Building Blocks

Entity Declaration

Description	Example

entity entity_name is
port (
[signal] identifier {, identifier}: [mode] signal_type
{; **[signal]** identifier {, identifier}: [mode] signal_type});
end [entity] [entity_name];
	entity register8 is
	port (
	clk, rst, en: in std_logic;
	data: in std_logic_vector(7 **downto** 0);
	q: out std_logic_vector(7 **downto** 0);
	end register8;

Entity Declaration with Generics

Description	Example

entity entity-name is
generic (
[signal] identifier {, identifier}: [mode] signal-type
[:= static_expression]
{; **[signal]** identifier {, identifier}: [mode] signal_type
[:= static_expression] }
);
port (
[signal] identifier {, identifier}: [mode] signal_type
{; [signal] identifier {, identifier}: [mode] signal_type}
);
end [entity] [entity_name] ;
	entity register_n is
	generic (
	width: integer := 8);
	port (
	clk, rst, en: **in** std_logic;
	data: **in** std_logic_vector(width-1 **downto** 0);
	q: **out** std_logic_vector(width-1 **downto** 0))
	end register_n;

Architecture Body

Description	Example

architecture architecture_name **of** entity **is**
type_declaration
| signal _declaration
| constant_declaration
| component_declaration
| alias_declaration
| attribute_specification
| subprogram_body
begin
{process_statement
| concurrent_signal_assignment_statement
| component_instantiation_statement
| generate_statement
end [architecture] [architecture_name];
	architecture archregister8 of register8 is
	begin
	process (rst, clk)
	begin
	if (rst = '1') **then**
	q <= (others => 0);
	elseif (clk'event **and** clk = '1') **then**
	if (en = '1') **then**
	q <= data;
	else
	q <= q;
	end if;
	end if;
	end process;
	end archregister8;
	
	architecture archfsm of fsm is
	type state)type is (st0, st1, st2);
	signal state: state_type;
	signal y, z: std_logic;
	begin
	process begin
	wait until clk' = '1';
	case state is
	when st0 =>
	state <= st1;
	y <= '1';
	when st1 =>
	state <= st2;
	z <= '1';
	when others =>
	state <= st3;
	y <= '0';
	z <= '0';
	end case;
	end process;
	end archfsm;

Declaring a Component

Description	Example

component component_name
port (
[signal] identifier {, identifier}: [mode] signal_type
{; **[signal]** identifier {, identifier}: [mode] signal_type]);
end component [component_name] ;
	component register8
	port (
	clk, rst, en: **in** std_logic ;
	data: **in** std_logic_vector(7 **downto** 0);
	q: **out** std_logic_vector(7 **downto** 0));
	end component;

Declaring a Component with Generics

Description	Example

component component_name
generic (
[signal] identifier {, identifier}: [mode] signal_type
[: =static_expression]
{; **[signal]** identifier {, identifier}: [mode] signal_type
[: =static_expression]);
port (
[signal] identifier {, identifier}: [mode] signal_type
{; **[signal]** identifier {, identifier}: [mode] signal_type);
end component [component_name];
	component register8
	generic (
	width: integer := 8);
	port (
	clk, rst, en: **in** std_logic;
	data: **in** std_logic_vector(width-1 **downto** 0);
	q: **out** std_logic_vector (width-1 **downto** 0));
	end component;

Component Instantiation (named association)

Description	Example

instantiation_label:
component_name
port map (
port_name => signal_name
| expression
| variable_name
| **open**
{, port_name => signal_name
| expression
| variable_name
| **open**});
	architecture archreg8 of reg8 is
	signal clock, reset, enable: std_logic;
	signal data-in, data-out: std_logic_vector(T **downto** 0);
	begin
	first_reg8:
	register8
	port map (
	clk => clock,
	rst => reset,
	en => enable,
	data => data_in,
	q => data_out);
	end archreg8;

Component Instantiation with Generics (named association)

Description	Example

Instantiation_label:
Component_name
generic map(
generic_name => signal_name
| expression
| variable_name
| **open**
{, generic_name => signal_name
| expression
| variable_name
| **open**})
port map (
port_name => signal_name
| expression
| variable_name
| **open**
{, port_name => signal_name
| expression
| variable_name
| **open**});
	architecture archreg5 **of** reg5 **is**
	signal clock, reset, enable: std_logic;
	signal data_in, data_out: std_logic_vector(7 **downto** 0);
	begin
	first_reg5:
	register_n
	generic map (width => 5) --no semicolon here
	port map (
	clk => clock ,
	rst => reset,
	en => enable,
	data => data-in,
	q => data_out);
	end archreg5;

Component Instantiation (positional association)

Description	Example
instantiation_label: component_name port map (signal_name | expression | variable_name | open {, signal_name | expression | variable_name | open});	**architecture** archreg8 **of** reg8 **is** **signal** clock, reset, enable: std_logic; **signal** data_in, data_out: std_logic_vector(7 **downto** 0); **begin** **first_reg8:** register8 **port map** (clock, reset, enable, data_in, data_out); **end** archreg8;

Component Instantiation with Generics (positional association)

Description	Example

instantiation_lable:
component_name
generic map (signal_name | expression
| variable_name | open
{, signal_name | expression
| variable_name | open})
port map (signal_name | expression
| variable_name | open
{, signal_name | expression
| variable_name | open});
	architecture archreg5 of reg5 is
	signal clock, reset, enable: std_logic;
	signal data_in, data_out: std_logic_vector(7 downto 0);
	begin
	first_reg5:
	register_n
	generic map (5)
	port map (clock, reset, enable, data_in, data_out);
	end archreg5;

Concurrent Statements

Boolean Equations

Description	Example
relation { and relation } | relation { or relation } | relation { xor relation } | relation { nand relation } | relation { nor relation }	v<= (a and b and c) or d; --parenthesis req'd w/ 2-level logic w <= a or b or c; x <= a xor b xor c; y <= a nand b nand c; z <= a nor b nor c;

When-else Conditional Signal Assignment

Description	Example
{expression when condition else} expression;	x<= '1' when b = c else '0'; x<= j when state = idle else k when state = first_state else l when state = second_state else m when others;

With-select-when Select Signal Assignment

Description	Example

with selection_expression select
{identifiers <= expression when
identifier | expression | discrete_range | others,}
identifier <= expression when
identifier | expression | discrete_range | others;
	architecture archfsm of fsm is
	type state_type is (st0, st1, st2, st3, st4, st5, st6, st7, st8);
	signal state: state_type;
	signal y, z: std_logic_vector(3 downto 0);
	begin
	with state select
	x<= "0000" when st0 | st1; -- st0 "or" st1
	"0010: when st2 | st3;
	z when st4;
	z when others;
	end archfsm;

Generate Scheme for Component Instantiation or Equations

Description	Example

generate_label: (for identifier in discrete_range)
| (if condition) generate
{concurrent_statement}
end generate [generate_label];
	g1: for i in 0 to 7 generate
	reg1: register8 port map (clock, reset, enable,
	data_in(i), data_out(i);
	g2: for j in 0 to 2 generate
	a(j) <= b(j) xor c(j);
	end generate g2;

Sequential Statements

Process Statement

Description	Example

[process_lable:]
process (sensitivity_list)
  type_declaration
| constant_declaration
| variable_declaration
|alias_declaration}
begin
{wait_statement
| signal_assignment_statement
| variable_assignment_statement
| if_statement
| case_statement
| loop_statement
end process [process_label];
	my_process
	process (rst, clk)
	  constant zilch : std-logic_vector(7 downto 0) :=
	"0000_0000";
	begin
	  wait until clk = '1';
	  if (rst = '1') then
	  q <= zilch;
	  elsif (en = '1') then
	  q <= data;
	  else
	  q <= q;
	  end if
	end my_process;

if-then-else Statement

Description	Example

if condition then sequence_of_statements
{elsif condition then sequence_of_statements}
[else sequence_of_statements}
end if;
	if (count = "00") then
	  a <= b;
	elsif (count = "10") then
	  a <= c;
	else
	  a <= d;
	end if;

case-when Statement

Description	Example

case expression is
{when identifier | expression | discrete_range | others =>
  sequence_of_statements}
end case;
	case count is
	  when "00" =>
	  a <= b;
	  when "10 =>
	  a <= c;
	  when others =>
	  a <= d;
	end case;

for-loop Statement

Description	Example

[loop_label:]
  for identifier in discrete_range loop
  {sequence_of_statements}
  end loop [loop_label];
	my_for_loop
	for i in 3 downto 0 loop
	  if reset(i) = '1' then
	  data_out(i) := '0';
	  end if;
	end loop my_for_loop;

while-loop Statement

Description	Example

[loop_label:]
  while condition loop
  {sequence_of_statements}
  end loop [loop_label];
	count := 16;
	my_while_loop:
	  while (count > 0) loop
	  count:= count – 1;
	  Result <= result + data_in;
	end loop my_while_loop;

Describing Synchronous Logic Using Processes

No Reset (Assume clock is of type std_logic)

Description	Example

[process_label:]
process (clock)
begin
  if clock'event and clock = '1' then --or rising_edge
  synchronous_signal_assignment_statement;
  end if;
end process [process_label];
----------or----------
	reg8_no_reset:
	process (clk)
	begin
	  if clk'event and clk = '1' then
	  q <= data;
	  end if;
	end process reg8_no_reset;
	----------or----------

[process_label:]
process
begin
  wait until clock = '1';
  synchronous_signal_assignment_statement;
end process [process_label];
	reg8_no-reest:
	process
	begin
	  wait until clock = '1';
	  q <= data;
	end process reg8_no_reset;

Synchronous Reset

Description	Example

[process_label:]
process (clock)
begin
  if clock'event and clock = '1' then
  if synch_reset_signal = '1' then
  synchronous_signal_assignment_statement;
  else
  synchronous_signal_assignment_statement;
  end if;
  end if;
end process [process_label];
	reg8_sync_reset:
	process (clk)
	begin
	  if clk'event and clk = '1' then
	  if sync_reset = '1' then
	  q <= "0000_0000";
	  else
	  q <= data;
	  end if;
	  end if;
	end process;

Asynchronous Reset or Preset

Description	Example

[process_label:]
process (reset, clock)
begin
  if reset = '1' then
  asynchronous_signal_assignment_statement;
  elsif clock'event and clock = '1' then
  synchronous_signal_assignment_statement;
  end if;
end process [process_label];
	reg8_async_reset:
	process (asyn_reset, clk)
	begin
	  if async_reset = '1' then
	  q <= (others => '0');
	  elsif clk'event and clk = '1' then
	  q <= data;
	  end if;
	  end process reg8_async_reset;

Asynchronous Reset and Preset

Description	Example

[process_label:]
process (reset, preset, clock)
begin
  if reset = '1' then
  asynchronous_signal_assignment_statement;
  elsif preset = '1' then
  asynchronous_signal_assignment_statement;
  elsif clock'event and clock = '1' then
  synchronous_signal_assignment_statement;
  end if;
end process [process_label];
	reg8_async:
	process (asyn_reset, async_preset, clk)
	begin
	  if async_reset = '1' then
	  q <= (others => '0');
	  elsif async_preset = '1' then
	  q <= (others => '1');
	  elsif clk'event and clk = '1' then
	  q <= data;
	  end if;
	end process reg8_async;

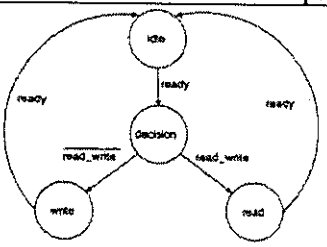
Conditional Synchronous Assignment (enables)

Description	Example

[process_label:]
process (reset, clock)
begin
  if reset = '1' then
  asynchronous_signal_assignment_statement;
  elsif clocl'event and clock = '1' then
  if enable = '1' then
  synchronous_signal_assignment_statement;
  else
  synchronous_signal_assignment_statement;
  end if;
  end if;
end process [process_label];
	reg8_sync_assign:
	process (rst, clk)
	begin
	  if rst = '1' then
	  q <= (others => '0');
	  elsif clk'event and clk = '1' then
	  if enable = '1' then
	  q <= data;
	  else
	  q <= q;
	  end if;
	  end if;
	end process reg8_sync_assign;

Translating a State Flow Diagram to a Two-Process FSM Description

Description



state	outputs oe	we
idle	0	0
decision	0	0
write	0	1
read	1	0

Example

```
architecture state_machine of example is
  type StateType is (idle, decision, read, write);
  signal present_state, next_state : StateType;
begin
state_comb:process(present_state, read_write, ready) begin
 case present_state is
  when idle =>       oe <= '0' ;  we <= '0';
    if ready = '1' then
      next_state <= decision;
    else
      next_state <= idle;
    end if;
  when decision =>   oe <= '0' ;  we <= '0';
    if (read_write = '1') then
       next_state <= read;
    else              -- read_write='0'
       next_state <=write;
    end if;
  when read =>           oe <= '1' ;  we <='0';
    if (read = '1') then
       next_state <= idle;
    else
       next_state <= read;
    end if;
  when write =>          oe <= '0' ;  we <= '1';
    if (ready = '1') then
       next_state <= idle;
    else
       next_state <= write;
    end if;
  end case;
end process state_comb;

state_clocked:process(clk) begin
  if (clk'event and clk = '1') then
     present_state <= next_state;
  end if;
end process state_clocked;
end state_machine;
```

Data Objects

Signals

Description

- Signals are the most commonly used data object in synthesis designs.
- Nearly all basic designs, and many large designs as well, can be fully described using signals as the only kind of data object.
- Signals have projected output waveforms.
- Signal assignments are scheduled, not immediate; they update projected output waveforms.

Example

```
architecture archinternal_counter of internal_counter is
  signal count, data:std_logic_vector(7 downto 0);
begin
process(clk)
 begin
   if (clk'event and clk = '1') then
    if en = '1' then
      count <= data;
    else
      count <= count + 1;
    end if;
  end if;
end process;
end archinternal_counter;
```

Constants

Description

Constants are used to hold a static value; they are typically used to improve the readability and maintenance of code.

Example

```
my_process:
process (rst, clk)
   constant zilch : std_logic_vector(7 downto 0) := "0000_0000";
begin
 wait until clk = '1';
   if (rst = '1') then
    q <= zilch;
   elsif (en = '1') then
    q <= data;
   else
     q <= q;
   end if;
end my_process;
```

bit and bit_vector

Description	Example

• Bit values are: '0' and '1'.
• Bit_vector is an array of bits.
• Pre-defined by the IEEE 1076 standard.
• This type was used extensively prior to the introduction and synthesis-tool vendor support of std_logic_1164.
• Useful when metalogic values not required.
	signal x: bit;
	. . .
	if x = '1' then
	state <= idle;
	else
	state <= start;
	end if;

Boolean

Description	Example

• Values are TRUE and FALSE.
• Often used as return value of function
	signal a: boolean;
	. . .
	if x = '1' then
	state <= idle;
	else
	state <= start;
	end if;

Integer

Description	Example

• Values are the set of integers.
• Data objects of this type are often used for defining widths of signals or as an operand in an addition or subtraction.
• The types std_logic_vector and bit_vector work better than integer for components such as counters because the use of integers may cause "out of range" run-time simulation errors when the counter reaches its maximum value.
	entity counter_n is
	generic (
	width: integer := 8);
	port (
	clk, rst, in std_logic;
	count: out std_logic_vector(width-1 downto 0));
	end counter_n;
	. . .
	process(clk)
	begin
	if (rst = '1') then
	count <= 0;
	elsif (clk'event and clk = '1') then
	count <= count +1;
	end if;
	end process;

Enumeration Types

Description	Example

• Values are user-defined
• Commonly used to define states for a state machine.
	architecture archfsm of fsm is
	type state_type is (st0, st1, st2);
	signal state: state_type;
	signal y, z: std_logic;
	begin
	process
	begin
	wait until clk'event = '1';
	case state is
	when st0 =>
	state <= st2;
	y <= '1'; z <= '0';
	when st1 =>
	state <= st3;
	y <= '1'; z <= '1';
	when others =>
	state <= st0;
	y <= '0'; z <= '0';
	end case;
	end process;
	end archfsm;

Variables

Description	Example

• Variables can be used in processes and subprograms -- that is, in sequential areas only.
• The scope of a variable is the process or subprogram
• A variable in a subprogram does not retain its value between calls.
• Variables are most commonly used as the indices of loops or for the calculation of intermediate values, or immediate assignment.
• To use the value of a variable outside of the process or subprogram in which it was declared the value of the variable must be assigned to a signal
• Variable assignment is immediate, not scheduled
	architecture archloopstuff of loopstuff is
	signal data: std_logic_vector(3 downto 0);
	signal result: std_logic;
	begin
	process (data)
	variable tmp: std_logic;
	begin
	tmp := '1';
	for i in a'range downto 0 loop
	tmp := tmp and data(i);
	end loop;
	result <= tmp;
	end process;
	end archloopstuff;

Data Types and Subtypes

std_logic

Description	Example
• Values are: 'U', -- Uninitialized 'X', -- Forcing unknown '0', -- Forcing 0 '1', -- Forcing 1 'Z', -- High impedance 'W', -- Weak unknown 'L', -- Weak 0 'H', -- Weak 1 '-', -- Don't care • The standard multivalue logic system for VHDL model inter-operability. • A resolved type (i.e., a resolution function is used to determine the value of a signal with more than one driver). • To use must include the following two lines: library ieee; use ieee.std_logic_1164.all;	Signal x, data, enable: std_logic; . . . x <= data when enable = '1' else 'Z';

std_ulogic

Description	Example
• Values are: 'U', -- Uninitialized 'X', -- Forcing unknown '0', -- Forcing 0 '1', -- Forcing 1 'Z', -- High impedance 'W', -- Weak unknown 'L', -- Weak 0 'H', -- Weak 1 '-', -- Don't care • An unresolved type (i.e., a signal of this type may have only one driver). • Along with its subtypes, std_ulogic should be used over user-defined ability of VHDL models among synthesis and simulation tools. • To use must include the following two lines: library ieee; use ieee.std_logic_1164.all;	Signal x, data, enable: std_ulogic; . . . x <= data when enable = '1' else 'Z';

std_logic_vector and std_ulogic_vector

Description	Example

• Are arrays of types std_logic and std_ulogic.
• Along with its subtypes, std_logic_vector should be used over user-defined types to ensure interoperability of VHDL models among synthesis and simulation tools.
• To use must include the following two lines:
library ieee;
use ieee.std_logic_1164.all;
	signal mux: std_logic_vector (7 downto 0)
	. . .
	if state = address or state = ras then
	mux <= dram_a;
	else
	mux <= (others => 'Z');
	end if;

In, Out, buffer, inout

Description	Example

• In: Used for signals (ports) that are inputs-only to an entity.
• Out: Used for signals that are outputs – only and for which the values are not required internal to the entity.
• Buffer: Used for signals that are outputs but for which the values are required internal to the given entity. Caveat with usage: If the local port of the instantiated component is of mode buffer, then if the actual is also a port it must of mode buffer as well. For this reason some designers standardize on mode buffer.
• Inout: Used for signals tha are truly bidirectional. May also be used for signals for that are input-only or output-only, at the expense of code readability.
	Entity counter_4 is
	port (
	clk, rst, ld: in std_logic;
	term_cnt: buffer std_logic;
	count: inout std_logic_vector (3 down to 0));
	end counter_4;
	architecture archcounter_4 of counter_4 is
	signal int_rst: std_logic;
	signal int_count: std_logic_vector(3 downto 0));
	begin
	process(int_rst, clk)
	begin
	if(int_rst = '1') then
	int_count <= "0000";
	elseif (clk'event and clk='1') then
	if(ld = '1') then
	int_count <=count;
	else
	int_count <=int_count + 1;
	end if;
	end if;
	end process;
	term_cnt <= count(2) and count(0);
	--term_cnt is 3
	int_rst <=term_cnt or rst;
	-- resets at term_cnt
	count <=int_count when ld='0' else "ZZZZ";
	--count is bidirectional
	end architecture_4;

Operators

All operators of the same class have the same level of precedence. The classes of operators are listed here in the order of decreasing precedence. Many of the operators are overloaded in the std_logic_1164, numeric_bit, and numeric_std packages.
Miscellaneous Operators...page 164

Description	Example
• Operators: **, abs, not • The not operator is used frequently, the other two are rarely used for designs to be synthesized. • Predefined for any integer type (**), any numeric type (abs), and either bit and Boolean (not).	signal a, b, c:bit; ... a <= not (b and c);

Multiplying Operators

Description	Example
• Operators: *, /, mod, rem. • The * operator is occassionaly used for multipliers; the other three are rarely used in synthesis. • Predefined for any integer type (*, /, mod, rem), and any floating point type (*,/).	variable a, b:integer range 0 to 255; ... a <= b * 2;

Sign

Description	Example
• Operators: +,-. • Rarely used for synthesis. • Predefined for any numeric type (floating – point or integer).	variable a, b, c: integer range 0 to 255; . . . a <= - (b+2);

Adding Operators

Description	Example
• Operators: +,- • Used frequently to describe incrementers, decrementers, adders and subtractors. • Predefined for any numeric type.	signal count: integer range 0 to 255; . . . count <= count+1;

Shift Operators

Description	Example

• Operators: sll, srl, sla, sra, rol, ror.
• Used occasionally.
• Predefined for any one-dimensional array with elements of type bit or Boolean. Overloaded for std_logic arrays.
	signal a, b: bit_vector(4 downto 0);
	signal c: integer range 0 to 4;
	. . .
	a<=b sll c;

Relational Operators

Description	Example

• Operators: =, /=, <, <=, >, >=.
• Used frequently for comparisons.
• Predefined for any type (both operands must be of same type)
	signal a, b: integer range 0 to 255;
	signal agtb: std_logic;
	. . .
	if a >=b then
	agtb <= '1';
	else
	agtb <='0';

Logical Operators

Description	Example
• Operators: and, or, nand, nor, xor, xnor. • Used frequently to generate Boolean equations. • Predefined for types bit and Boolean. Std_logic_1164 overloads these operators for std_ulogic and its subtypes.	signal a, b, c:std_logic; . . . a<=b and c;