

Structural Design

Task:

Implement a 2-bit adder using 1-bit full adder and 1-bit half adder as components (Figure 1) that are connected together in a top-level module. Describe both components in VHDL. Prepare two implementations where VHDL components are instantiated in:

- VHDL top-level file
- Block Design top-level file

Simulate and implement each project on FPGA development board.

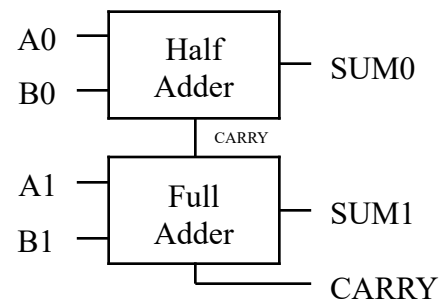


Figure 1: 2-bit Adder

Structural design

The system can be represented as a collection of components and their interconnections using structural design approach. In this way the hardware is described as schematic or netlist, where internal structure of the interconnected components is hidden. The components can be either regular structures (like logic gates, adders, comparators, registers, etc.) or previously defined sources, which are used within another higher level design to create a hierarchy.

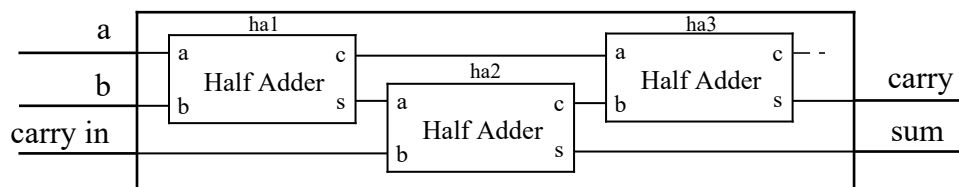


Figure 2: Full Adder Block Diagram

A simple 1-bit full adder circuit has three inputs and two outputs. It can be built from three

half adders as shown in Figure 2. The carry output of the *ha3* half adder is left floating, as it would always equal to '0' (other half adders cannot have their carry outputs equal to '1' both at the same time). Note that this example is meant only to illustrate the principle of structural design and does not suggest the best way to describe a full adder.

Structural design using VHDL

In order to construct the full adder in Figure 2 using VHDL, the structural description style can be used. The half adder design can be used as a component, thus effectively creating a textual description of a schematic in Figure 2. Component is a piece of conventional VHDL code, which can be used within another description. This allows to partition, share and reuse VHDL code.

The half adder component should be designed first (refer to the example in the Combinational Logic lab appendix). Once the half adder has been described, it can be used to form full adder design by declaring it as a component in the declarative part of the full adder architecture (before **begin** keyword). The component declaration is very similar to entity declaration with keywords **entity** substituted for keyword **component** (Listing 1).

Listing 1: VHDL Declaration of Component Half Adder

```
component half_adder is  
    port (a, b: in std_logic;  
          sum, carry: out std_logic);  
end component;
```

The next step is to instantiate a component in the architecture body. Component instantiation starts with a label, followed by component's name. The label is required to differentiate between multiple instances of the same component. The final component instantiation part is mapping of component's inputs/outputs to the ports and signals of the higher level description. The mapping can be done in two ways as shown in Listing 2.

The named association maps each input/output of the component (to the left of "=>" operator) to a corresponding signal (to the right of "=>" operator) of the higher level description. Note, that the order, in which the ports are being mapped, does not correspond

to the order in component declaration. This is due to the fact that association is being stated explicitly. On the other hand, in the positional association the signals are ordered exactly as in component declaration. This in turn allows to omit the “=>” operator.

Listing 2: a) Positional and b) Named Association of Component Half Adder

<pre> ha1: half_adder port map (ha1_a, ha1_b, ha1_sum, ha1_carry); </pre> <p style="text-align: center;">a)</p>	<pre> ha1: half_adder port map (a => ha1_a, sum => ha1_sum, b => ha1_b, carry => ha1_carry); </pre> <p style="text-align: center;">b)</p>
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Listing 3 shows three instantiation of *half_adder* component (all three using positional association for port mapping), which form the full adder as shown in Figure 2. Note, that the order of components is not important, since they are working concurrently (in parallel). The schematic, which can be reconstructed from this structural VHDL description, should be identical to the one in Figure 2.

Listing 3: Structural Description of Full Adder

```

ha3: half_adder port map (c_a, c_b, carry, open);
ha1: half_adder port map (a, b, s_a, c_a);
ha2: half_adder port map (s_a, carry_in, sum, c_b);

```

Note, that in order to form internal connection between components, three additional signals must be declared: *c_a*, *s_a*, *c_b*. The connection is created by mapping the same signal (e.g., *c_a*) to output port for one component (*ha1*) and to input for the other component (*ha3*). This signal can be viewed as corresponding wire from full adder schematic in Figure 2. The floating *carry* output of the *ha3* half adder is specified with the keyword **open**.

Structural design using Vivado Block Design

Similarly the full adder in Figure 2 can be created using Vivado Block Design. The VHDL description of half adder can be packaged into IP and instantiated from the list of IPs. However, for such trivial design IP generation may not be needed. As an alternative,

VHDL source file can be added to the block design as an RTL module.

Select *Create Block Design* option in the *Flow Navigator* under *IP Integrator* flow section, provide *Design name* and click *OK* to create a new Block design source file. Right-click on an empty space in the block design and select *Add Module* option. Highlight half adder design and click *OK* to place it in the block design. Add two more half adders and connect them. For each port that should be connected to the pins of the FPGA (e.g. “A” and “B” of *HA_2*), right-click on the port and select *Make External* option. This will create an *External Port* and connect it to the selected port of RTL Module. Also, it is possible to right-click on the RTL Module itself and select *Make External* option to create *External Ports* for all unconnected ports of that RTL Module. The *External Port* name can be changed in the *External Port Properties*. The end result should look similar to the one shown in Figure 3. Note that carry output of the half adder “*HA_0*” is left floating. The logic associated with that output (AND gate) will be automatically removed during implementation phase.

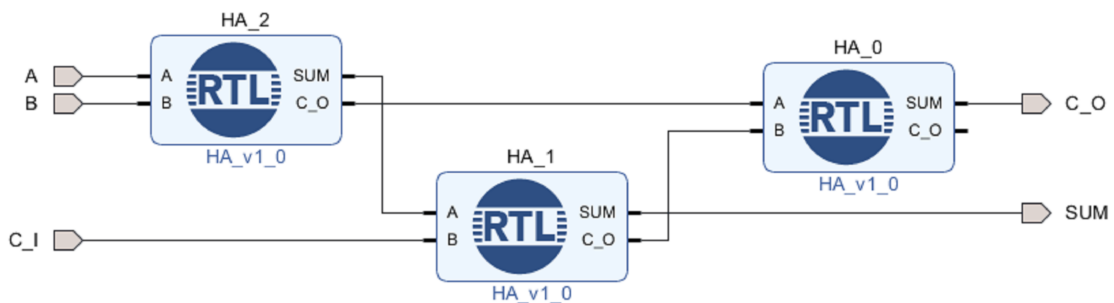


Figure 3: Full Adder Block Design

When the block design is ready, it should be set as the top source file of the project. However, it is not possible to set a block design as top source file directly. Right-click block design source file in the *Sources* window under *Design Sources* category in the *Project Manager* flow section layout. Select *Create HDL Wrapper* option and click *OK*. Leave the default *Let Vivado manage wrapper and auto-updates* option so that in case any changes are made to the block design, the wrapper would update automatically. When HDL wrapper is created for the block design, it can now be set as the top source file. This is done automatically by the tool, however, if this is not the case (or in order to set a different

source file as top), right-click the wrapper and select *Set as Top* option. From this point the design flow becomes identical to VHDL-based design flow.