

Using Library Modules in VHDL Designs

This tutorial explains how Altera's library modules can be included in VHDL-based designs, which are implemented by using the Quartus[®] II software.

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Practical designs often include commonly used circuit blocks such as adders, subtractors, multipliers, decoders, counters, and shifters. Altera provides efficient implementations of such blocks in the form of library modules that can be instantiated in VHDL designs. The compiler may recognize that a standard function specified in VHDL code can be realized using a library module, in which case it may automatically *infer* this module. However, many library modules provide functionality that is too complex to be recognized automatically by the compiler. These modules have to be instantiated in the design explicitly by the user.

Quartus[®] II software includes a *library of parameterized modules (LPM)*. The modules are general in structure and they are tailored to a specific application by specifying the values of general parameters.

Doing this tutorial, the reader will learn about:

- Library of parameterized modules (LPMs)
- Configuring an LPM for use in a circuit
- Instantiating an LPM in a designed circuit

The detailed examples in the tutorial were obtained using the Quartus II version 5.0, but other versions of the software can also be used.

1 Example Circuit

As an example, we will use the adder/subtractor circuit shown in Figure 1. It can add, subtract, and accumulate n -bit numbers using the 2's complement number representation. The two primary inputs are numbers $A = a_{n-1}a_{n-2} \cdots a_0$ and $B = b_{n-1}b_{n-2} \cdots b_0$, and the primary output is $Z = z_{n-1}z_{n-2} \cdots z_0$. Another input is the *AddSub* control signal which causes $Z = A + B$ to be performed when *AddSub* = 0 and $Z = A - B$ when *AddSub* = 1. A second control input, *Sel*, is used to select the accumulator mode of operation. If *Sel* = 0, the operation $Z = A \pm B$ is performed, but if *Sel* = 1, then B is added to or subtracted from the current value of Z . If the addition or subtraction operations result in arithmetic overflow, an output signal, *Overflow*, is asserted.

To make it easier to deal with asynchronous input signals, they are loaded into flip-flops on a positive edge of the clock. Thus, inputs A and B will be loaded into registers *Areg* and *Breg*, while *Sel* and *AddSub* will be loaded into flip-flops *SelR* and *AddSubR*, respectively. The adder/subtractor circuit places the result into register *Zreg*.

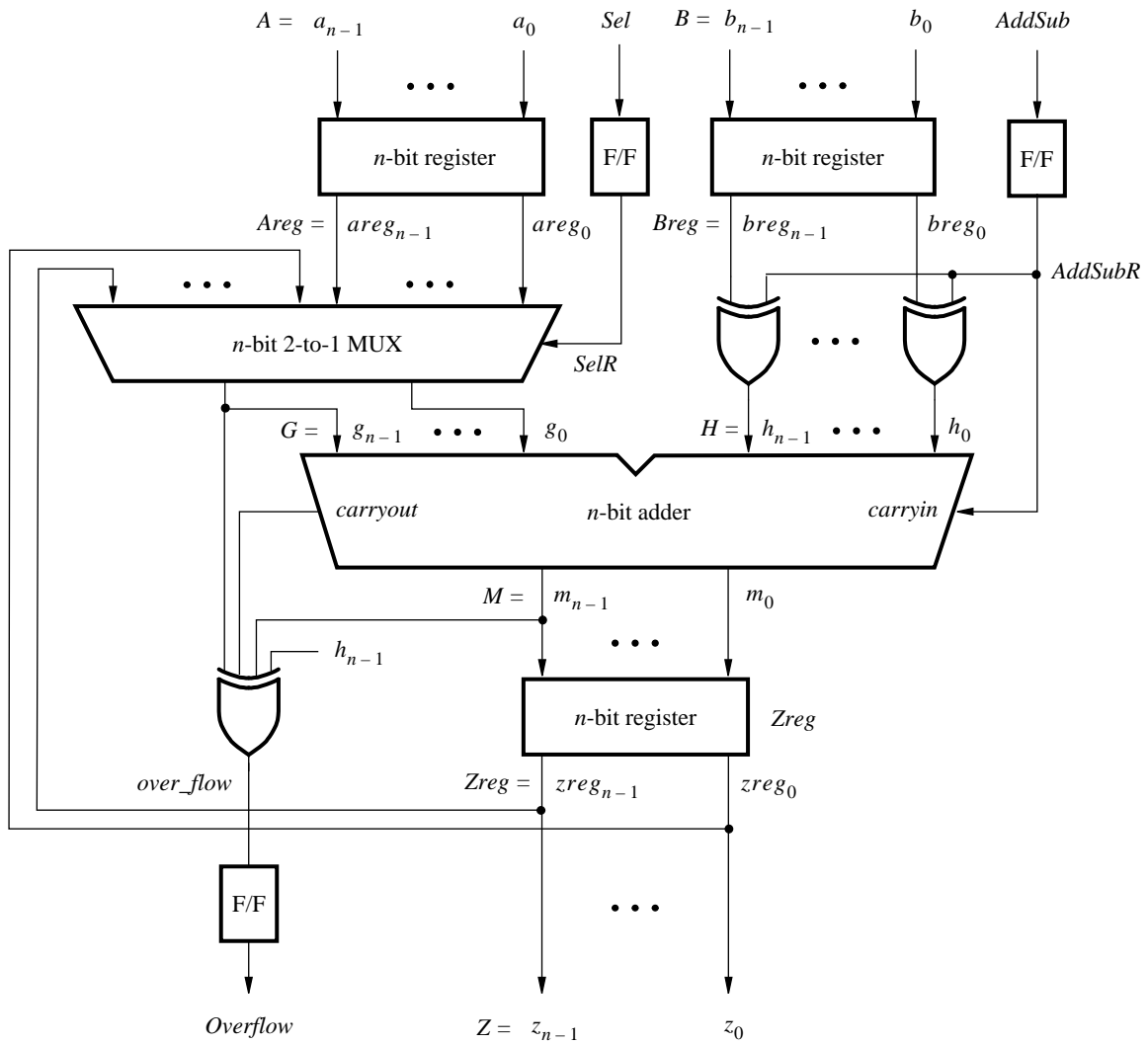


Figure 1. The adder/subtractor circuit.

The required circuit is described by the VHDL code in Figure 2. For our example, we use a 16-bit circuit as specified by $n = 16$. Implement this circuit as follows:

- Create a project *addersubtractor*.
- Include a file *addersubtractor.vhd*, which corresponds to Figure 2, in the project. For convenience, this file is provided in the directory *DE2_tutorials\design_files*, which is included on the CD-ROM that accompanies the DE2 board and can also be found on Altera's DE2 web pages.
- Choose the Cyclone II EP2C35F672C6 device, which is the FPGA chip on Altera's DE2 board.
- Compile the design.
- Simulate the design by applying some typical inputs.

```

LIBRARY ieee ;
USE ieee.std_logic_1164.all ;

-- Top-level entity
ENTITY addersubtractor IS
    GENERIC ( n : INTEGER := 16 ) ;
    PORT ( A, B          : IN STD_LOGIC_VECTOR(n-1 DOWNTO 0) ;
          Clock, Reset, Sel, AddSub : IN STD_LOGIC ;
          Z              : BUFFER STD_LOGIC_VECTOR(n-1 DOWNTO 0) ;
          Overflow      : OUT STD_LOGIC ) ;
END addersubtractor ;

ARCHITECTURE Behavior OF addersubtractor IS
    SIGNAL G, H, M, Areg, Breg, Zreg, AddSubR_n : STD_LOGIC_VECTOR(n-1 DOWNTO 0) ;
    SIGNAL SelR, AddSubR, carryout, over_flow : STD_LOGIC ;
    COMPONENT mux2to1
        GENERIC ( k : INTEGER := 8 ) ;
        PORT ( V, W : IN STD_LOGIC_VECTOR(k-1 DOWNTO 0) ;
              Selm : IN STD_LOGIC ;
              F    : OUT STD_LOGIC_VECTOR(k-1 DOWNTO 0) ) ;
    END COMPONENT ;
    COMPONENT adderk
        GENERIC ( k : INTEGER := 8 ) ;
        PORT ( carryin : IN STD_LOGIC ;
              X, Y    : IN STD_LOGIC_VECTOR(k-1 DOWNTO 0) ;
              S      : OUT STD_LOGIC_VECTOR(k-1 DOWNTO 0) ;
              carryout : OUT STD_LOGIC ) ;
    END COMPONENT ;
BEGIN
    PROCESS ( Reset, Clock )
    BEGIN
        IF Reset = '1' THEN
            Areg <= (OTHERS => '0'); Breg <= (OTHERS => '0');
            Zreg <= (OTHERS => '0'); SelR <= '0'; AddSubR <= '0'; Overflow <= '0';
        ELSIF Clock'EVENT AND Clock = '1' THEN
            Areg <= A; Breg <= B; Zreg <= M;
            SelR <= Sel; AddSubR <= AddSub; Overflow <= over_flow;
        END IF ;
    END PROCESS ;

    nbit_adder: adderk
        GENERIC MAP ( k => n )
        PORT MAP ( AddSubR, G, H, M, carryout ) ;
    multiplexer: mux2to1
        GENERIC MAP ( k => n )
        PORT MAP ( Areg, Z, SelR, G ) ;
    AddSubR_n <= (OTHERS => AddSubR) ;
    H <= Breg XOR AddSubR_n ;
    over_flow <= carryout XOR G(n-1) XOR H(n-1) XOR M(n-1) ;
    Z <= Zreg ;
END Behavior;
... continued in Part b

```

Figure 2. VHDL code for the circuit in Figure 1 (Part a).

```

-- k-bit 2-to-1 multiplexer
LIBRARY ieee ;
USE ieee.std_logic_1164.all ;

ENTITY mux2to1 IS
    GENERIC ( k : INTEGER := 8 ) ;
    PORT ( V, W : IN STD_LOGIC_VECTOR(k-1 DOWNTO 0) ;
          Selm : IN STD_LOGIC ;
          F : OUT STD_LOGIC_VECTOR(k-1 DOWNTO 0) ) ;
END mux2to1 ;

ARCHITECTURE Behavior OF mux2to1 IS
BEGIN
    PROCESS ( V, W, Selm )
    BEGIN
        IF Selm = '0' THEN
            F <= V ;
        ELSE
            F <= W ;
        END IF ;
    END PROCESS ;
END Behavior ;

-- k-bit adder
LIBRARY ieee ;
USE ieee.std_logic_1164.all ;
USE ieee.std_logic_signed.all ;

ENTITY adderk IS
    GENERIC ( k : INTEGER := 8 ) ;
    PORT ( carryin : IN STD_LOGIC ;
          X, Y : IN STD_LOGIC_VECTOR(k-1 DOWNTO 0) ;
          S : OUT STD_LOGIC_VECTOR(k-1 DOWNTO 0) ;
          carryout : OUT STD_LOGIC ) ;
END adderk ;

ARCHITECTURE Behavior OF adderk IS
    SIGNAL Sum : STD_LOGIC_VECTOR(k DOWNTO 0) ;
BEGIN
    Sum <= ('0' & X) + ('0' & Y) + carryin ;
    S <= Sum(k-1 DOWNTO 0) ;
    carryout <= Sum(k) ;
END Behavior ;

```

Figure 2. VHDL code for the circuit in Figure 1 (Part *b*).

2 Library of Parameterized Modules

The LPMs in the library of parameterized modules are general in structure and they can be configured to suit a specific application by specifying the values of various parameters. Select **Help > Megafunctions/LPM** to see a listing of the available LPMs. One of them is an adder/subtractor module called *lpm_add_sub megafunction*. Select this module to see its description. The module has a number of inputs and outputs, some of which may be omitted in a given application. Several parameters can be defined to specify a particular mode of operation. For example, the number of bits in the operands is specified in the parameter LPM_WIDTH. The LPM_REPRESENTATION parameter specifies whether the operands are to be interpreted as signed or unsigned numbers, and so on. Templates on how an LPM can be instantiated in a hardware description language are given in the description of the module. Using these templates is somewhat cumbersome, so Quartus II software provides a wizard that makes the instantiation of LPMs easy.

We will use the *lpm_add_sub* module to simplify our adder/subtractor circuit defined in Figures 1 and 2. The augmented circuit is given in Figure 3. The *lpm_add_sub* module, instantiated under the name *megaddsub*, replaces the adder circuit as well as the XOR gates that provide the input *H* to the adder. Since arithmetic overflow is one of the outputs that the LPM provides, it is not necessary to generate this output with a separate XOR gate.

To implement this adder/subtractor circuit, create a new directory named *tutorial_lpm*, and then create a project *addersubtractor2*. Choose the same Cyclone II EP2C35F672C6 device, to allow a direct comparison of implemented designs.

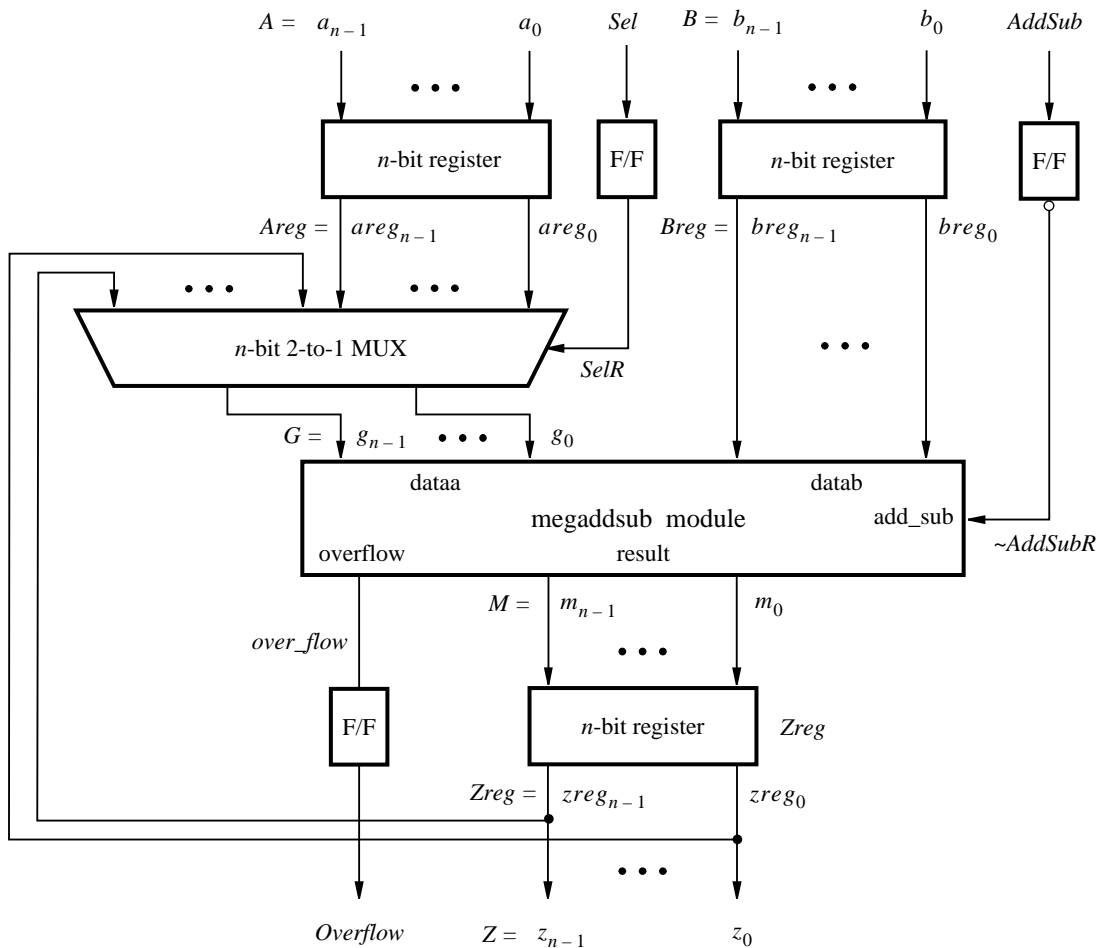


Figure 3. The augmented adder/subtractor circuit.

The new design will include the desired LPM subcircuit specified as a VHDL component that will be instantiated in the top-level VHDL design entity. The VHDL component for the LPM subcircuit is generated by using a wizard as follows:

1. Select Tools > MegaWizard Plug-in Manager, which leads to a sequence of seven pop-up boxes in which the user can specify the details of the desired LPM.
2. In the box shown in Figure 4 indicate Create a new custom megafunction variation and click Next.

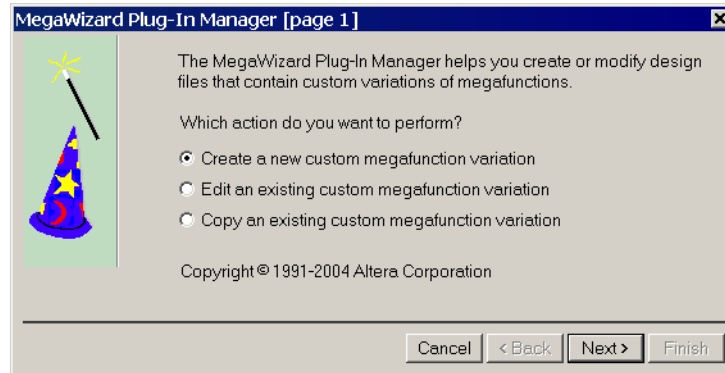


Figure 4. Choose to define an LPM.

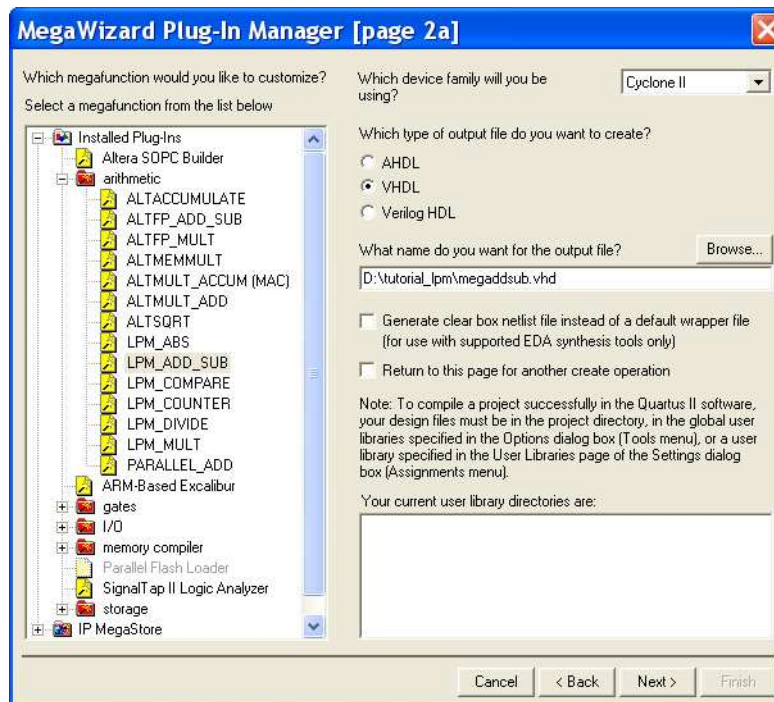


Figure 5. Choose an LPM from the available library.

3. The box in Figure 5 provides a list of the available LPMs. Expand the “arithmetic” sublist and select LPM_ADD.SUB. Choose VHDL as the type of output file that should be created. The output file must be

given a name; choose the name *megaddsub.vhd* and indicate that the file should be placed in the directory *tutorial_lpm* as shown in the figure. Press **Next**.

4. In the box in Figure 6 specify that the width of the data inputs is 16 bits. Also, specify the operating mode in which one of the ports allows performing both addition and subtraction of the input operand, under the control of the *add_sub* input. A symbol for the resulting LPM is shown in the top left corner. Note that if $add_sub = 1$ then $result = A + B$; otherwise, $result = A - B$. This interpretation of the control input and the operation performed is different from our original design in Figures 1 and 2, which we have to account for in the modified design. Observe that we have included this change in the circuit in Figure 3. Click **Next**.

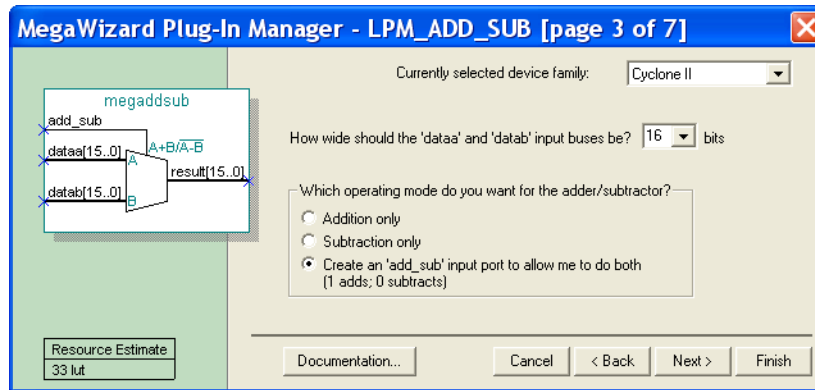


Figure 6. Specify the size of data inputs.

5. In the box in Figure 7, specify that the values of both inputs may vary and click **Next**.

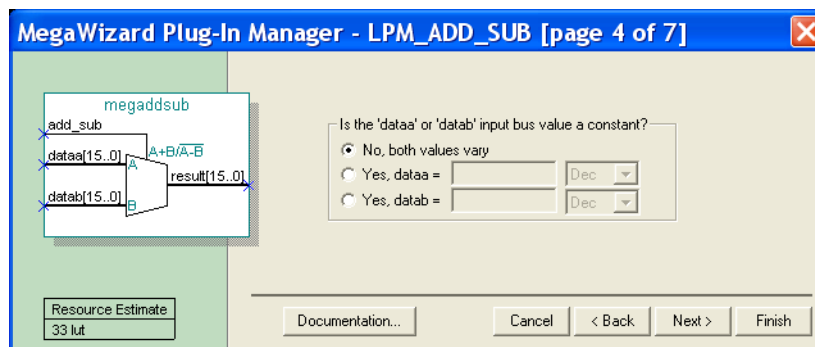


Figure 7. Further specification of inputs.

6. The box in Figure 8 allows the designer to indicate optional inputs and outputs that may be specified. Since we need the overflow signal, make the **Create an overflow output** choice and press **Next**.

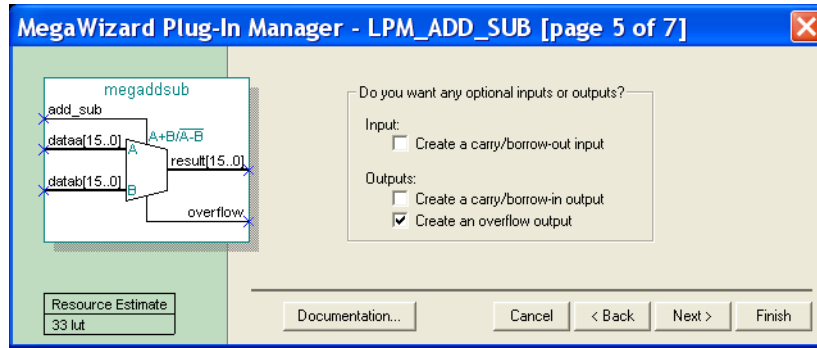


Figure 8. Specify the Overflow output.

7. In the box in Figure 9 say No to the pipelining option and click Next.

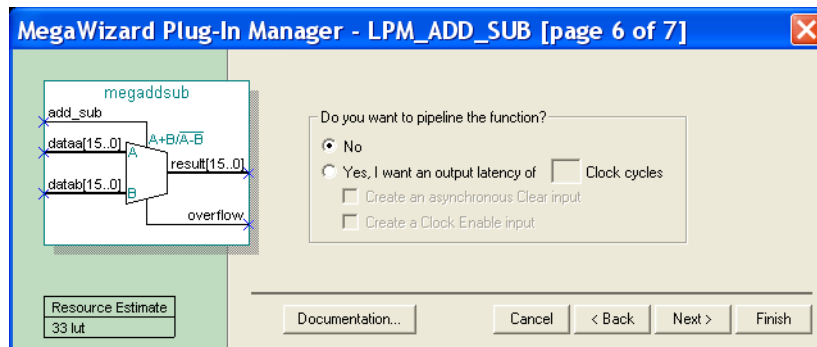


Figure 9. Refuse the pipelining option.

8. Figure 10 gives a summary which shows the files that the wizard will create. Press Finish to complete the process.

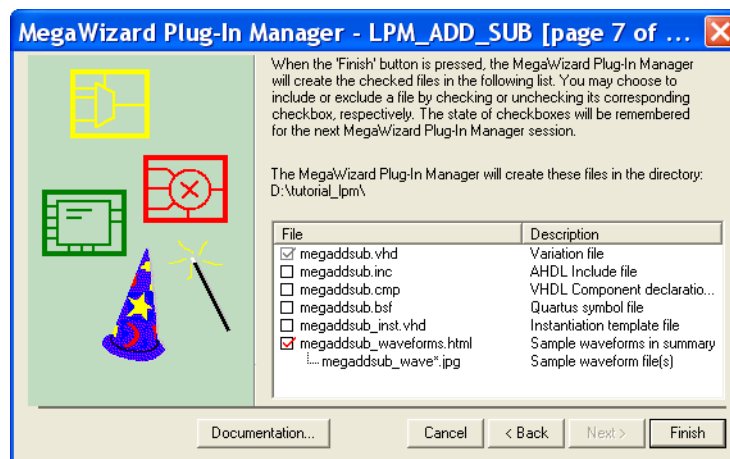


Figure 10. Files created by the wizard.

3 Augmented Circuit with an LPM

We will use the file *megaddsub.vhd* in our modified design. Figure 11 depicts the VHDL code in this file; note that we have not shown the comments in order to keep the figure small.

```
// Adder/subtractor module created by the MegaWizard
LIBRARY ieee;
USE ieee.std_logic_1164.all;
LIBRARY lpm;
USE lpm.lpm_components.all;

ENTITY megaddsub IS
    PORT ( add_sub : IN STD_LOGIC ;
          dataa   : IN STD_LOGIC_VECTOR (15 DOWNT0 0);
          datab  : IN STD_LOGIC_VECTOR (15 DOWNT0 0);
          result  : OUT STD_LOGIC_VECTOR (15 DOWNT0 0);
          overflow : OUT STD_LOGIC );
END megaddsub;
ARCHITECTURE SYN OF megaddsub IS
    SIGNAL sub_wire0 : STD_LOGIC ;
    SIGNAL sub_wire1 : STD_LOGIC_VECTOR (15 DOWNT0 0);

    COMPONENT lpm_add_sub
    GENERIC ( lpm_width : NATURAL;
             lpm_direction : STRING;
             lpm_type : STRING;
             lpm_hint : STRING );
    PORT ( dataa : IN STD_LOGIC_VECTOR (15 DOWNT0 0);
          add_sub : IN STD_LOGIC ;
          datab : IN STD_LOGIC_VECTOR (15 DOWNT0 0);
          overflow : OUT STD_LOGIC ;
          result : OUT STD_LOGIC_VECTOR (15 DOWNT0 0) );
    END COMPONENT;

BEGIN
    overflow <= sub_wire0;
    result <= sub_wire1(15 DOWNT0 0);
    lpm_add_sub_component : lpm_add_sub
    GENERIC MAP ( lpm_width => 16,
                 lpm_direction => "UNUSED",
                 lpm_type => "LPM_ADD_SUB",
                 lpm_hint => "ONE_INPUT_IS_CONSTANT=NO,CIN_USED=NO" )
    PORT MAP ( dataa => dataa,
              add_sub => add_sub,
              datab => datab,
              overflow => sub_wire0,
              result => sub_wire1 );
END SYN;
```

Figure 11. VHDL code for the ADD.SUB LPM.

The modified VHDL code for the adder/subtractor design is given in Figure 12. It incorporates the code in Figure 11 as a component. Put the code in Figure 12 into a file *tutorial_lpm\addersubtractor2.vhd*. For convenience, the required file *addersubtractor2.vhd* is provided in the directory *DE2_tutorials\design_files*, which is included on the CD-ROM that accompanies the DE2 board and can also be found on Altera's DE2 web pages.

```

LIBRARY ieee ;
USE ieee.std_logic_1164.all ;

-- Top-level entity
ENTITY addersubtractor2 IS
    GENERIC ( n : INTEGER := 16 ) ;
    PORT ( A, B          : IN STD_LOGIC_VECTOR(n-1 DOWNTO 0) ;
          Clock, Reset, Sel, AddSub : IN STD_LOGIC ;
          Z              : BUFFER STD_LOGIC_VECTOR(n-1 DOWNTO 0) ;
          Overflow      : OUT STD_LOGIC ) ;
END addersubtractor2 ;

ARCHITECTURE Behavior OF addersubtractor2 IS
    SIGNAL G, M, Areg, Breg, Zreg, : STD_LOGIC_VECTOR(n-1 DOWNTO 0) ;
    SIGNAL SelR, AddSubR, over_flow : STD_LOGIC ;
    COMPONENT mux2to1
        GENERIC ( k : INTEGER := 8 ) ;
        PORT ( V, W : IN STD_LOGIC_VECTOR(k-1 DOWNTO 0) ;
              Selm : IN STD_LOGIC ;
              F    : OUT STD_LOGIC_VECTOR(k-1 DOWNTO 0) ) ;
    END COMPONENT ;
    COMPONENT megadddsub
        PORT ( add_sub      : IN STD_LOGIC ;
              dataa, datab : IN STD_LOGIC_VECTOR(15 DOWNTO 0) ;
              result       : OUT STD_LOGIC_VECTOR(15 DOWNTO 0) ;
              overflow     : OUT STD_LOGIC ) ;
    END COMPONENT ;

BEGIN
-- Define flip-flops and registers
PROCESS ( Reset, Clock )
BEGIN
    IF Reset = '1' THEN
        Areg <= (OTHERS => '0'); Breg <= (OTHERS => '0');
        Zreg <= (OTHERS => '0'); SelR <= '0'; AddSubR <= '0'; Overflow <= '0';
    ELSIF Clock'EVENT AND Clock = '1' THEN
        Areg <= A; Breg <= B; Zreg <= M;
        SelR <= Sel; AddSubR <= AddSub; Overflow <= over_flow;
    END IF ;
END PROCESS ;

... continued in Part b

```

Figure 12. VHDL code for the circuit in Figure 3 (Part a).

```

-- Define combinational circuit
nbit_addsub: megaddsub
    PORT MAP ( AddSubR, G, Breg, M, over_flow );
multiplexer: mux2to1
    GENERIC MAP ( k => n )
    PORT MAP ( Areg, Z, SelR, G );
    Z <= Zreg ;
END Behavior;

-- k-bit 2-to-1 multiplexer
LIBRARY ieee ;
USE ieee.std_logic_1164.all ;

ENTITY mux2to1 IS
    GENERIC ( k : INTEGER := 8 );
    PORT ( V, W : IN STD_LOGIC_VECTOR(k-1 DOWNTO 0);
          Selm : IN STD_LOGIC ;
          F : OUT STD_LOGIC_VECTOR(k-1 DOWNTO 0) );
END mux2to1 ;

ARCHITECTURE Behavior OF mux2to1 IS
BEGIN
    PROCESS ( V, W, Selm )
    BEGIN
        IF Selm = '0' THEN
            F <= V ;
        ELSE
            F <= W ;
        END IF ;
    END PROCESS ;
END Behavior ;

-- 16-bit adder/subtractor LPM created by the MegaWizard
LIBRARY ieee;
USE ieee.std_logic_1164.all;
LIBRARY lpm;
USE lpm.lpm_components.all;

ENTITY megaddsub IS
    PORT ( add_sub : IN STD_LOGIC ;
          dataa : IN STD_LOGIC_VECTOR (15 DOWNTO 0);
          datab : IN STD_LOGIC_VECTOR (15 DOWNTO 0);
          result : OUT STD_LOGIC_VECTOR (15 DOWNTO 0);
          overflow : OUT STD_LOGIC );
END megaddsub;
ARCHITECTURE SYN OF megaddsub IS
    SIGNAL sub_wire0 : STD_LOGIC ;
    SIGNAL sub_wire1 : STD_LOGIC_VECTOR (15 DOWNTO 0);

... continued in Part c

```

Figure 12. VHDL code for the circuit in Figure 3 (Part b).

```

COMPONENT lpm_add_sub
  GENERIC ( lpm_width : NATURAL;
            lpm_direction : STRING;
            lpm_type : STRING;
            lpm_hint : STRING );
  PORT ( dataa : IN STD_LOGIC_VECTOR (15 DOWNT0 0);
        add_sub : IN STD_LOGIC ;
        datab : IN STD_LOGIC_VECTOR (15 DOWNT0 0);
        overflow : OUT STD_LOGIC ;
        result : OUT STD_LOGIC_VECTOR (15 DOWNT0 0) );
END COMPONENT;

BEGIN
  overflow <= sub_wire0;
  result <= sub_wire1(15 DOWNT0 0);

  lpm_add_sub_component : lpm_add_sub
  GENERIC MAP ( lpm_width => 16,
                lpm_direction => "UNUSED",
                lpm_type => "LPM_ADD_SUB",
                lpm_hint => "ONE_INPUT_IS_CONSTANT=NO,CIN_USED=NO" )
  PORT MAP ( dataa => dataa,
            add_sub => add_sub,
            datab => datab,
            overflow => sub_wire0,
            result => sub_wire1 );
END SYN;

```

Figure 12. VHDL code for the circuit in Figure 3 (Part c).

The key differences between this code and Figure 2 are:

- The statements that define the *overflow* signal and the XOR gates (along with the signal H) are no longer needed.
- The *adderk* entity, which specifies the adder circuit, is replaced by *megaddsub* entity. Note that the *dataa* and *datab* inputs shown in Figure 6 are driven by the *G* and *Breg* vectors, respectively.
- *AddSubR* signal is specified to be the inverted version of the *AddSub* signal to conform with the usage of this control signal in the LPM.

If you copied the file *addersubtractor2.vhd* from the *qdesigns* directory, you have to include this file in the project. To do so, select Project > Add/Remove Files in Project to reach the window in Figure 13. Browse for the available files by clicking the button File name: ... to reach the window in Figure 14. Select the file *addersubtractor2.vhd* and click Open, which returns to the window in Figure 13. Click Add to include the file and then click OK. Now, the modified design can be compiled and simulated in the usual way.

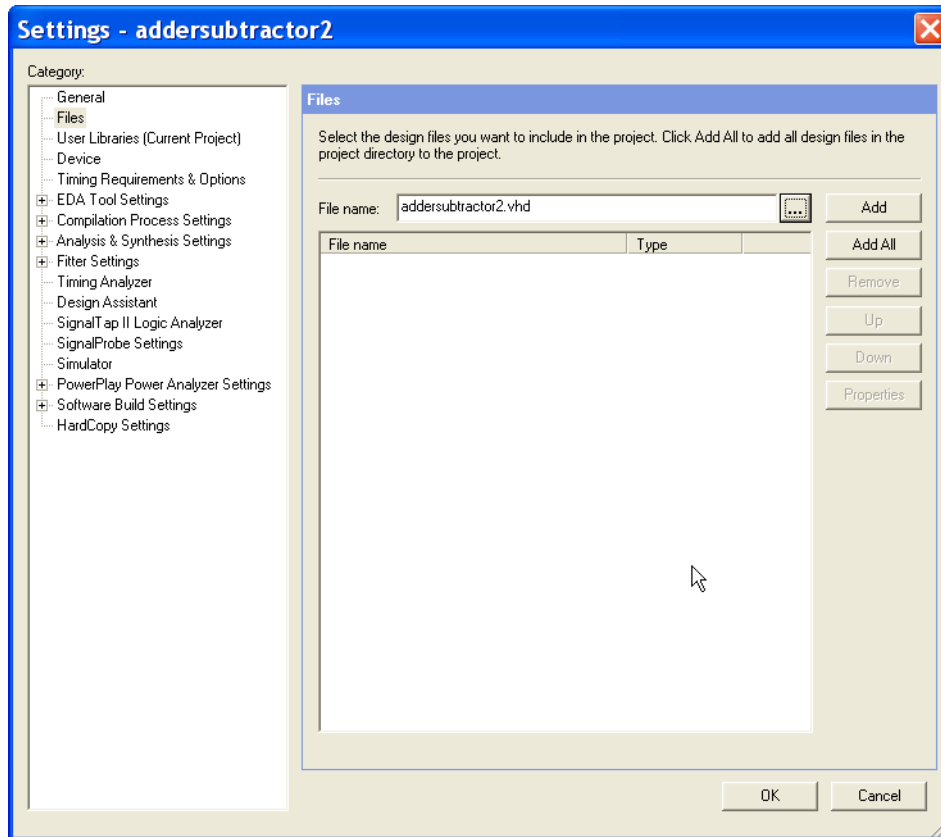


Figure 13. Inclusion of the new file in the project.

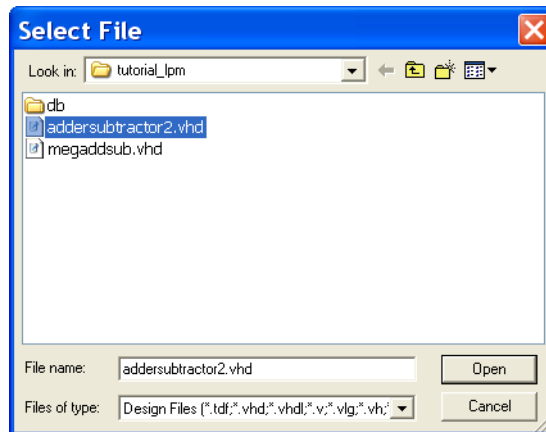
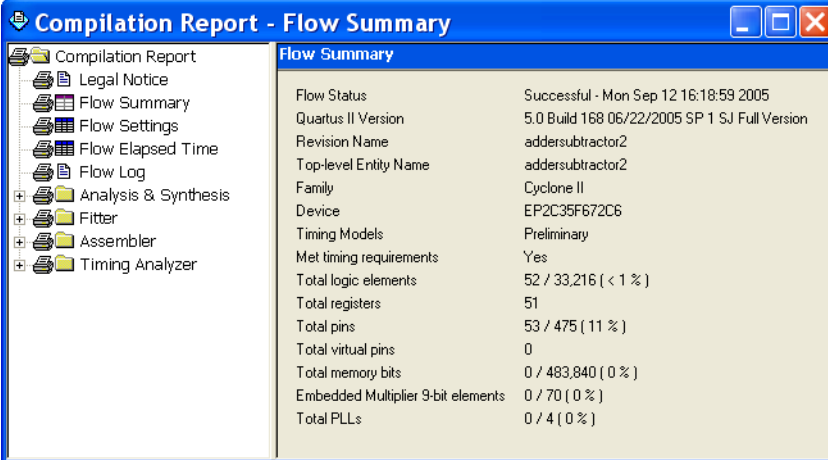


Figure 14. Specify the *addersubtractor.vhd* file.

4 Results for the Augmented Design

Compile the design and look at the summary, which is depicted in Figure 15. Observe that the modified design is implemented in 52 logic elements, which is the same as when using the code in Figure 2. In very small circuits, which is the case with our example, it is unlikely that using LPMs will result in a significant advantage. However, in more complex designs the advantage of using LPMs is likely to be significant. The reason is that the LPMs implement the required logic more efficiently than what the compiler can do from simple VHDL code, such as the code in Figure 2. The user should consider using an LPM whenever a suitable one exists.



Flow Summary	
Flow Status	Successful - Mon Sep 12 16:18:59 2005
Quartus II Version	5.0 Build 168 06/22/2005 SP 1 SJ Full Version
Revision Name	addersubtractor2
Top-level Entity Name	addersubtractor2
Family	Cyclone II
Device	EP2C35F672C6
Timing Models	Preliminary
Met timing requirements	Yes
Total logic elements	52 / 33,216 (< 1 %)
Total registers	51
Total pins	53 / 475 (11 %)
Total virtual pins	0
Total memory bits	0 / 483,840 (0 %)
Embedded Multiplier 9-bit elements	0 / 70 (0 %)
Total PLLs	0 / 4 (0 %)

Figure 15. Compilation Results for the Augmented Circuit.

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