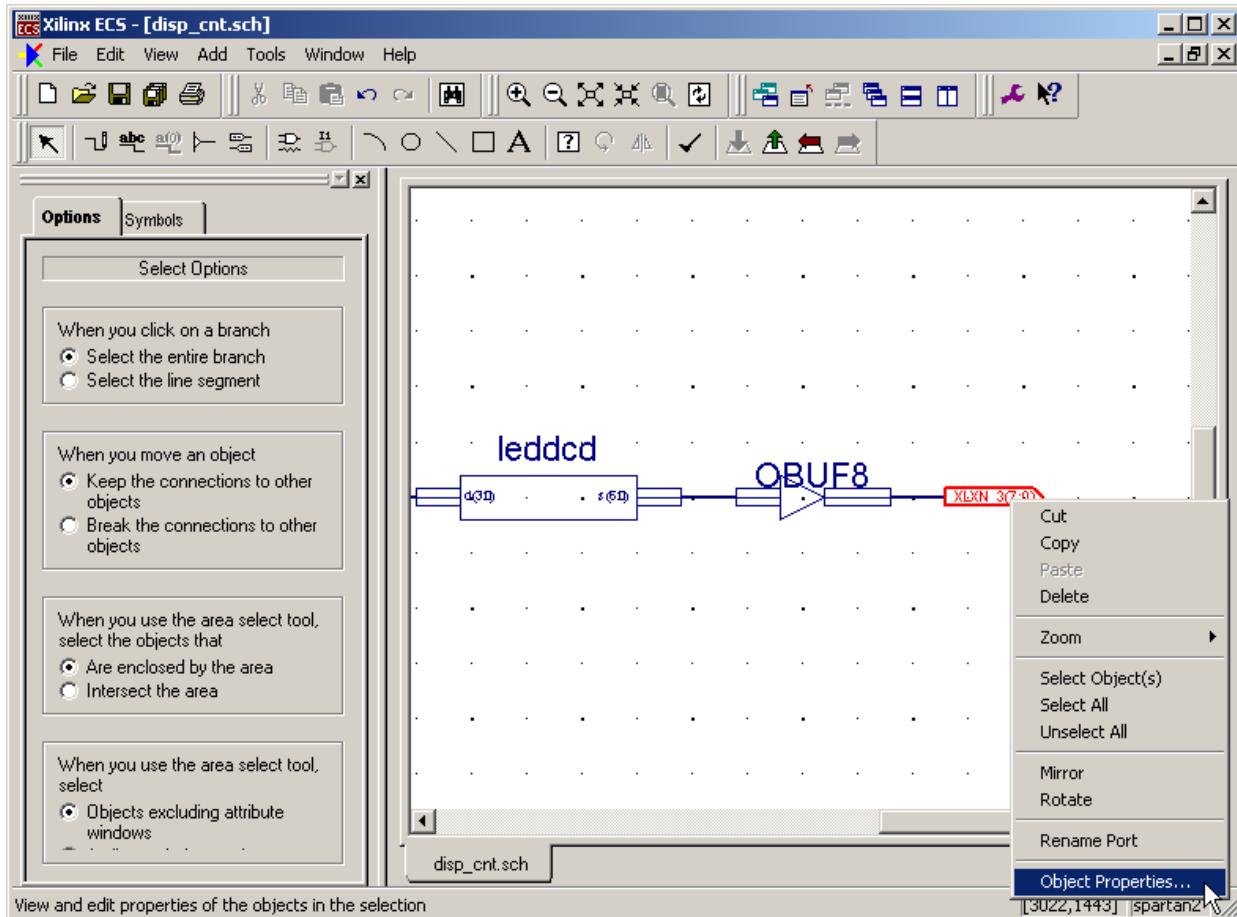
Now click on the  button for adding I/O markers. Click on the Add an output marker button in the Options tab and then click on the free end of the wire segment that you just added.



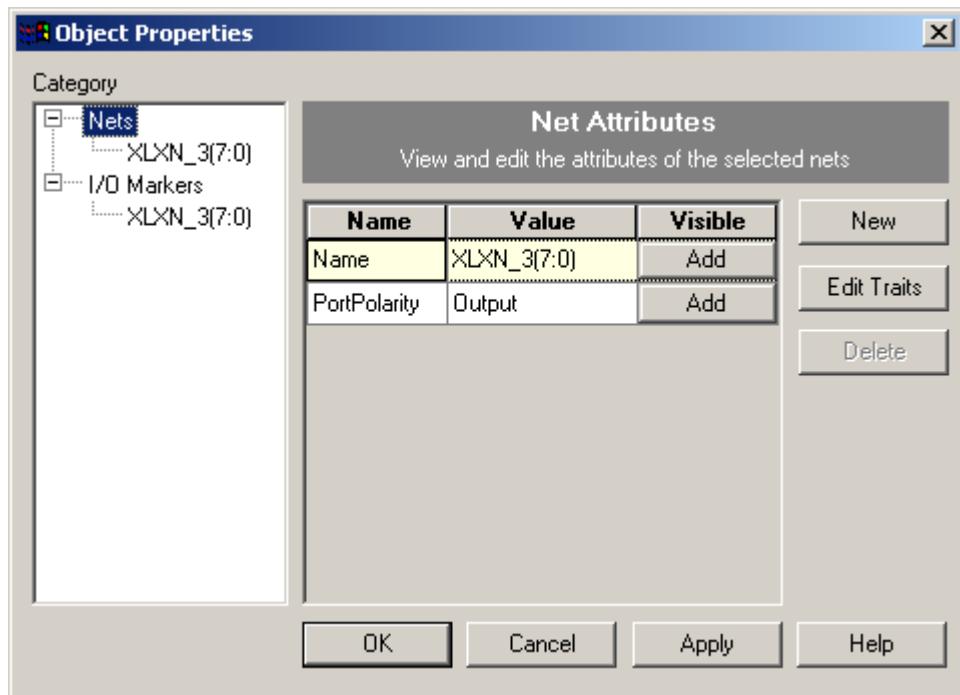
Clicking on the end of the wire creates a byte-wide set of output pins.



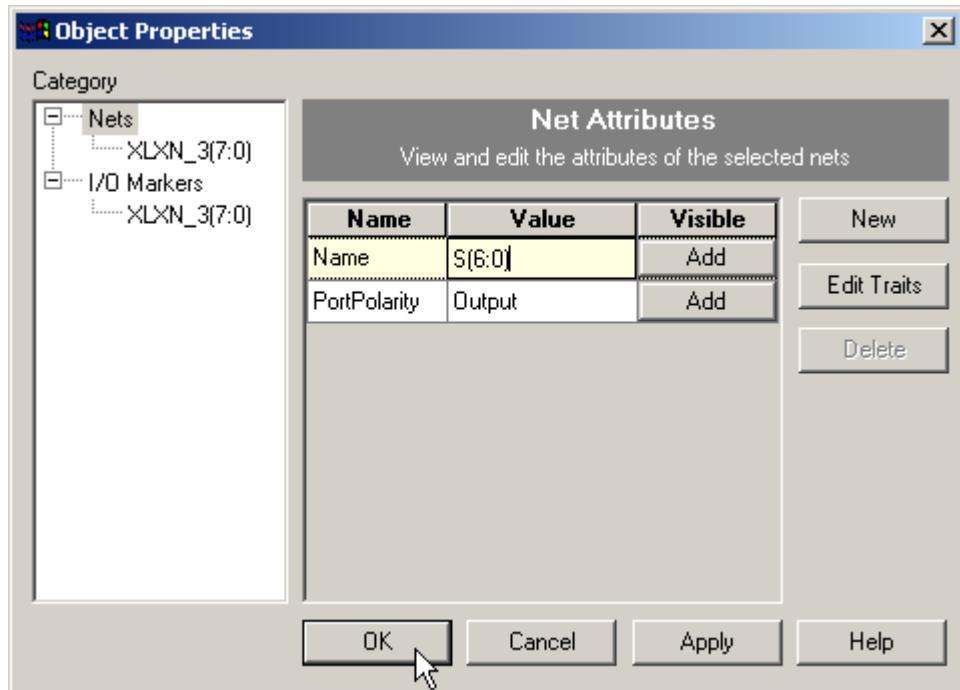
The output pins automatically assume the same name as the bus to which they are attached, but this name was automatically generated and doesn't carry a lot of meaning. To change the name of the outputs (and the associated bus), right-click on the I/O marker and select Object Properties... from the pop-up menu.



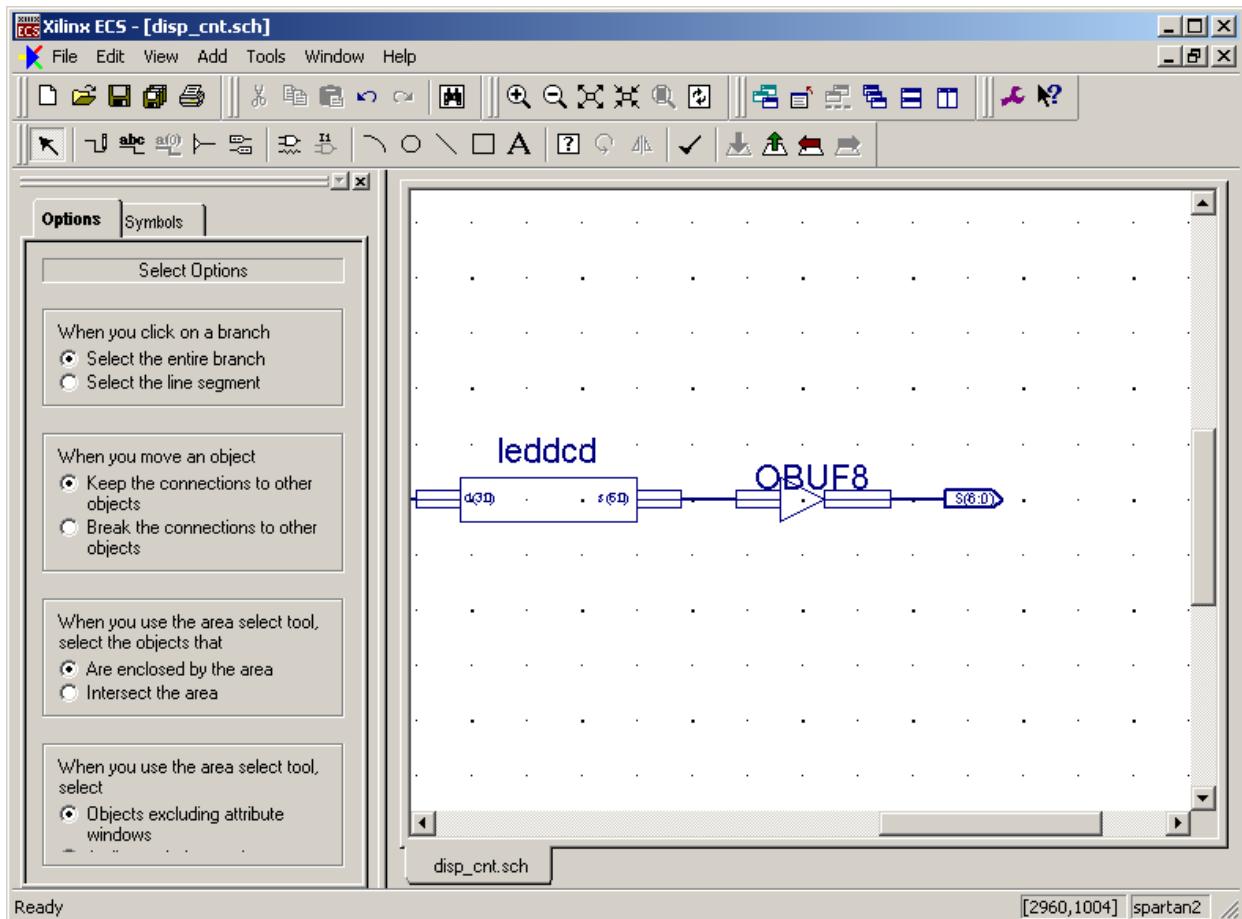
The **Object Properties** window allows you to set the name and direction of the pins.



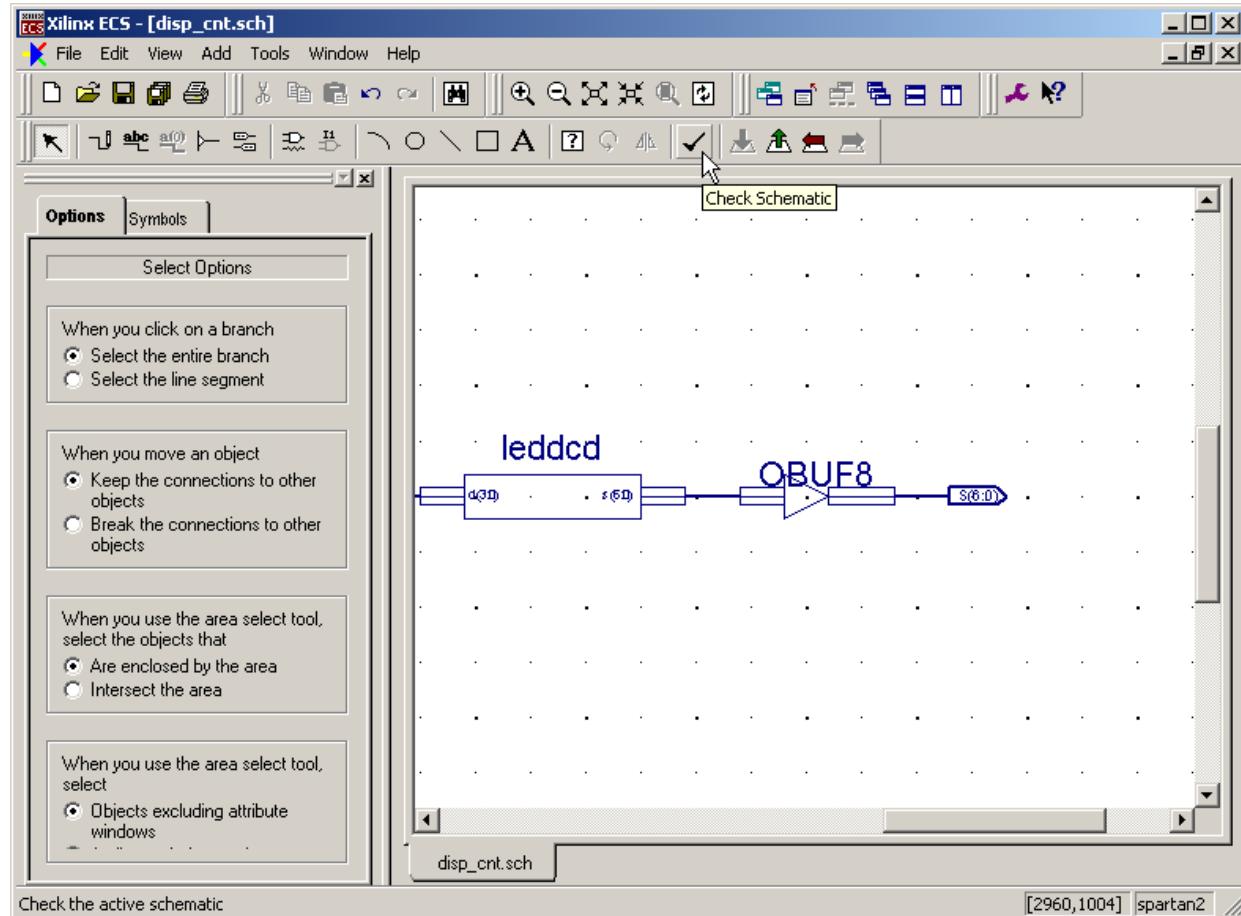
Replace the existing bus name with a seven-bit bus for driving the LED segments: **S(6:0)**. The direction of the bus pins is already set to Output so you can finish by clicking on the OK button.



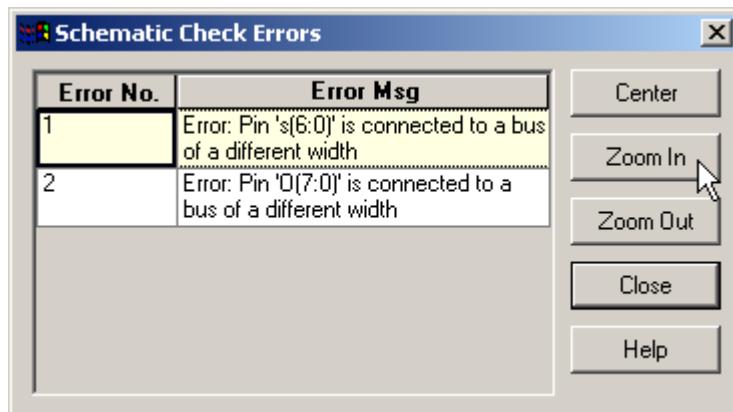
The output pins now appear with their new name, width, and direction.



At this point, it makes sense to check the schematic to see if there are any errors such as unterminated wire stubs or mismatched bus widths. Click on the button to perform a schematic check.

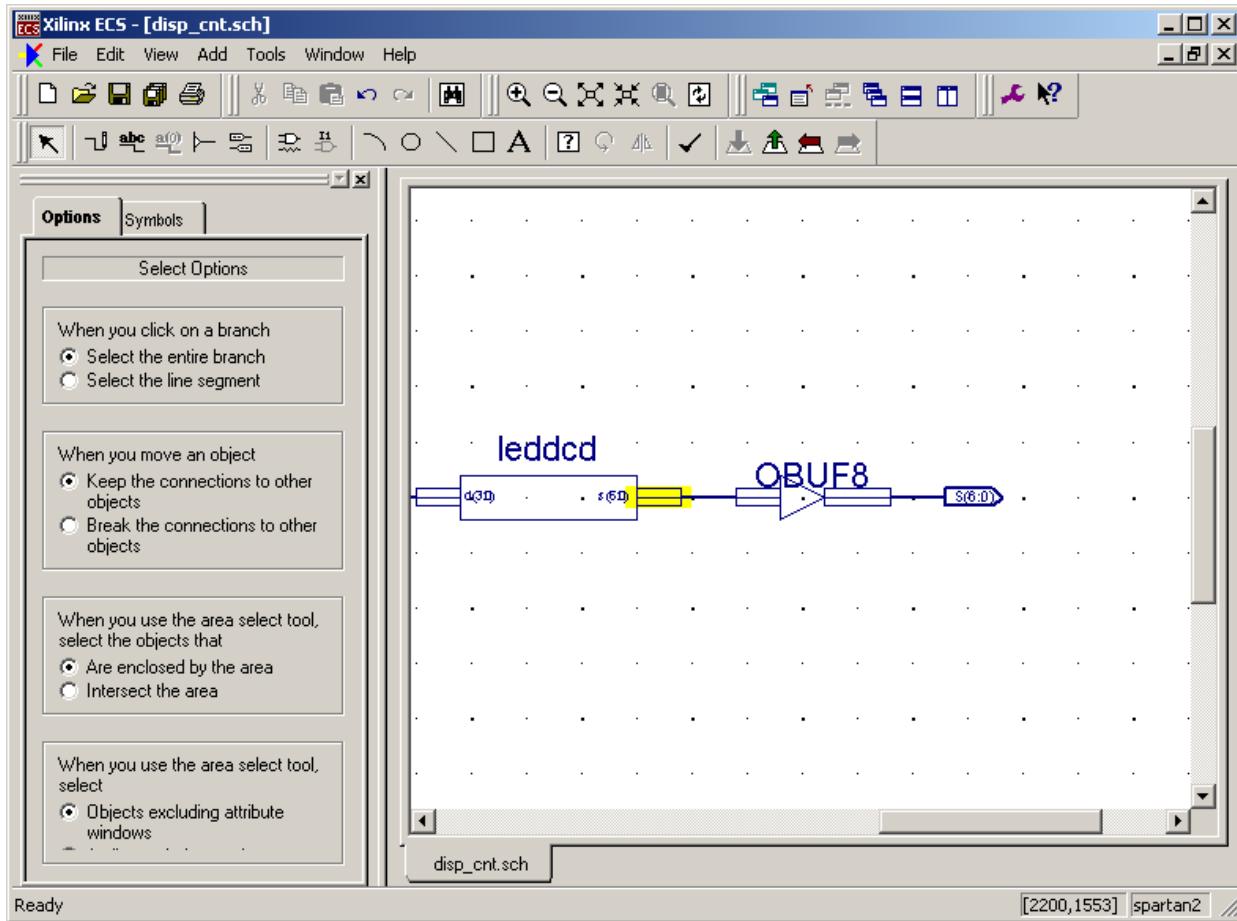


The **Schematic Check Errors** window will appear showing two errors. You can find the place in the schematic where the error occurs by clicking on the associated error message. Then click on the Zoom In button to see an enlarged view of the area where the error lies.

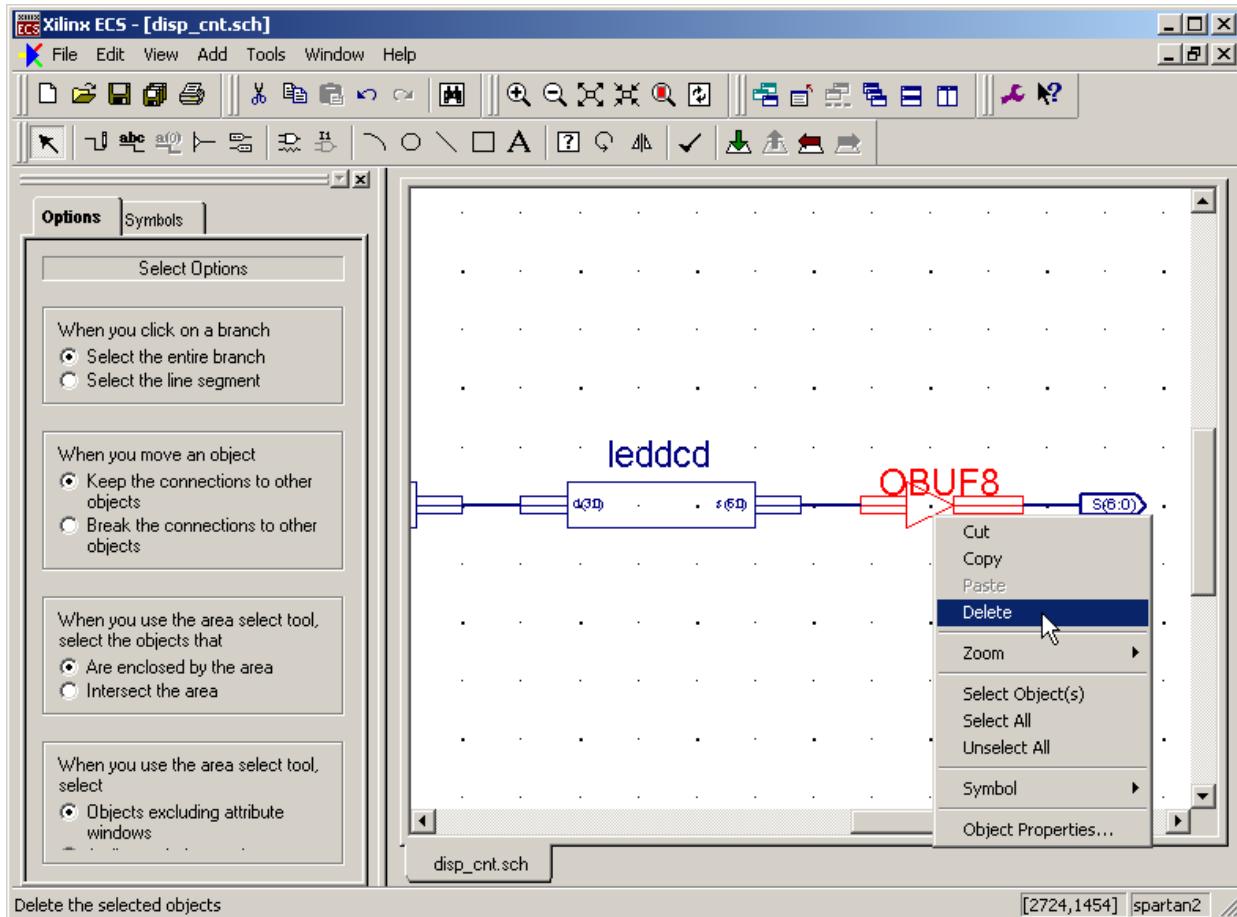


The first error indicates that the seven-bit output of the LED decoder does not match with the byte-wide input of the output buffer symbol. Note how the output of the leddcd symbol is

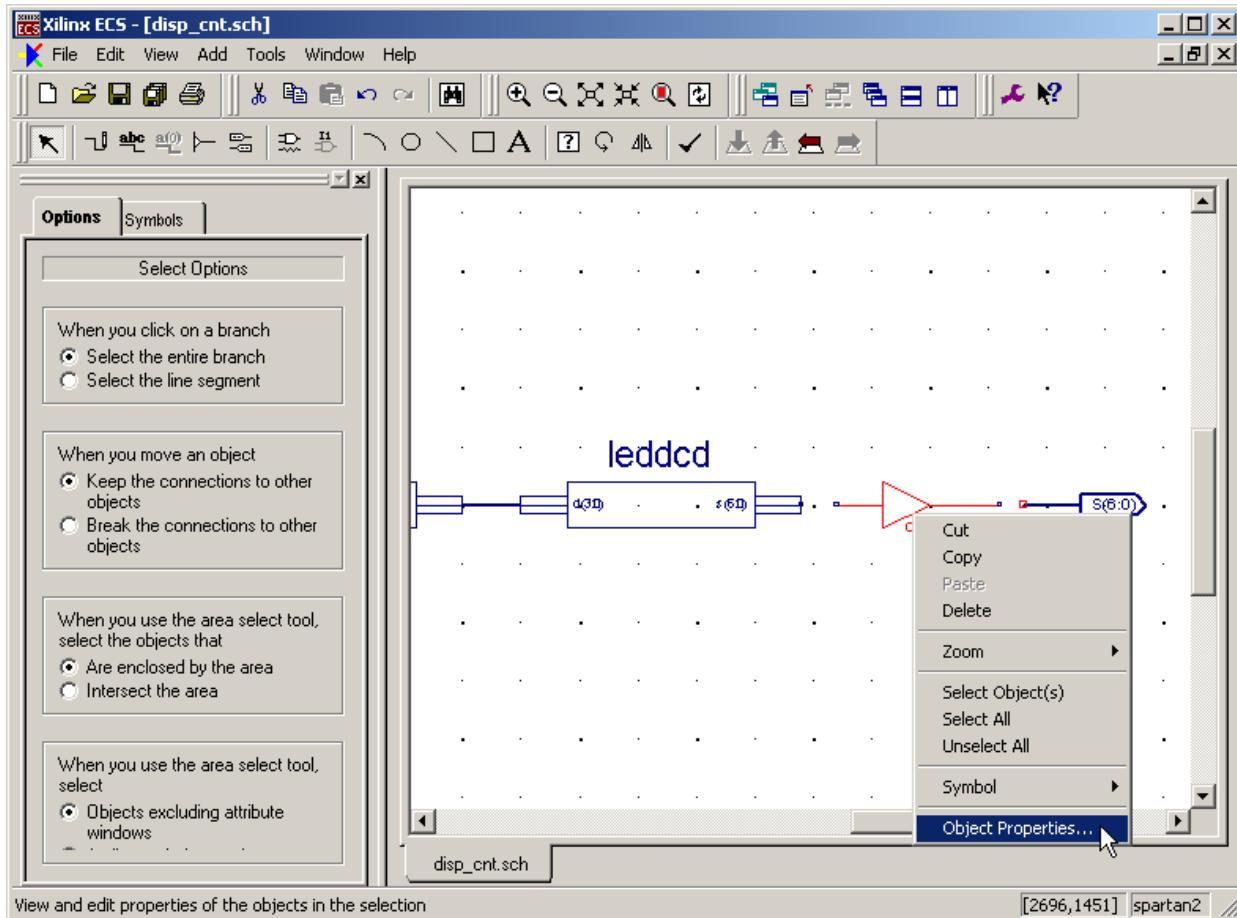
highlighted to indicate the error. The second error is similar to the first in that the byte-wide output of the OBUF8 symbol does not match the width of the seven-bit output pin marker.



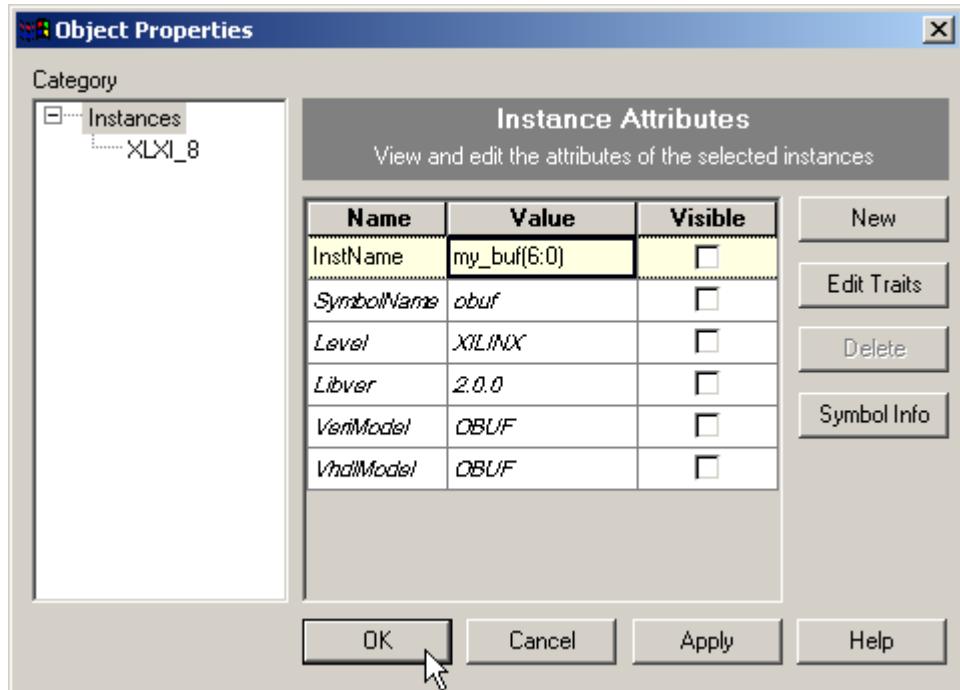
The simplest way remove these errors is to replace the byte-wide output buffer with a seven-bit wide version. To remove the byte-wide buffer, right-click on the OBUF8 symbol and select delete from the pop-up menu. Do the same for the bus that connected to the input of the byte-wide buffer.



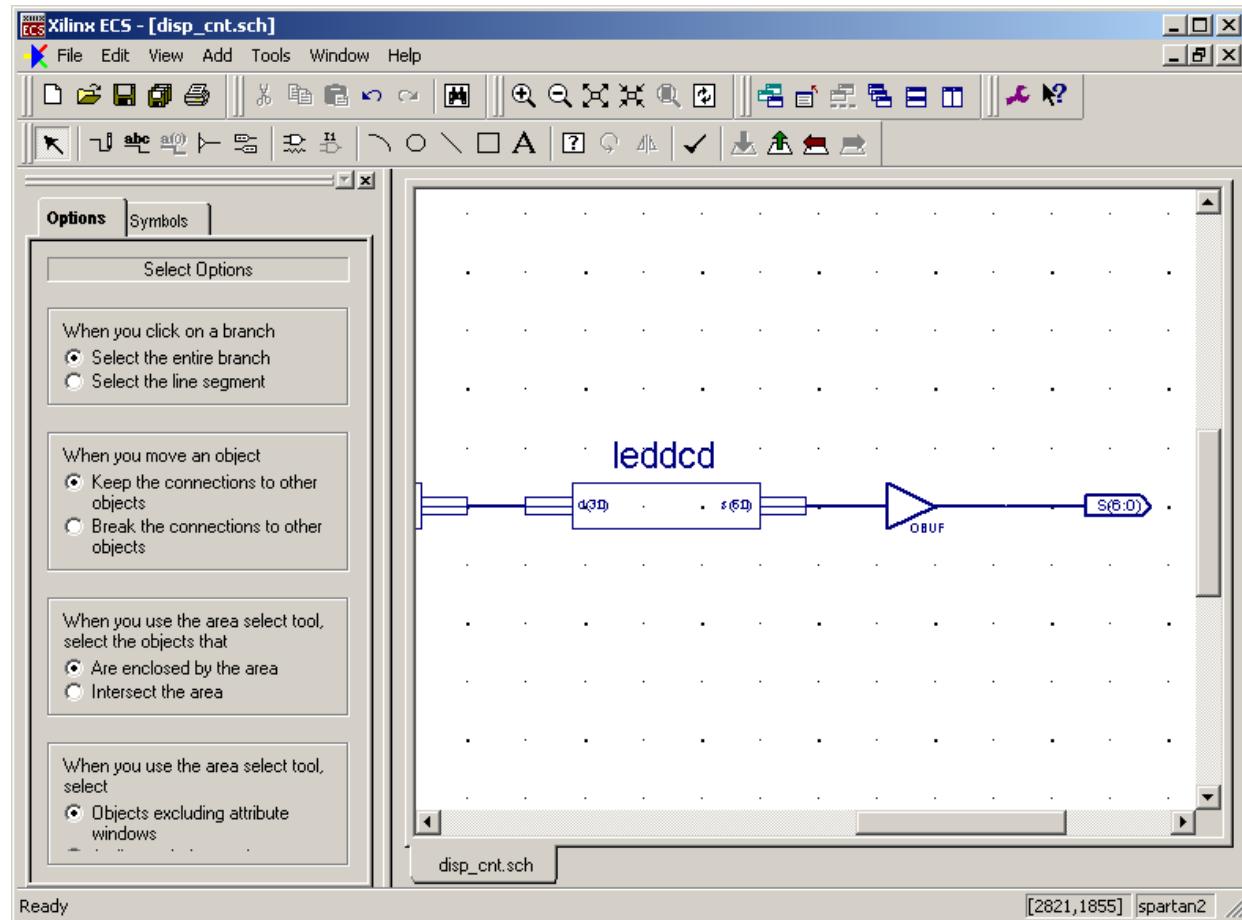
Now add a single OBUF symbol to the schematic. Then right-click on it and select Object Properties... from the pop-up menu.



In the **Object Properties** window, highlight the instance name for the buffer and change it to mybuf(6:0) and then click on the OK button. This will change the single-bit output buffer to an array of seven output buffers.



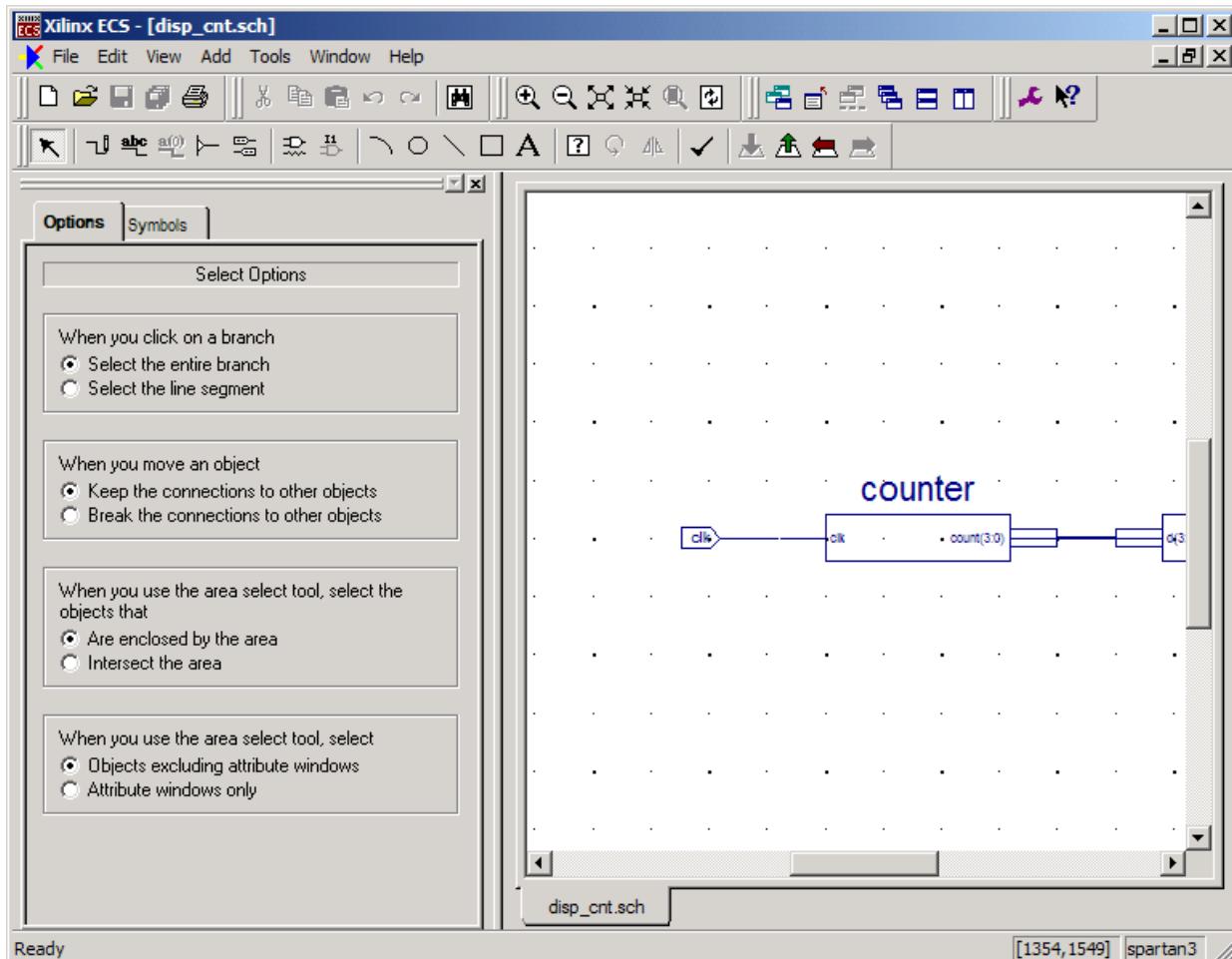
After changing the width of the output buffer, reconnect it to the LED decoder and the output terminals as shown below.



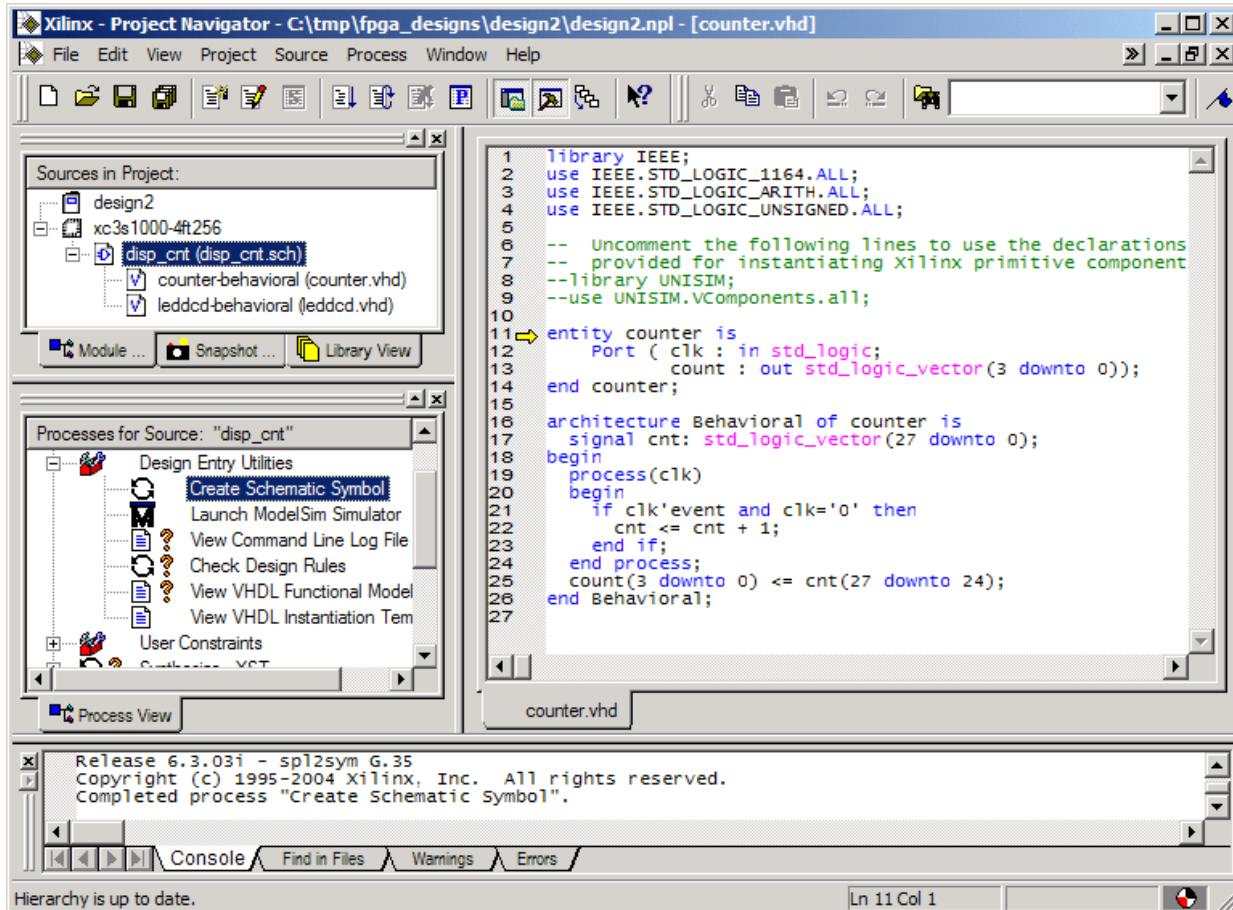
Now when you click on the schematic check button, , you can see the errors have been corrected.



Once the outputs from the circuit are in place, you can connect a single input I/O marker to the clock input of the counter. (No input buffer is needed because the clock signal will enter the FPGA through a dedicated global clock input.) Right-click on the I/O marker and rename it to clk. After this, perform another schematic check to detect any errors, save the schematic using the File ➔ Save command and then close the schematic editor.

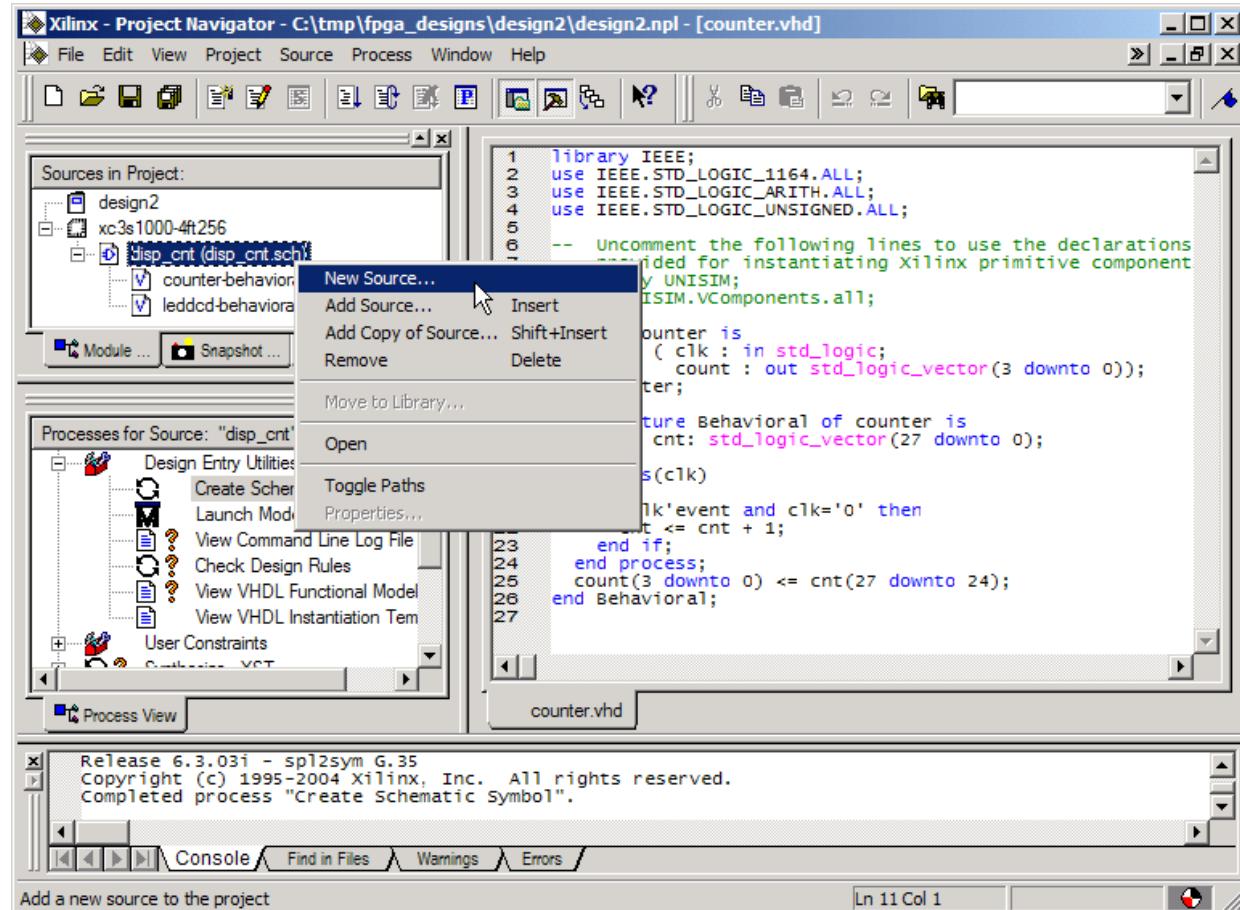


Once you save the schematic for the top-level module, the hierarchy in the Sources pane of the **Project Navigator** window gets updated. Now the **counter** and **leddcod** modules are shown as lower-level modules that are included within the top-level **disp_cnt** module.

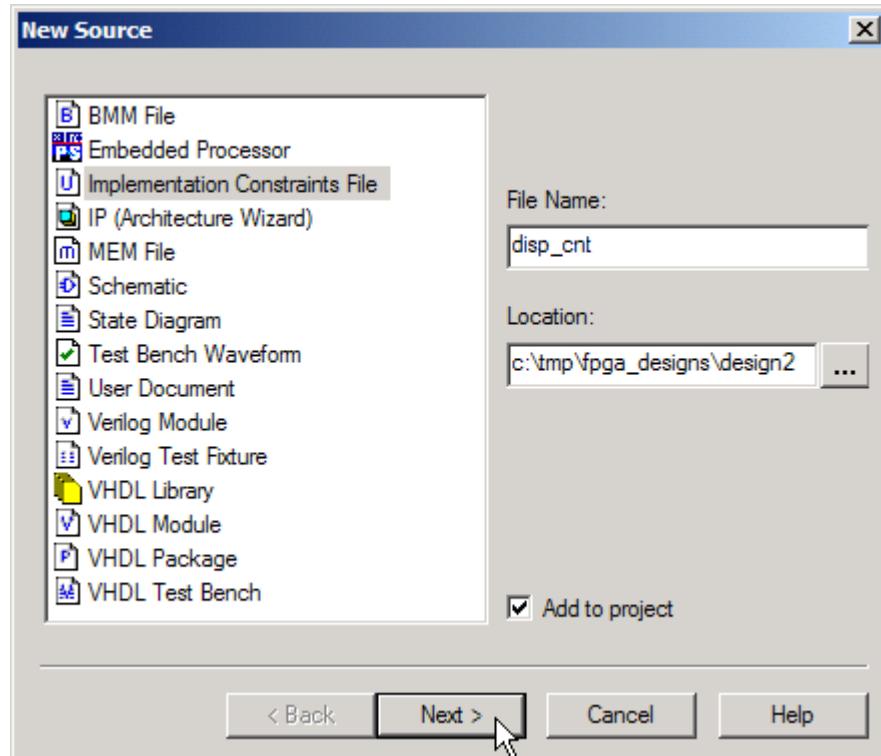


Constraining the Design

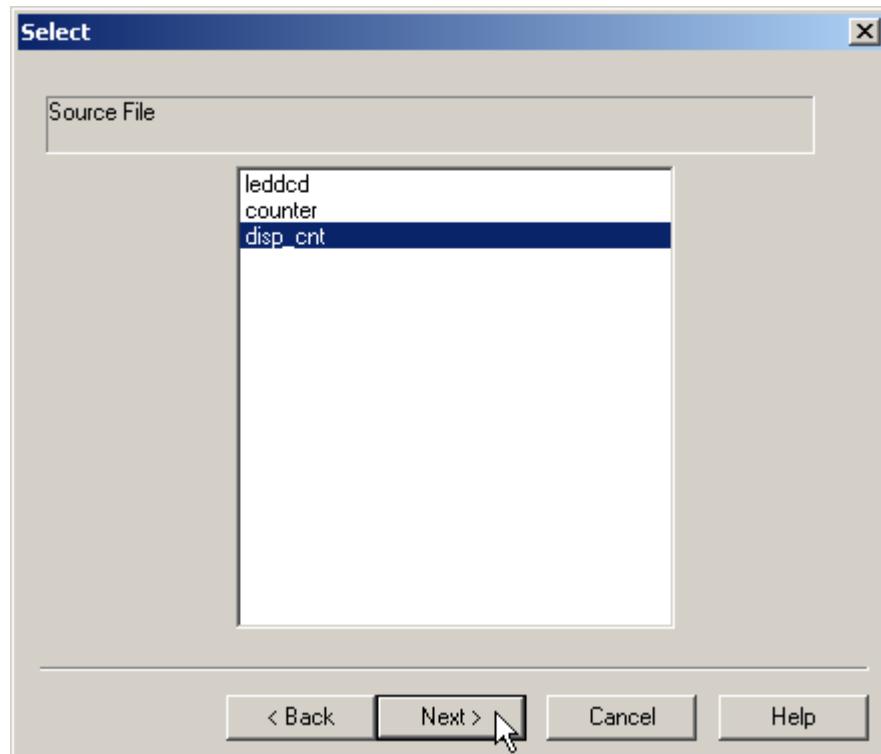
Before synthesizing the displayable counter, you need to assign the pins which the inputs and outputs will use. Start by right-clicking the disp_cnt object in the Sources pane and selecting New Source... from the pop-up menu.



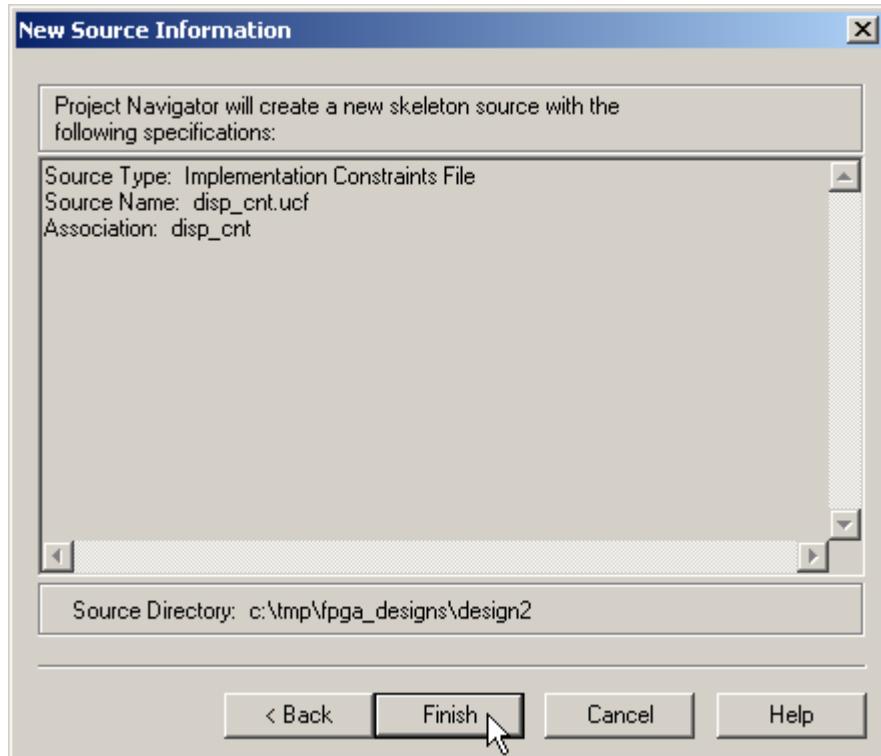
Select Implementation Constraints File as the type of source file to add and type `disp_cnt` in the File Name field. Then click on the Next button.



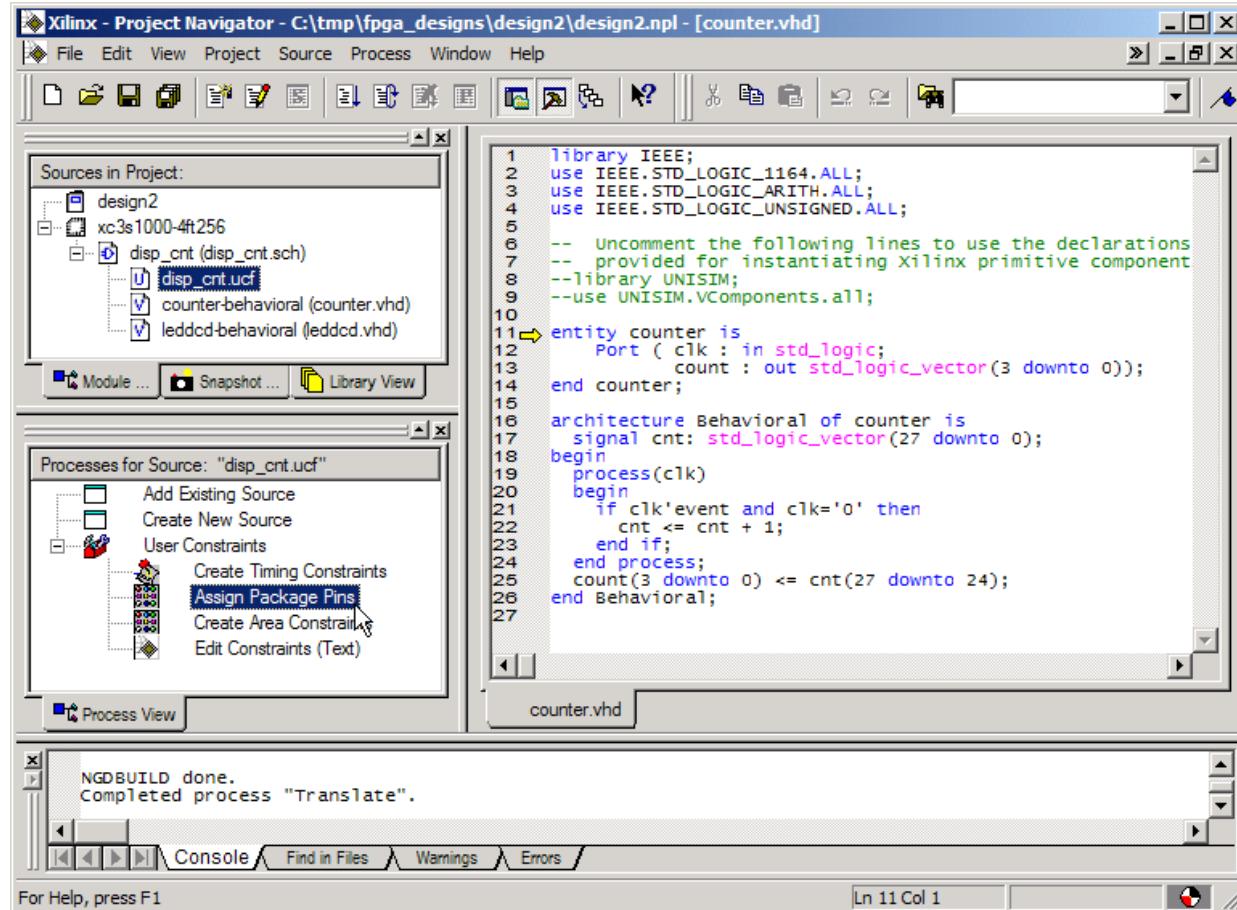
Then you are asked to pick the file the constraints will apply to. The pin assignments will be made for the top-level module in the design hierarchy, so highlight the `disp_cnt` item in the list. Then click on the Next button and proceed.



You will receive a feedback window that shows the name and type of the file you created and the file to which it is associated. Click on the Finish button to complete the addition of the disp_cnt.ucf file to this project.



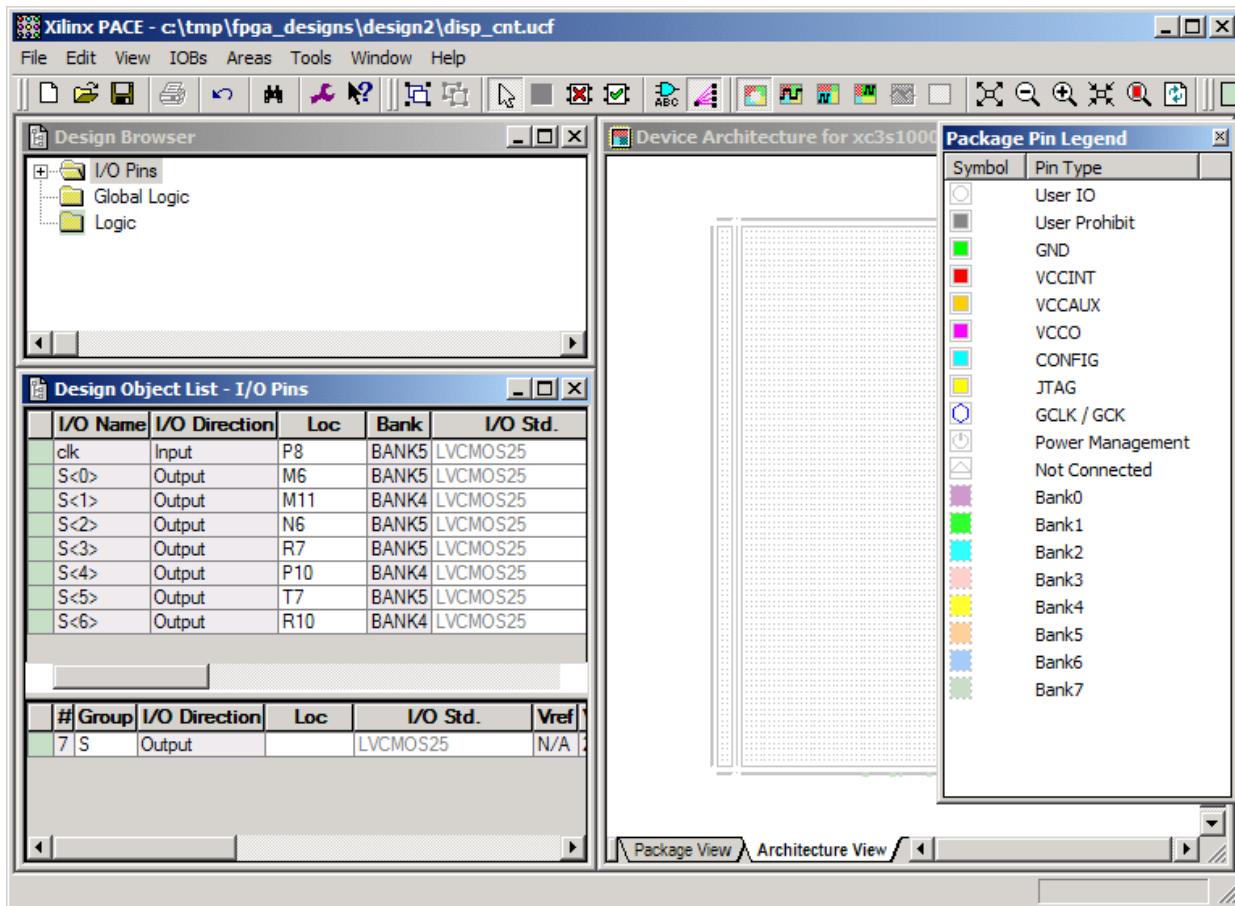
Now highlight the disp_cnt.ucf object in the Sources pane and double-click the Assign Package Pins process to begin adding pin assignment constraints to the design.



The appropriate pin assignments for each model of XSA Board are shown below. The **clk** input is assigned to a dedicated clock input on each FPGA to which a A 50 MHz clock signal is applied. The seven-segment LED pin assignments are the same as in the previous design.

I/O Signal	XSA-50	XSA-100	XSA-200	XSA-3S1000
clk	P88	P88	B8	P8
s0	P67	P67	N14	M6
s1	P39	P39	D14	M11
s2	P62	P62	N16	N6
s3	P60	P60	M16	R7
s4	P46	P46	F15	P10
s5	P57	P57	J16	T7
s6	P49	P49	G16	R10

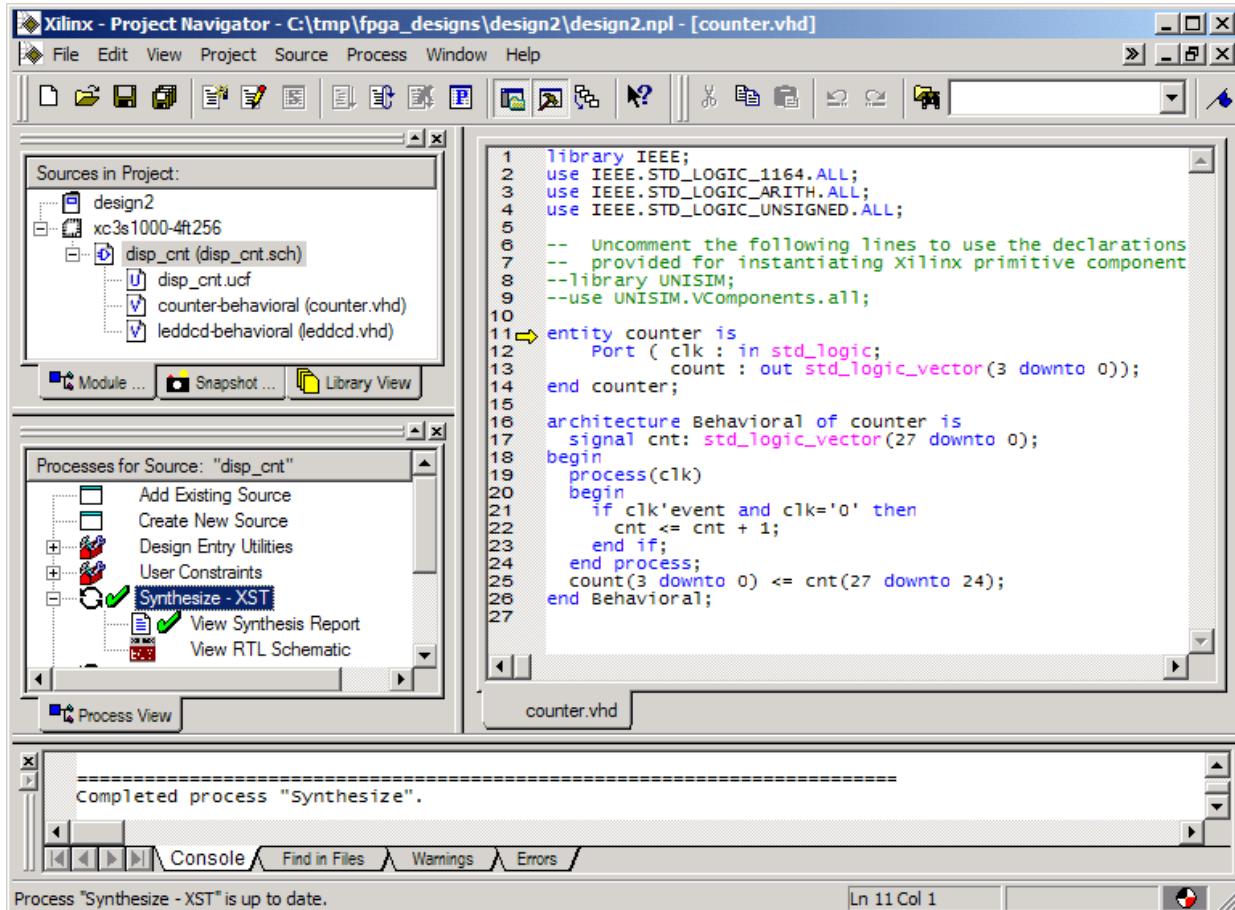
In the **Design Object List – I/O Pins** pane of the **Xilinx PACE** window that appears, set the pin assignments for the clock input and LED segment drivers as shown below.



After the pin assignments are entered, click on the button to save the pin assignment constraints. Then select File→Exit to close the **Xilinx PACE** window.

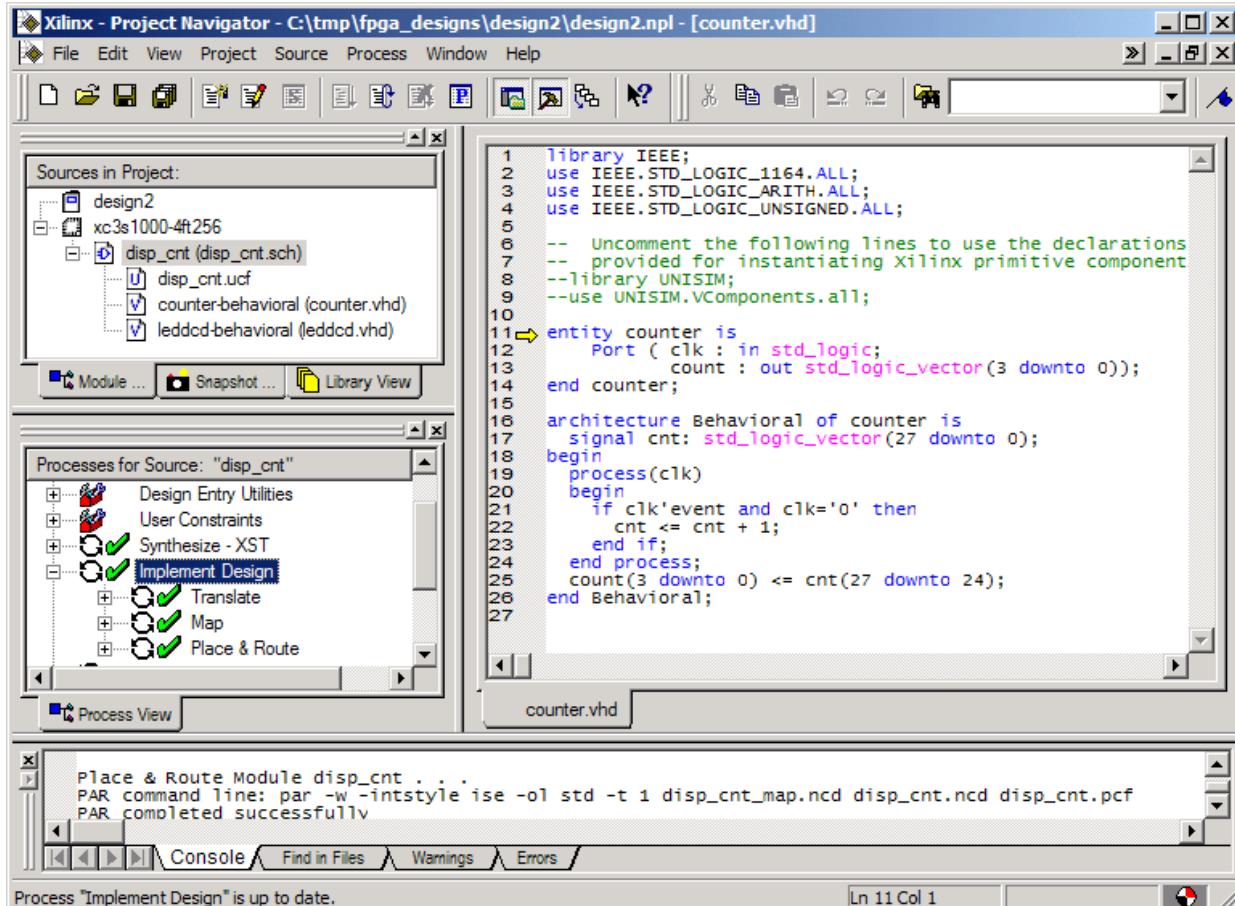
Synthesizing the Logic Circuitry for the Design

Now you can synthesize the logic circuit netlist by highlighting the top-level disp_cnt module in the Sources pane and double-clicking the Synthesize process. There should be no problems synthesizing the netlist from the combined VHDL and schematic files.



Implementing the Logic Circuitry in the FPGA

Once the netlist is synthesized, you can begin the process of translating, mapping and placing & routing it into the FPGA. Highlight the disp_cnt object in the Sources pane and then double-click the Implement Design process. There should be no problems implementing the design in the FPGA.



Checking the Implementation

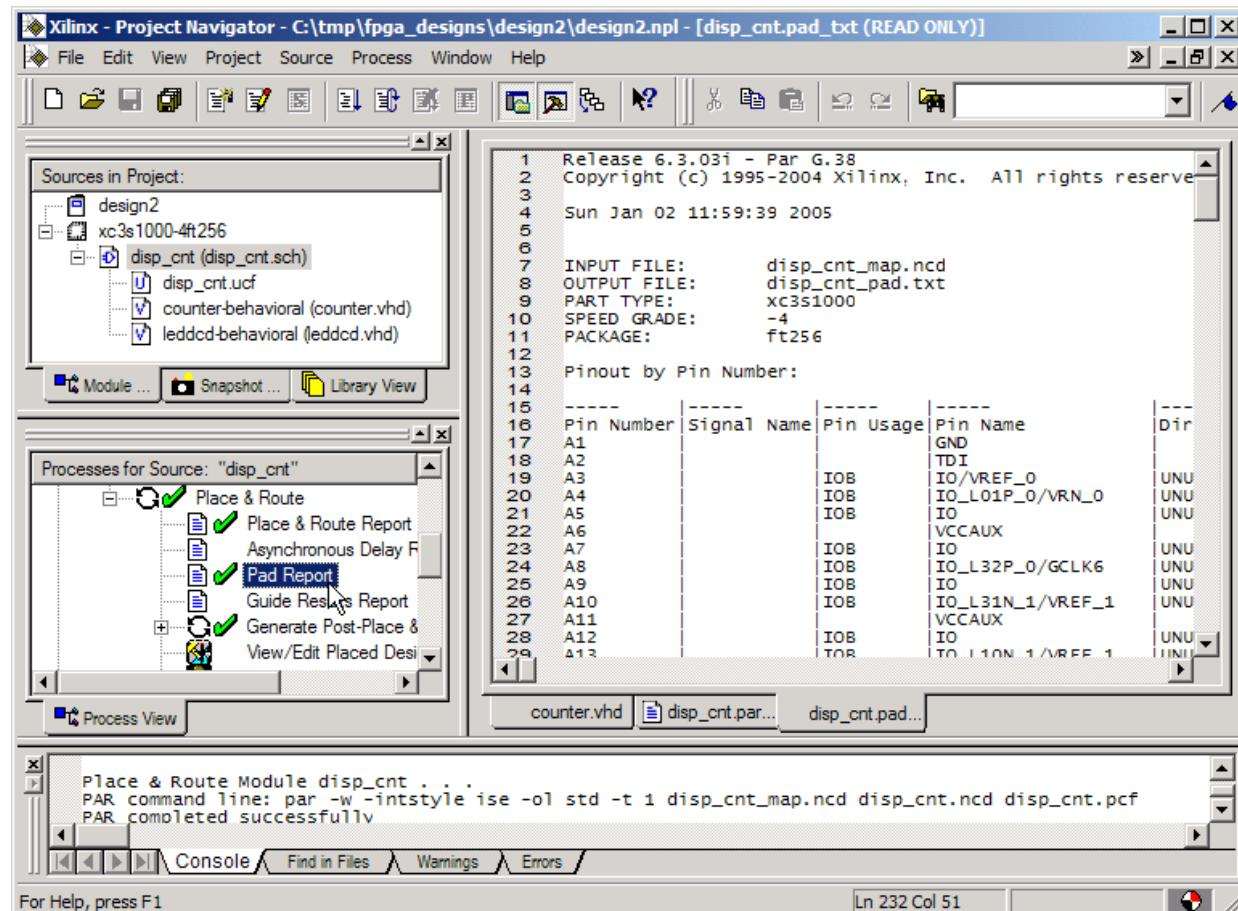
After the implementation process is done, you can check the logic utilization by double-clicking on the Place & Route Report process. Near the top of the file you will find:

Device utilization summary:

Number of External IOBs	8 out of 173	4%
Number of LOCed External IOBs	8 out of 8	100%
Number of Slices	18 out of 7680	1%
Number of BUFGMUXs	1 out of 8	12%

The displayable counter consumes 18 of the 7680 slices in the FPGA. Each slice contains two CLBs, so the displayable counter uses a maximum of 36 CLBs. The 28-bit counter requires at least 28 CLBs and the LED decoder requires 7 CLBs so this totals to 35 CLBs.

As a precaution, you should also double-click the Pads Report and check that the pin assignments for the clock input and LED decoder outputs match the assignments we made with PACE.

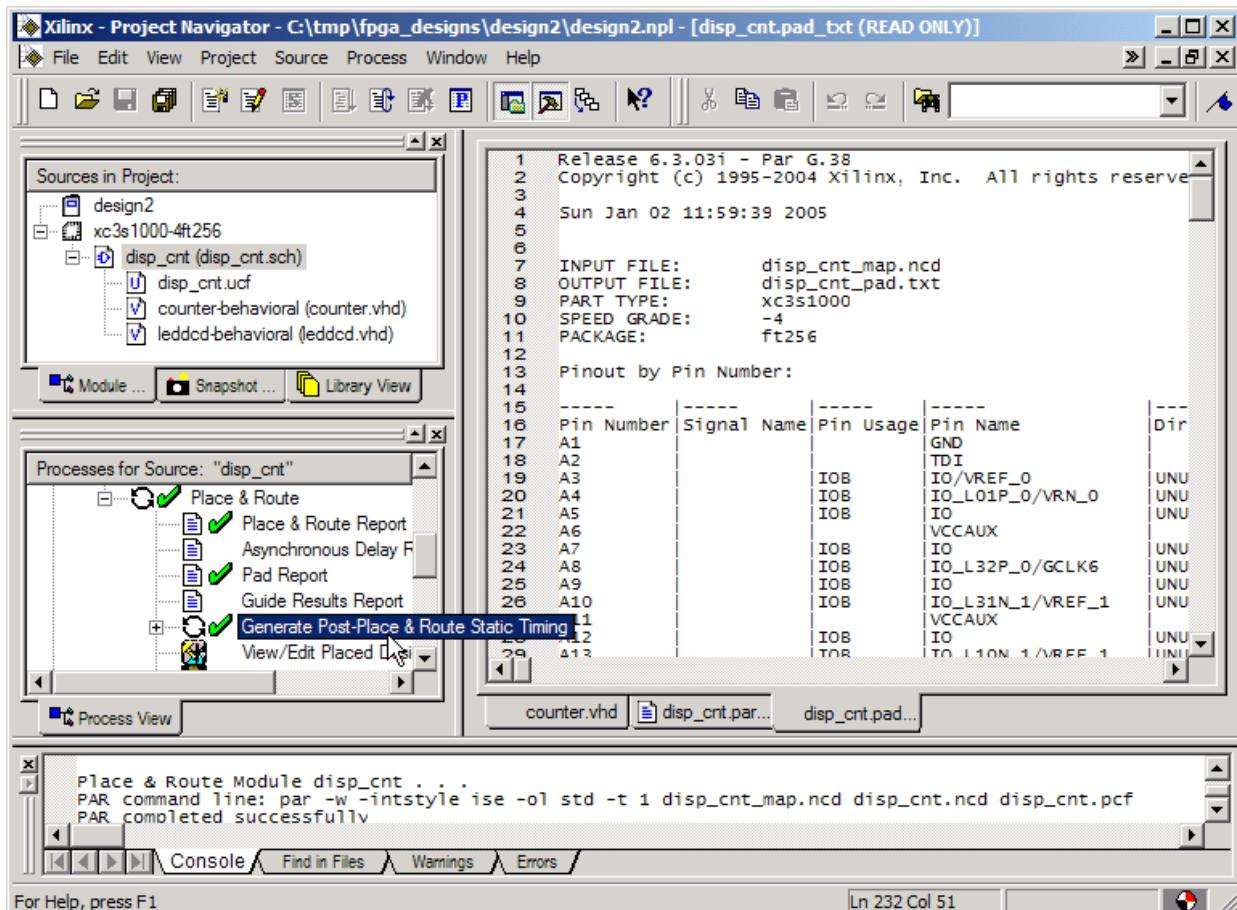


You can see that the pin assignments for the clock input and the LED decoder outputs agree with the constraints you placed in the UCF file.

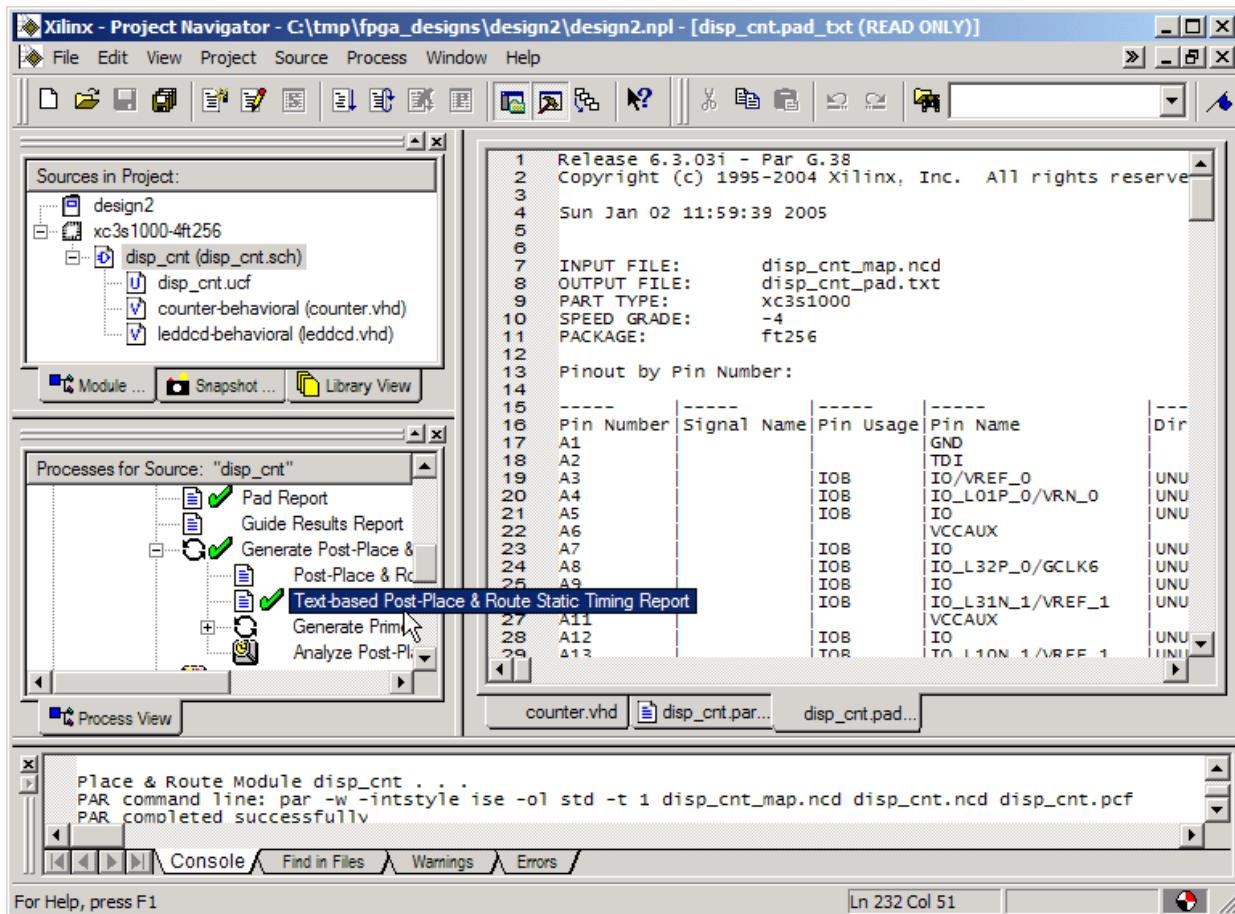
Pin Number	Signal Name	Pin Usage	Direction	IO Standard
M6	s<0>	IOB	OUTPUT	LVCMS25
M11	s<1>	IOB	OUTPUT	LVCMS25
N6	s<2>	IOB	OUTPUT	LVCMS25
P8	clk	IOB	INPUT	LVCMS25
P10	s<4>	IOB	OUTPUT	LVCMS25
R7	s<3>	IOB	OUTPUT	LVCMS25
R10	s<6>	IOB	OUTPUT	LVCMS25
T7	s<5>	IOB	OUTPUT	LVCMS25

Checking the Timing

You have the displayable counter synthesized and implemented in the FPGA with the correct pin assignments. But how fast can the counter run? To find out, double-click on the Generate Post-Place & Route Static Timing process. This will determine the maximum delays between logic elements in the design taking into account logic and wiring delays for the routed circuit.



After the static timing delays are calculated, double-click the Text-based Post-Place & Route Static Timing Report to view the results of the analysis.

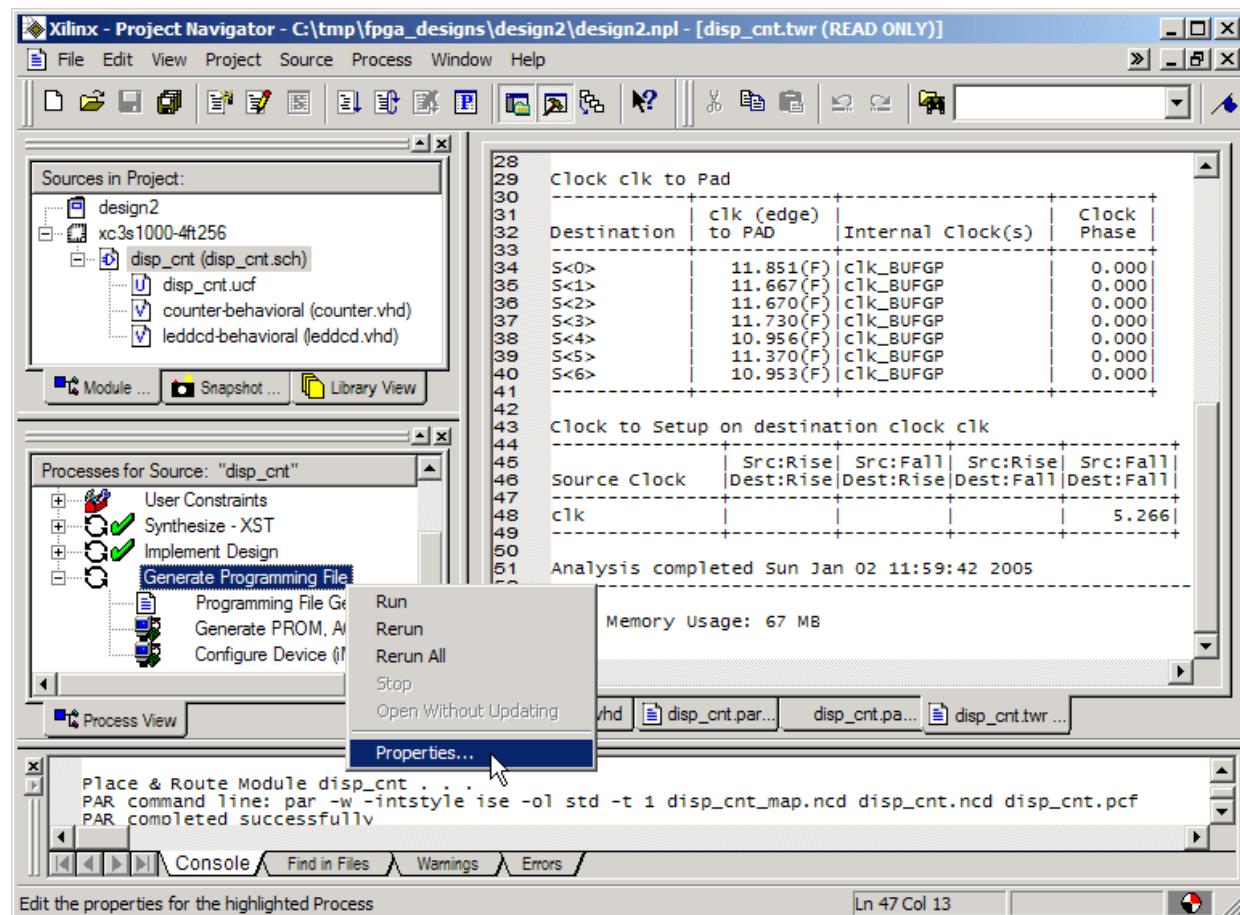


From the information shown in the timing report, the minimum clock period for this design is seen to be 5.266 ns which means the maximum clock frequency is 189.9 MHz. The clock frequency on the XSA Board is 50 MHz which is well below the maximum allowable frequency for this design.

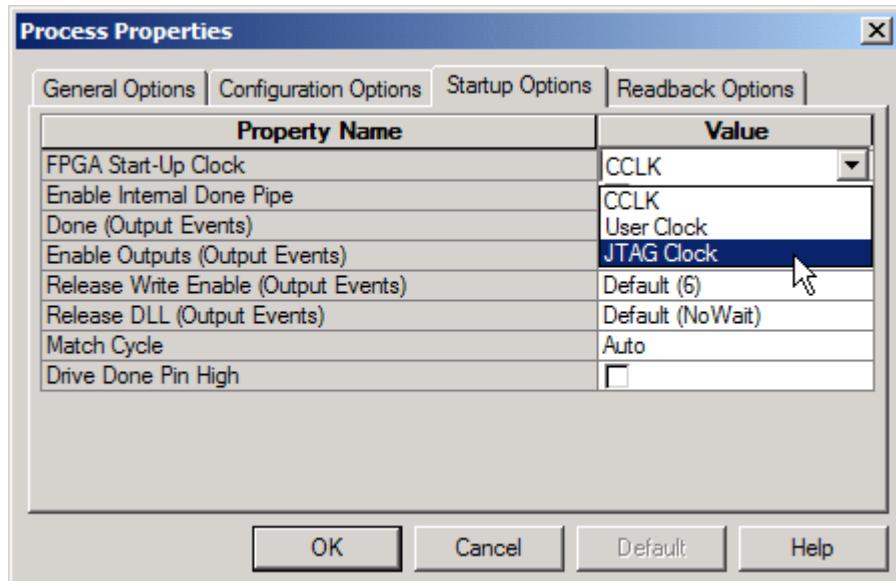
```
Clock to Setup on destination clock clk
-----+-----+-----+-----+
      | Src:Rise| Src:Fall| Src:Rise| Src:Fall|
Source Clock |Dest:Rise|Dest:Rise|Dest:Fall|Dest:Fall|
-----+-----+-----+-----+
clk          |           |           |           5.266|
-----+-----+-----+-----+
```

Generating the Bitstream

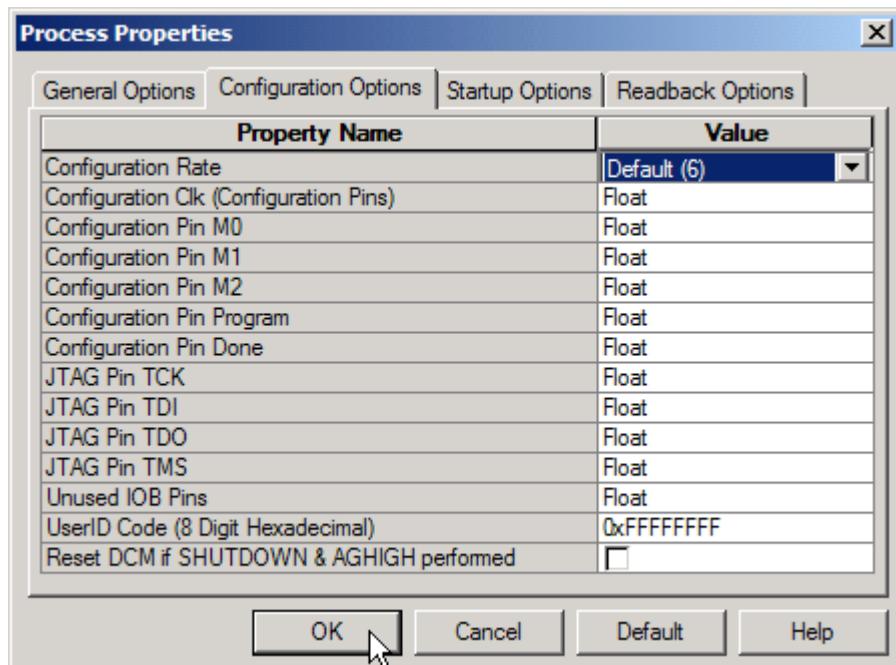
Now that you have synthesized our design and mapped it to the FPGA with the correct pin assignments, you are ready to generate the bitstream that is used to program the actual chip. In this example, rather than use the gxsload utility you will employ the downloading utilities built into WebPACK. The iMPACT programming tool downloads the bitstream through the JTAG interface of the FPGA, so you need to adjust the way the bitstream is generated to account for this. Right click on the Generate Programming File process and select the Properties... entry from the pop-up menu.



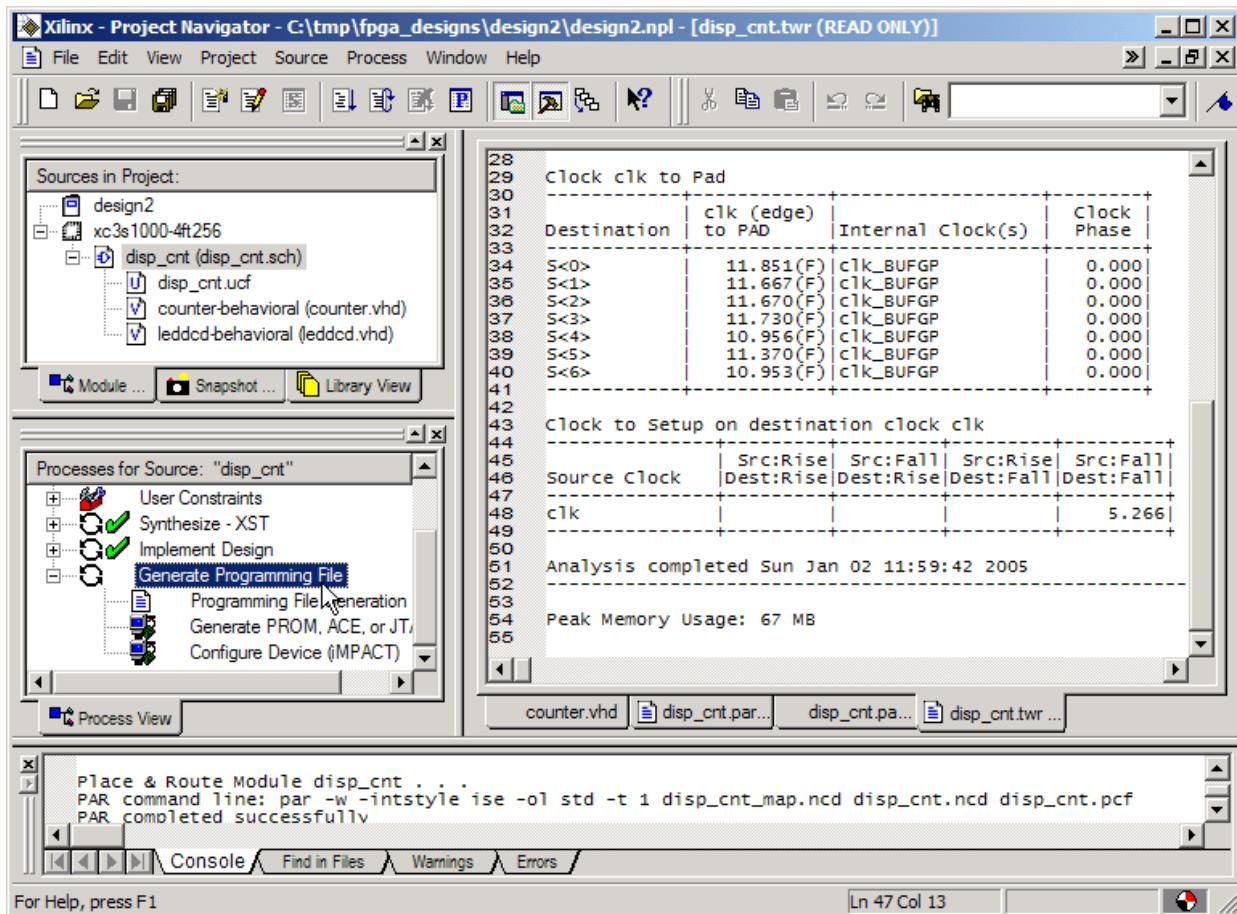
Select the Startup options tab of the Process Properties window. Change the Start-Up Clock property to JTAG Clock so the FPGA will react to the clock pulses put out by the iMPACT tool during the final phase of the downloading process. If this option is not selected, the FPGA will not finish its configuration process and it will fail to operate after the downloading completes. Note that the startup clock is only used to complete the configuration process; it has no affect on the clock that is used to drive the actual circuit after the FPGA is configured.



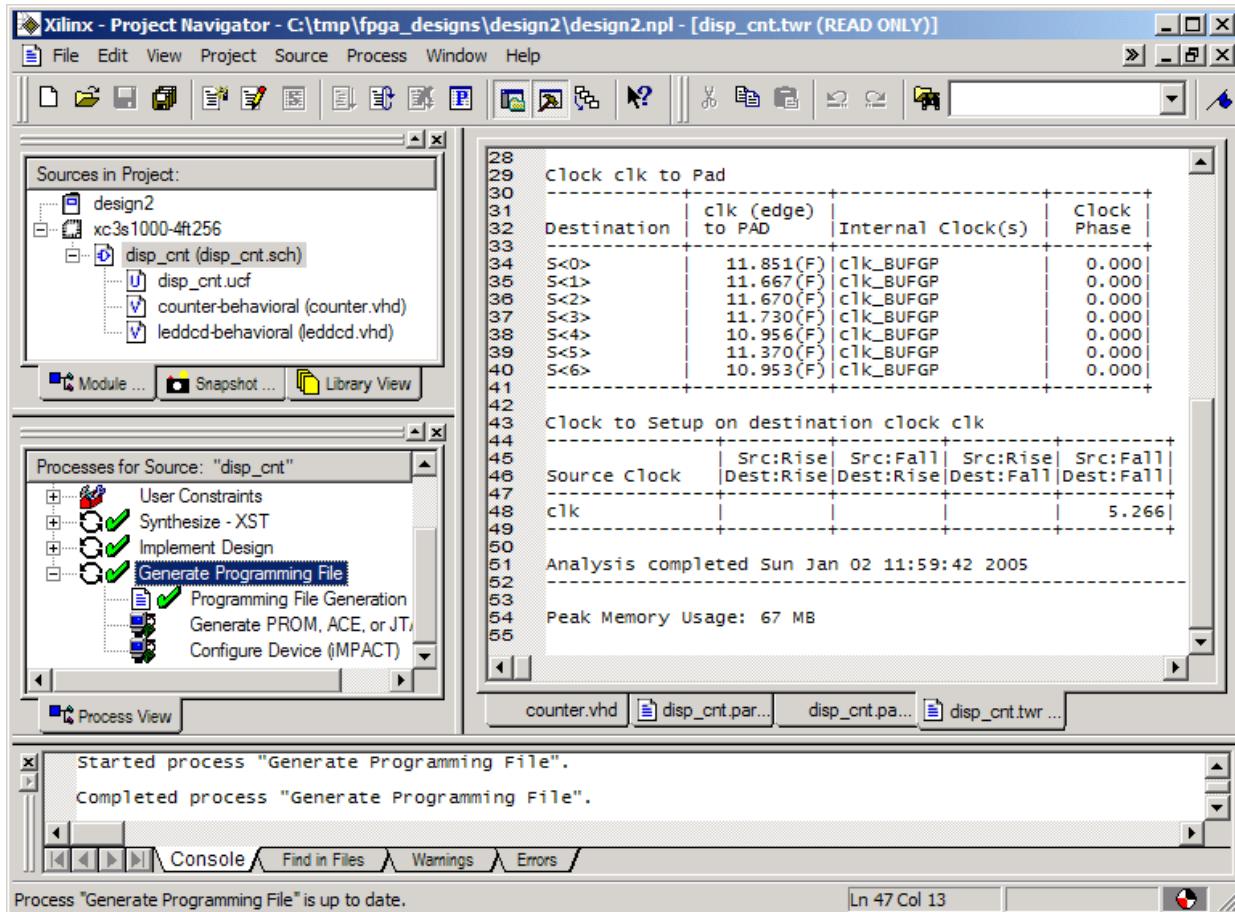
Next, click on the Configuration Options tab and disable all the internal pull-up and pull-down resistors in the FPGA as we did in the previous design. Then click OK.



Now that the bitstream generation options are set, highlight the disp_cnt object in the Sources pane and double-click on the Generate Programming File process to create the bitstream file.



Within a few seconds, a  will appear next to the Generate Programming File process and a file detailing the bitstream generation process will be created. A bitstream file named disp_cnt.bit is placed in the design2 folder.

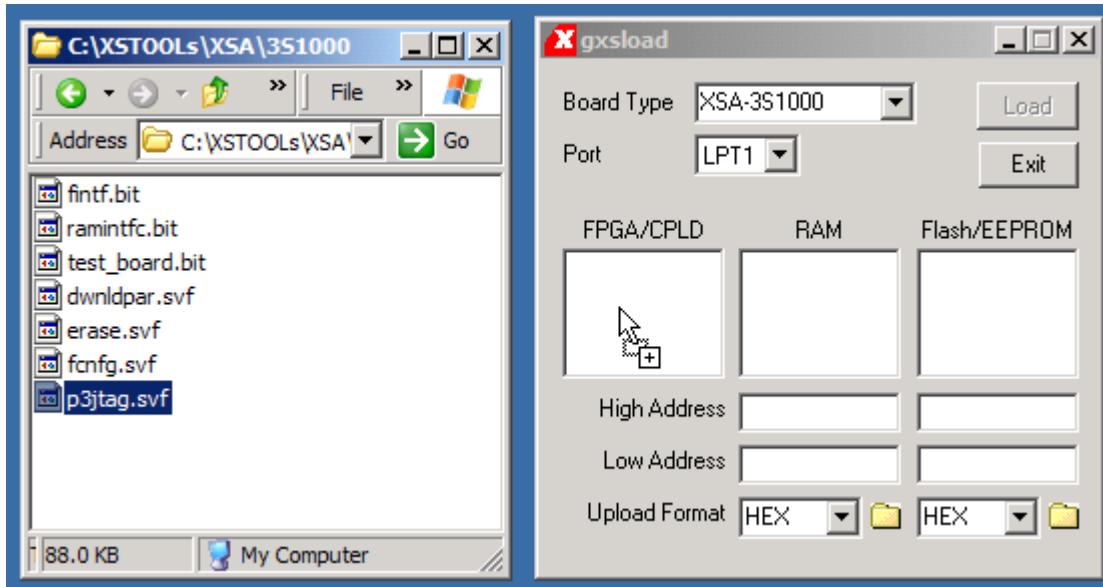


Downloading the Bitstream

Before downloading the disp_cnt.bit file, you must configure the interface CPLD on the XSA-3S1000 board so it will work with the iMPACT programming tool. Double click the

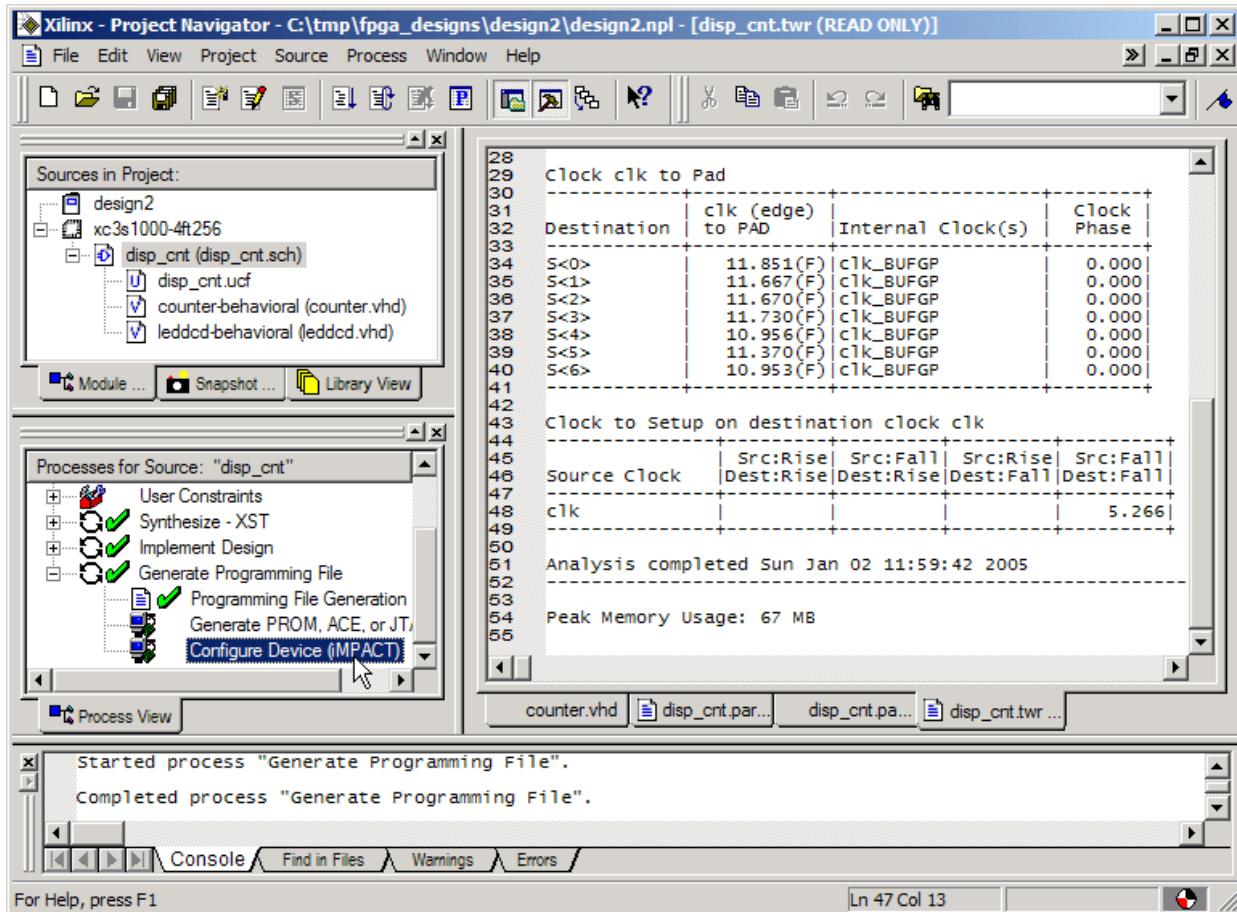


icon and then drag & drop the p3jtag.svf file from the C:\XSTOOLS\XSA\3S1000 folder into the FPGA/CPLD pane of the **gxsload** window. Then click on the Load button and the CPLD will be reprogrammed in less than a minute.

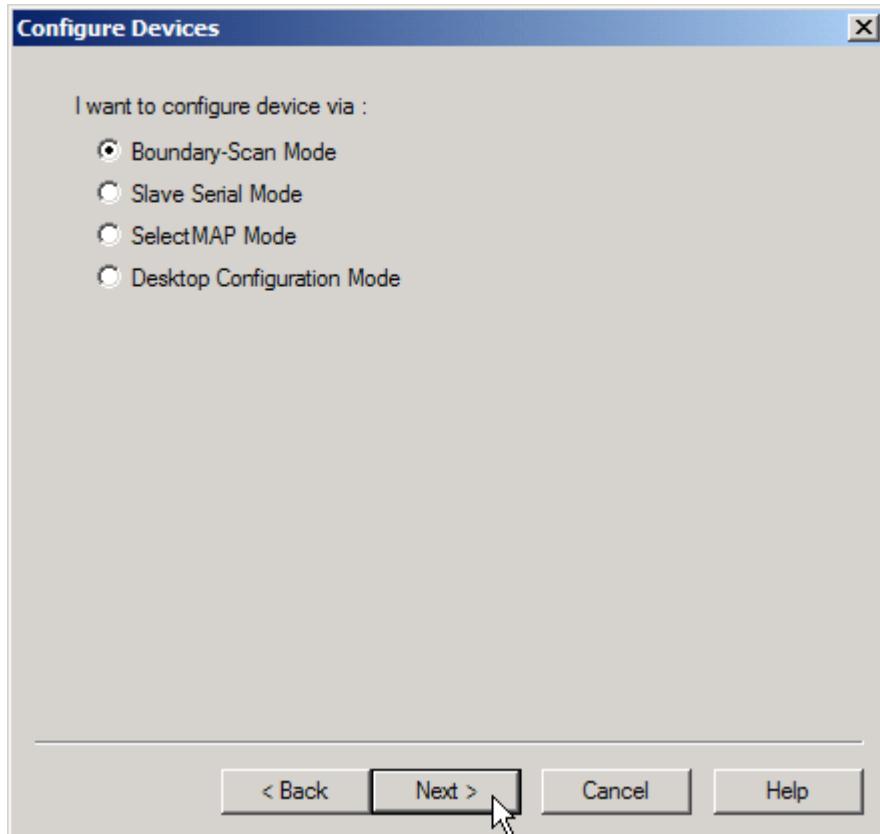


After the p3jtag.svf file is loaded into the XSA Board, move the shunt on jumper J9 from the **xs** to the **xi** position. The XSA Board is now setup so the FPGA can be configured through its boundary-scan pins with the iMPACT programming tool. Note that this process only needs to be done once because the CPLD on the XSA Board will retain its configuration even when power is removed from the board. (If you want to go back to using the gxsload programming utility, you must move the shunt on J9 back to the **xs** position and download the dwldpar.svf file into the CPLD.)

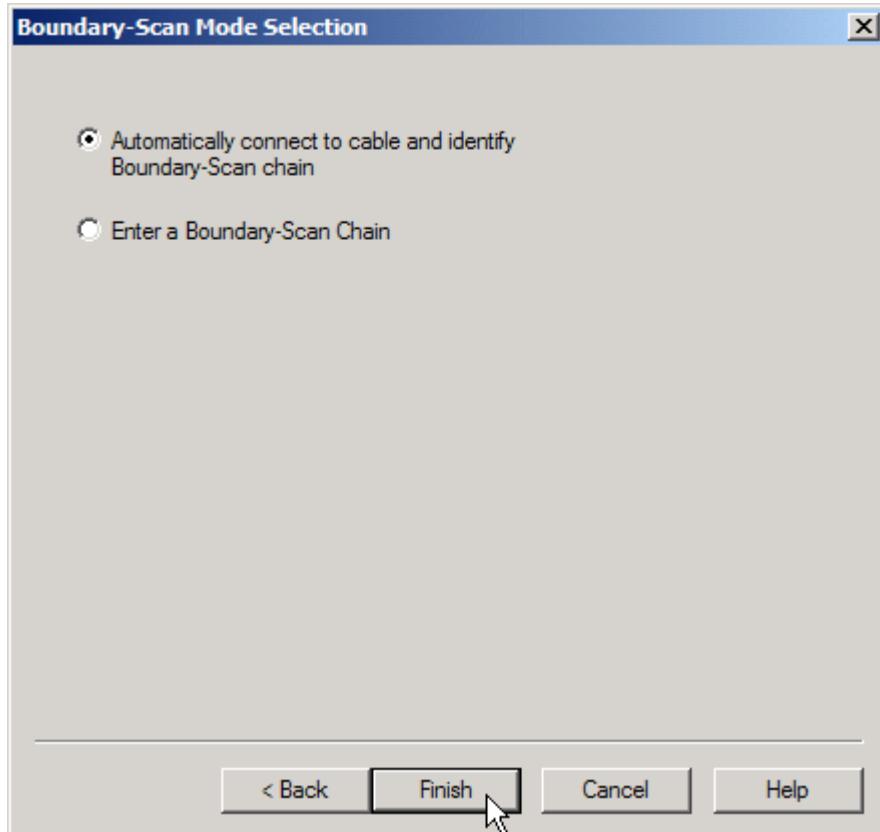
Now double-click on the Configure Device (iMPACT) process.



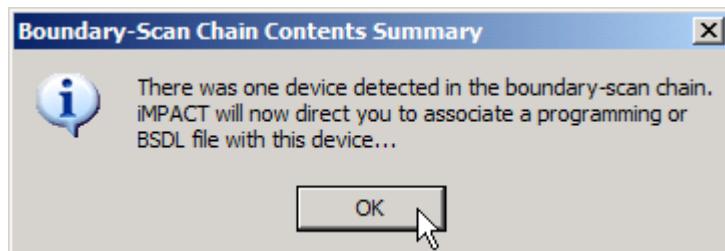
The **Configure Devices** window now appears. You just programmed the CPLD on the XSA Board so it would support programming of the FPGA through its boundary-scan pins. So select the Boundary-Scan Mode option and click on the Next button.



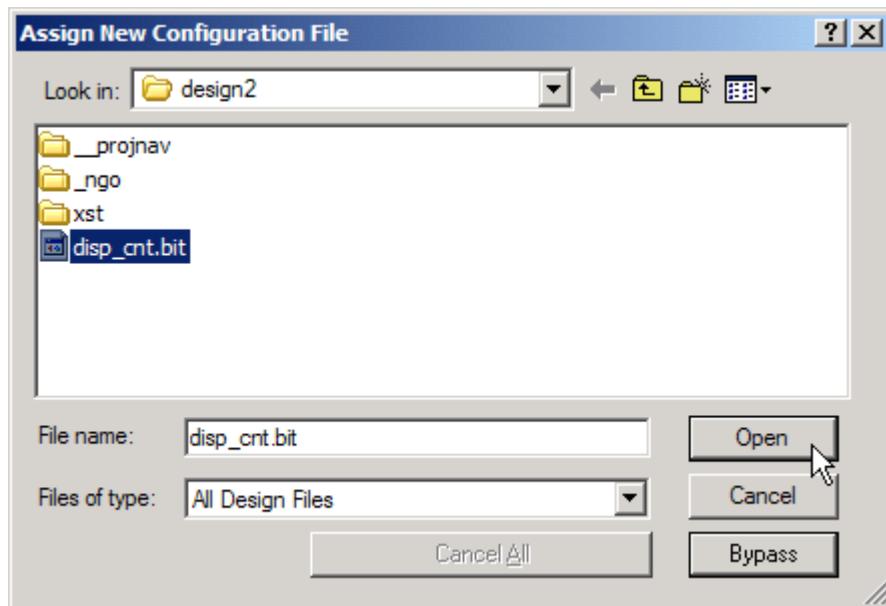
Boundary-scan mode allows the configuration of multiple FPGAs connected together in a chain. To accomplish this, the iMPACT software needs to know the types of the FPGAs in the chain. There is just a single FPGA on the XSA Board and you could easily describe this to iMPACT. But iMPACT can also probe the boundary-scan chain and automatically identify the types of the FPGAs. This is even easier, so select the automatic identification option and click on the Finish button.



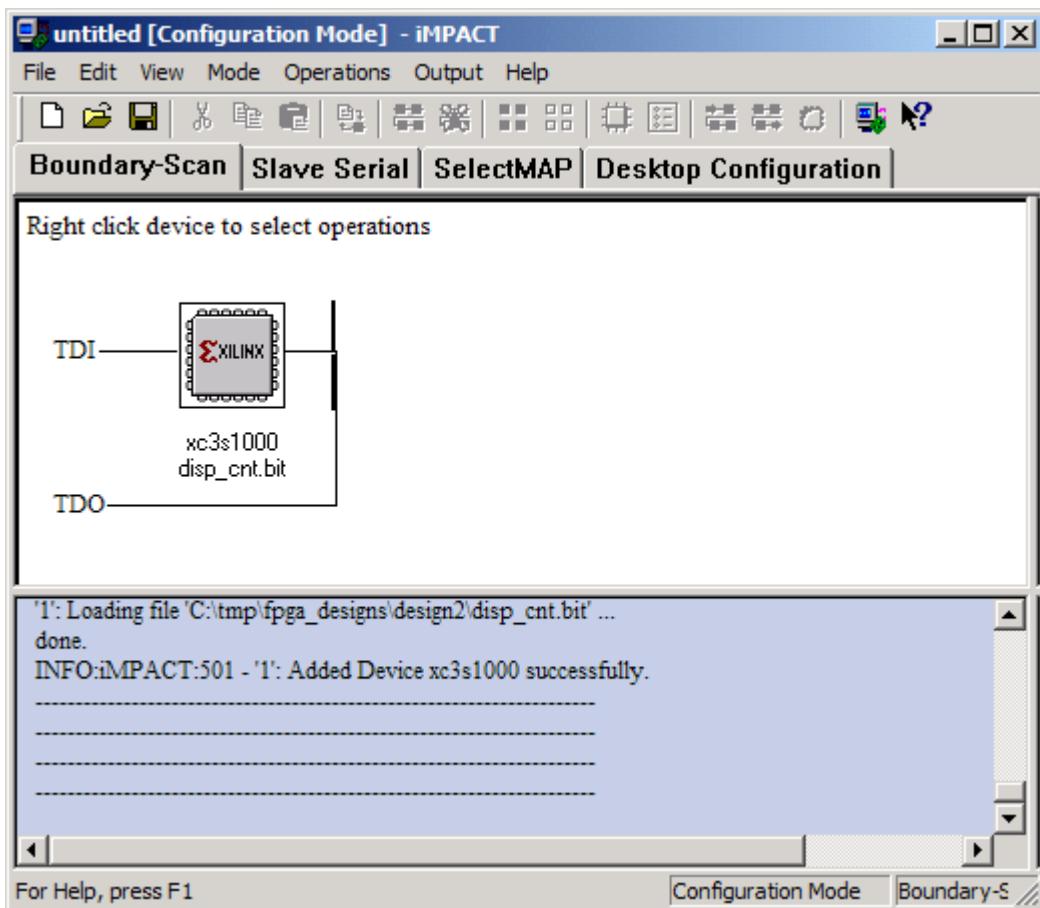
The iMPACT software will probe the boundary-scan chain and find there is only a single FPGA present. Now you need to tell iMPACT what bitstream file to download into the FPGA. Click on the OK button to proceed.



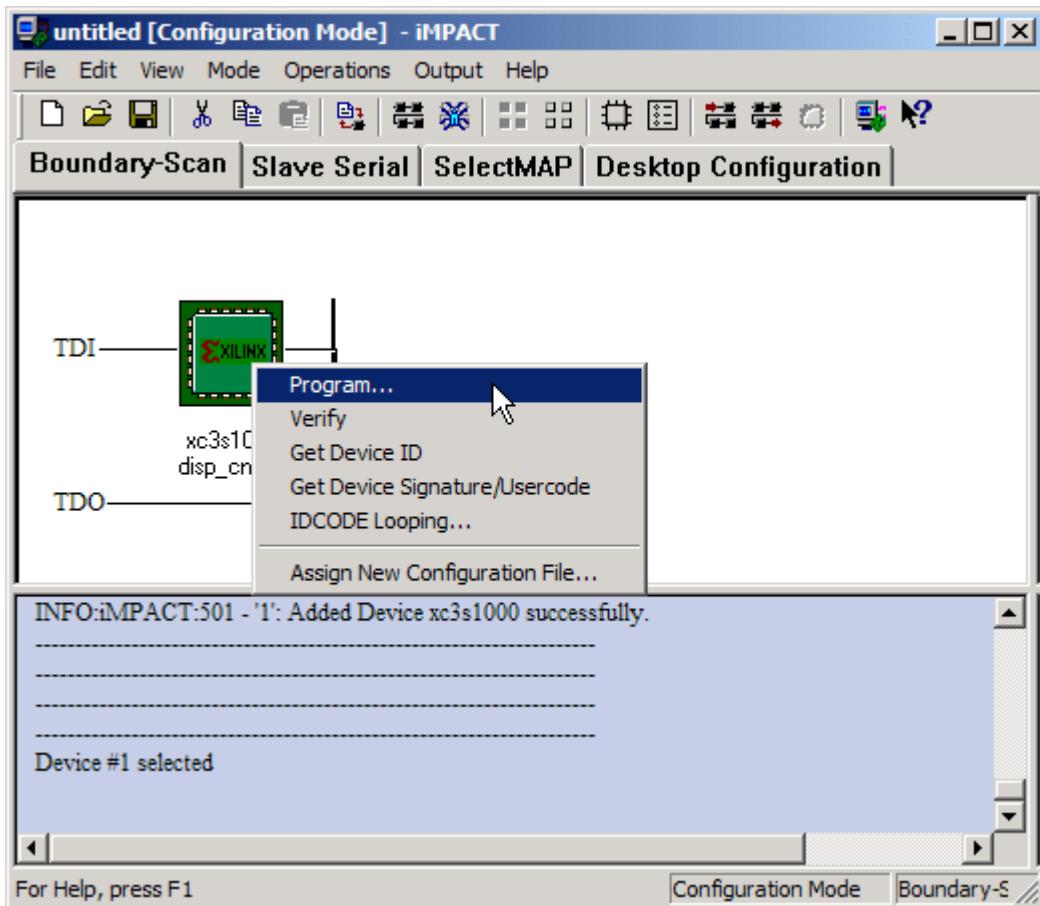
The **Assign New Configuration File** window now appears. Go to the tmp\fpga_designs\design2 folder and highlight the disp_cnt.bit file. Then click on the Open button.



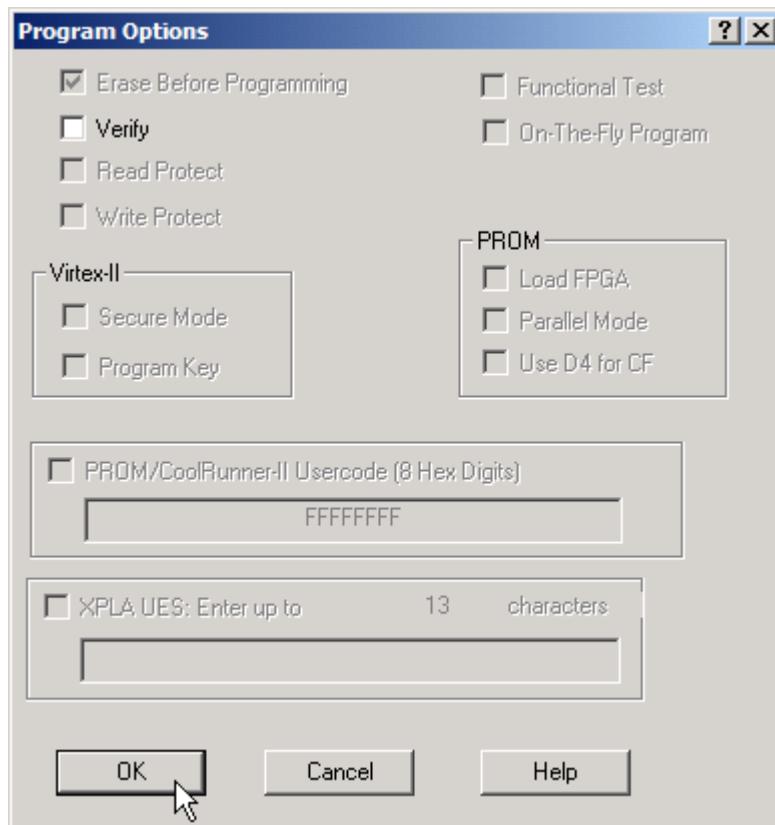
The main **iMPACT** window appears with a boundary-scan chain consisting of a single XC3S1000 FPGA.



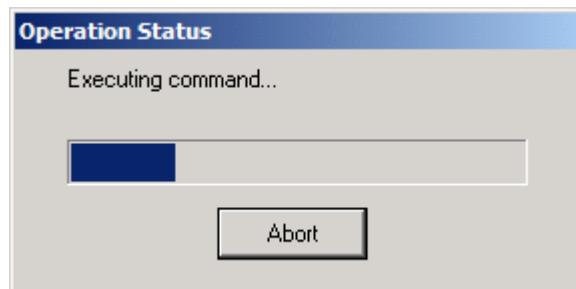
Now right-click on the xc3s1000 icon and select the Program... item on the pop-up menu.



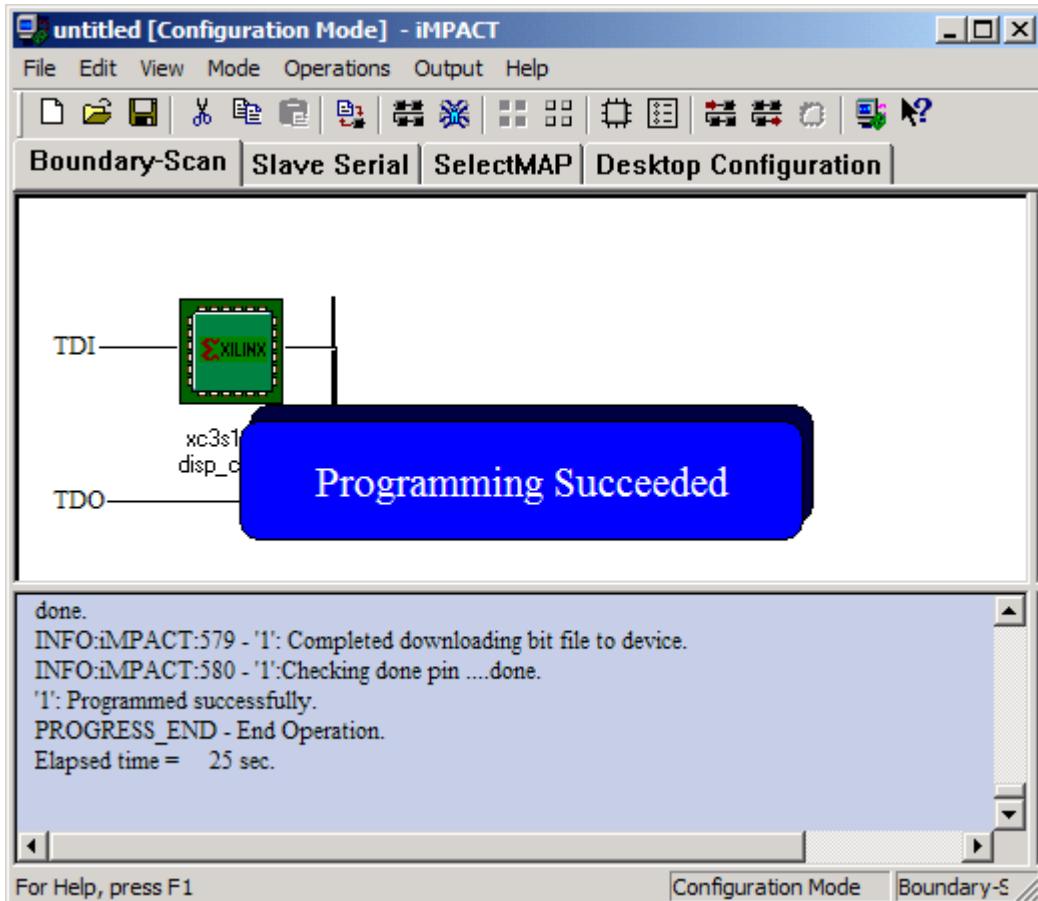
The **Program Options** window will appear. All you need to do at this point is click on the OK button to begin loading the disp_cnt.bit file into the FPGA.



The progress of the bitstream download will be displayed. The download operation should complete within twenty seconds.



After the download operation completes, you can check the status messages in the bottom pane of the iMPACT window to see if the FPGA was configured successfully. The large message block in the main window also helps.



Testing the Circuit

Once the FPGA on the XSA Board is programmed, the circuit will begin operating without any further action from you. The LED display should repeatedly count through the sequence 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, A, b, c, d, E, F with a complete cycle taking 5.4 seconds.

5

Going Further...

OK! You made it to the end! You have scratched the surface of programmable logic design, but how do you learn even more? Here are a few easy things to do:

- In the Project Navigator window, select Help→ISE Help Contents. You will be presented with a browser window containing topics that will let you learn more about the WebPACK software.
- Get *Essential VHDL* (ISBN:0-9669590-0-0) or *The Designer's Guide to VHDL* (ISBN:1-55860-270-4) to learn more about VHDL for logic design.
- Go to the Xilinx web site and read their application notes and data sheets.
- Read the *comp.arch.fpga* newsgroup for helpful questions and answers about programmable logic design.