

UNIVERSIDAD NACIONAL DE CÓRDOBA

FACULTAD DE MATEMÁTICA ASTRONOMÍA, FÍSICA Y
COMPUTACIÓN.

ARQUITECTURA DE COMPUTADORAS

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T2: HARDWARE DESCRIPTION LANGUAGES (A8 Parametrized Modules – N-bit Multiplexers)

Example A.40 Parameterized N-bit Multiplexers

SystemVerilog

```
module mux2
    #(parameter width = 8)
    (input  logic [width-1:0] d0, d1,
     input  logic             s,
     output logic [width-1:0] y);

    assign y = s ? d1 : d0;
endmodule
```

T2: HARDWARE DESCRIPTION LANGUAGES (A8 Parametrized Modules – N-bit Multiplexers)

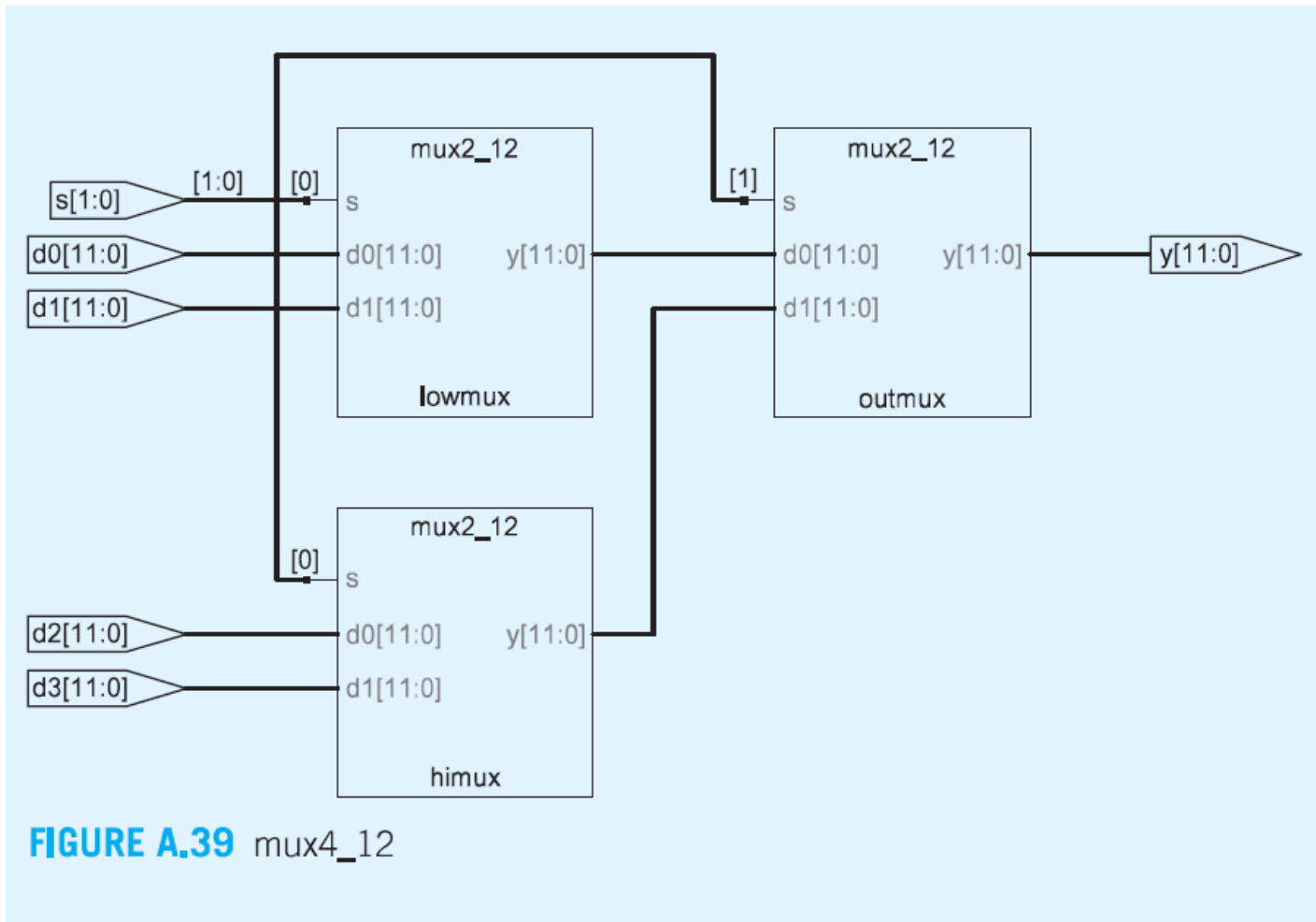
SystemVerilog (continued)

```
module mux4_8(input  logic [7:0] d0, d1, d2, d3,  
              input  logic [1:0] s,  
              output logic [7:0] y);  
  
    logic [7:0] low, hi;  
  
    mux2 lowmux(d0, d1, s[0], low);  
    mux2 himux(d2, d3, s[0], hi);  
    mux2 outmux(low, hi, s[1], y);  
endmodule
```

T2: HARDWARE DESCRIPTION LANGUAGES (A8 Parametrized Modules – N-bit Multiplexers)

```
module mux4_12(input logic [11:0] d0, d1, d2, d3,  
               input logic [1:0] s,  
               output logic [11:0] y);  
  
    logic [11:0] low, hi;  
  
    mux2 #(12) lowmux(d0, d1, s[0], low);  
    mux2 #(12) himux(d2, d3, s[0], hi);  
    mux2 #(12) outmux(low, hi, s[1], y);  
endmodule
```

T2: HARDWARE DESCRIPTION LANGUAGES (A8 Parametrized Modules – N-bit Multiplexers)



T2: HARDWARE DESCRIPTION LANGUAGES (A8 Parametrized Modules – N-bit Decoder)

Example A.41 Parameterized $N:2^N$ Decoder

SystemVerilog

```
module decoder #(parameter N = 3)
    (input  logic [N-1:0]    a,
     output logic [2**N-1:0] y);

    always_comb
    begin
        y = 0;
        y[a] = 1;
    end
endmodule
```

$2^{**}N$ indicates 2^N .

T2: HARDWARE DESCRIPTION LANGUAGES (A8 Parametrized Modules – N-bit AND remember Reductor Operators)

Example A.42 Parameterized *N*-input AND Gate

SystemVerilog

```
module andN
  #(parameter width = 8)
  (input  logic [width-1:0] a,
   output logic             y);

  genvar i;
  logic [width-1:1] x;

  generate
    for (i=1; i<width; i=i+1) begin:forloop
      if (i == 1)
        assign x[i] = a[0] & a[1];
      else
        assign x[i] = a[i] & x[i-1];
      end
    endgenerate
    assign y = x[width-1];
endmodule
```

T2: HARDWARE DESCRIPTION LANGUAGES (A8 Parametrized Modules N-bit AND remember Reductor Operators)

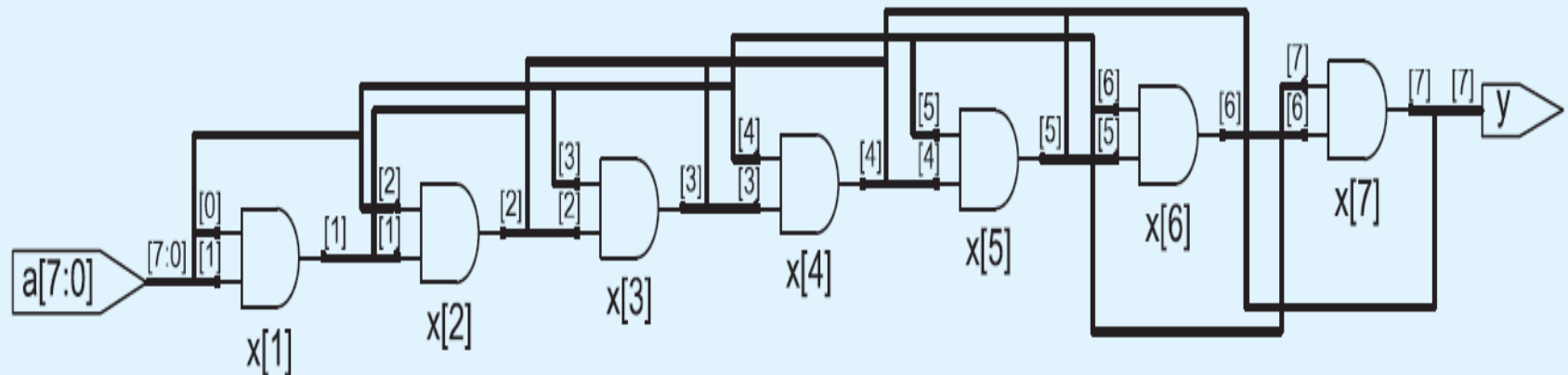


FIGURE A.40 andN

T2: HARDWARE DESCRIPTION LANGUAGES (A9 Memories – RAM With Separate Din and Dout)

Example A.43 RAM

SystemVerilog

```
module ram #(parameter N = 6, M = 32)
    (input  logic      clk,
     input  logic      we,
     input  logic [N-1:0] adr,
     input  logic [M-1:0] din,
     output logic [M-1:0] dout);

    logic [M-1:0] mem[2*N-1:0];

    always @(posedge clk)
        if (we) mem[adr] <= din;

    assign dout = mem[adr];
endmodule
```

T2: HARDWARE DESCRIPTION LANGUAGES (A9 Memories – RAM With Separate Din and Dout)

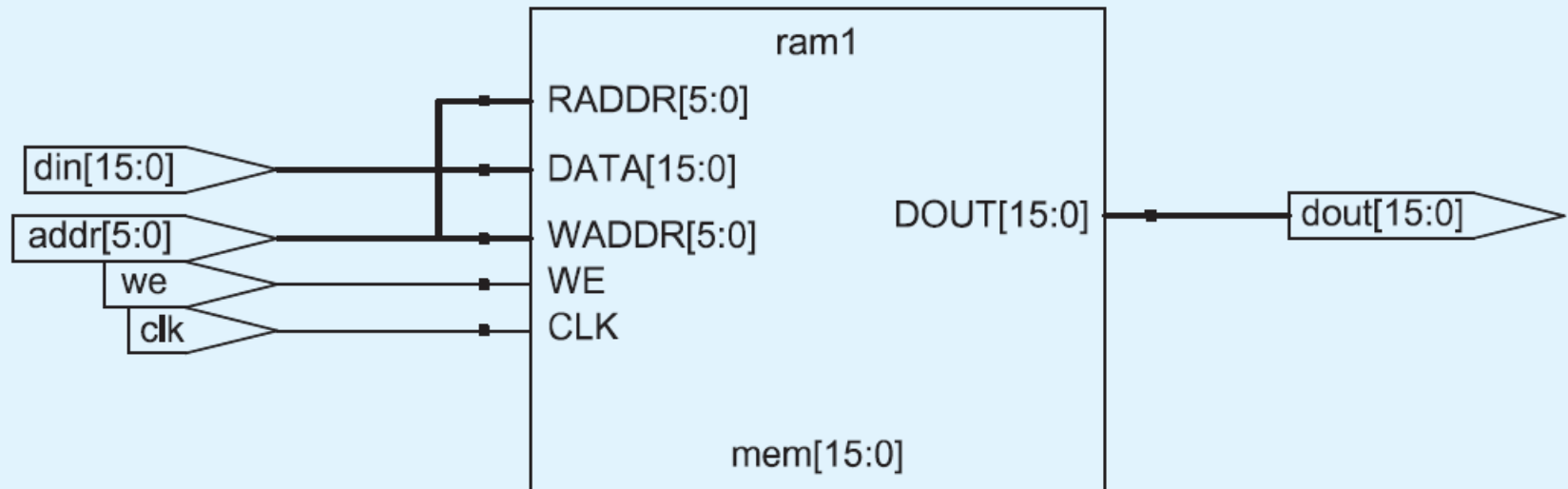


FIGURE A.41 Synthesized ram

T2: HARDWARE DESCRIPTION LANGUAGES (A9 Memories RAM With Bidirectional Data Bus)

Example A.44 RAM with Bidirectional Data Bus

SystemVerilog

```
module ram #(parameter N = 6, M = 32)
    (input  logic      clk,
     input  logic      we,
     input  logic [N-1:0] adr,
     inout  tri  [M-1:0] data);

    logic [M-1:0] mem[2**N-1:0];

    always @(posedge clk)
        if (we) mem[adr] <= data;

    assign data = we ? 'z : mem[adr];
endmodule
```

T2: HARDWARE DESCRIPTION LANGUAGES (A9 Memories RAM With Bidirectional Data Bus)

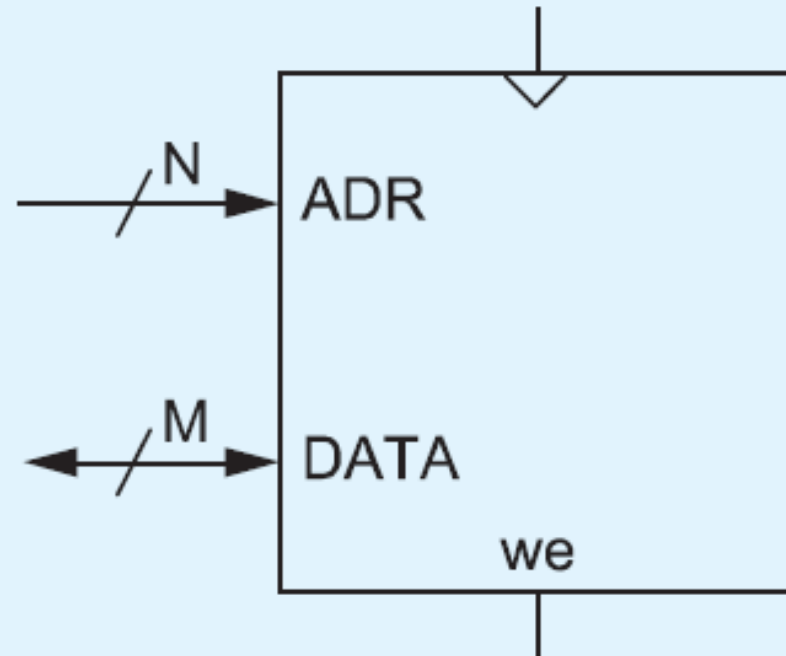


FIGURE A.42 Synthesized ram
with bidirectional data bus

T2: HARDWARE DESCRIPTION LANGUAGES (A9 Memories – Three Ported Registers Files)

Example A.45 Three-Ported Register File

SystemVerilog

```
module ram3port #(parameter N = 6, M = 32)
    (input  logic      clk,
     input  logic      we3,
     input  logic [N-1:0] a1, a2, a3,
     output logic [M-1:0] d1, d2,
     input  logic [M-1:0] d3);

    logic [M-1:0] mem[2**N-1:0];

    always @(posedge clk)
        if (we3) mem[a3] <= d3;

    assign d1 = mem[a1];
    assign d2 = mem[a2];
endmodule
```

T2: HARDWARE DESCRIPTION LANGUAGES (A9 Memories – Three Ported RegistersFiles)

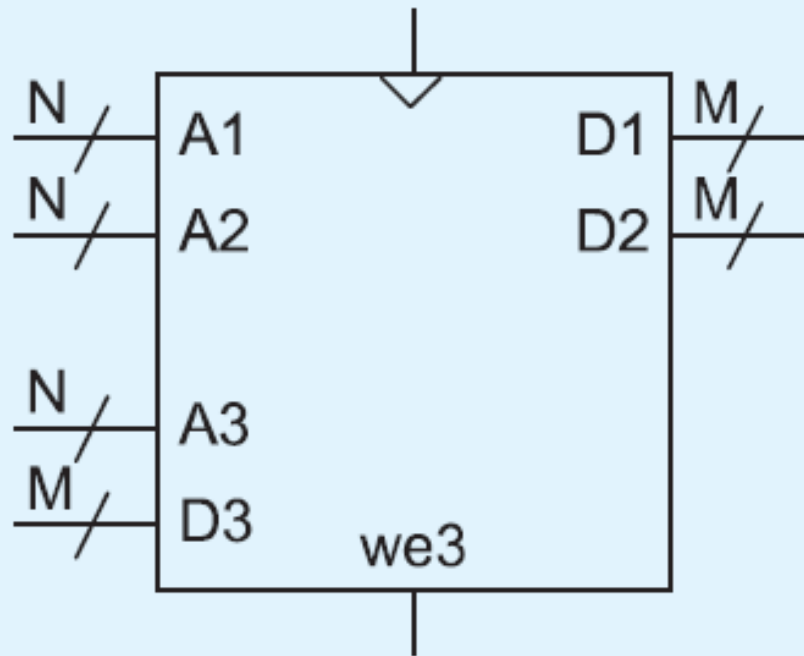


FIGURE A.43

Three-ported register file

T2: HARDWARE DESCRIPTION LANGUAGES (A9 Memories – ROMs)

Example A.46 ROM

SystemVerilog

```
module rom(input  logic [1:0] adr,
           output logic [2:0] dout);

    always_comb
        case(adr)
            2'b00: dout = 3'b011;
            2'b01: dout = 3'b110;
            2'b10: dout = 3'b100;
            2'b11: dout = 3'b010;
        endcase
endmodule
```

T2: HARDWARE DESCRIPTION LANGUAGES (A10 Test Benches –Basic Tests)

Example A.47 Testbench

SystemVerilog

```
module testbench1();
    logic a, b, c;
    logic y;

    // instantiate device under test
    sillyfunction dut(a, b, c, y);

    // apply inputs one at a time

    initial begin
        a = 0; b = 0; c = 0; #10;
        c = 1; #10;
        b = 1; c = 0; #10;
        c = 1; #10;
        a = 1; b = 0; c = 0; #10;
        c = 1; #10;
        b = 1; c = 0; #10;
        c = 1; #10;
    end
endmodule
```


T2: HARDWARE DESCRIPTION LANGUAGES (A10 Test Benches – Self Ch)

Example A.48 Self-Checking Testbench

SystemVerilog

```
module testbench2();
    logic a, b, c;
    logic y;

    // instantiate device under test
    sillyfunction dut(a, b, c, y);

    // apply inputs one at a time
    // checking results

    initial begin
        a = 0; b = 0; c = 0; #10;
        assert (y === 1) else $error("000 failed.");
        c = 1; #10;
        assert (y === 0) else $error("001 failed.");
        b = 1; c = 0; #10;
        assert (y === 0) else $error("010 failed.");
        c = 1; #10;
        assert (y === 0) else $error("011 failed.");
        a = 1; b = 0; c = 0; #10;
        assert (y === 1) else $error("100 failed.");
        c = 1; #10;
        assert (y === 1) else $error("101 failed.");
        b = 1; c = 0; #10;
        assert (y === 0) else $error("110 failed.");
```

T2: HARDWARE DESCRIPTION LANGUAGES (A10 Test Benches – Self Checking)

```
    assert (y === 0) else $error("010 failed.");  
    c = 1;                                #10;  
    assert (y === 0) else $error("011 failed.");  
    a = 1; b = 0; c = 0; #10;  
    assert (y === 1) else $error("100 failed.");  
    c = 1;                                #10;  
    assert (y === 1) else $error("101 failed.");  
    b = 1; c = 0;                          #10;  
    assert (y === 0) else $error("110 failed.");  
    c = 1;                                #10;  
    assert (y === 0) else $error("111 failed.");  
end  
endmodule
```

T2: HARDWARE DESCRIPTION LANGUAGES (A10 Test Benches)

Example A.49 Testbench with Test Vector File

SystemVerilog

```
module testbench3();
    logic          clk, reset;
    logic          a, b, c, yexpected;
    logic          y;
    logic [31:0]    vectornum, errors;
    logic [3:0]     testvectors[10000:0];

    // instantiate device under test
    sillyfunction dut(a, b, c, y);

    // generate clock
    always
    begin
        clk = 1; #5; clk = 0; #5;
    end

    // at start of test, load vectors
    // and pulse reset
```

T2: HARDWARE DESCRIPTION LANGUAGES (A10 Test Benches – Automatic File Based)

```
// at start of test, load vectors
// and pulse reset
initial
    begin
        $readmemb("example.tv", testvectors);
        vectornum = 0; errors = 0;
        reset = 1; #27; reset = 0;
    end

// apply test vectors on rising edge of clk
always @(posedge clk)
    begin
        #1; {a, b, c, yexpected} =
            testvectors[vectornum];
    end
end
```

T2: HARDWARE DESCRIPTION LANGUAGES (A10 Test Benches – Automatic File Based)

SystemVerilog (continued)

```
// check results on falling edge of clk
always @(negedge clk)
  if (~reset) begin // skip during reset
    if (y !== yexpected) begin
      $display("Error: inputs = %b", {a, b, c});
      $display("  outputs = %b (%b expected)",
        y, yexpected);
      errors = errors + 1;
    end
    vectornum = vectornum + 1;
    if (testvectors[vectornum] === 'bx) begin
      $display("%d tests completed with %d
        errors", vectornum, errors);
      $finish;
    end
  end
end
endmodule
```