FSM Example (2A)

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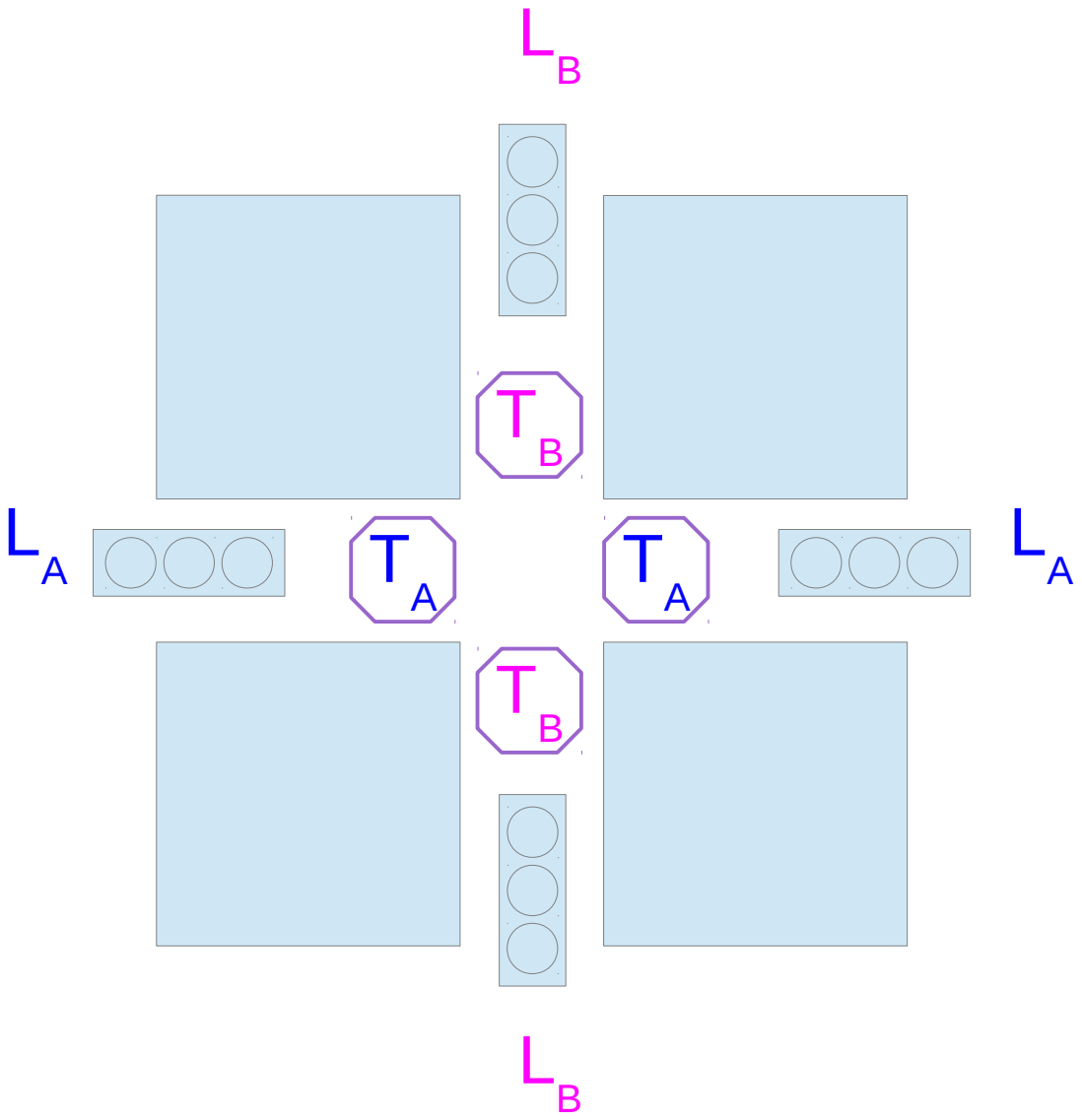
FSM Inputs and Outputs



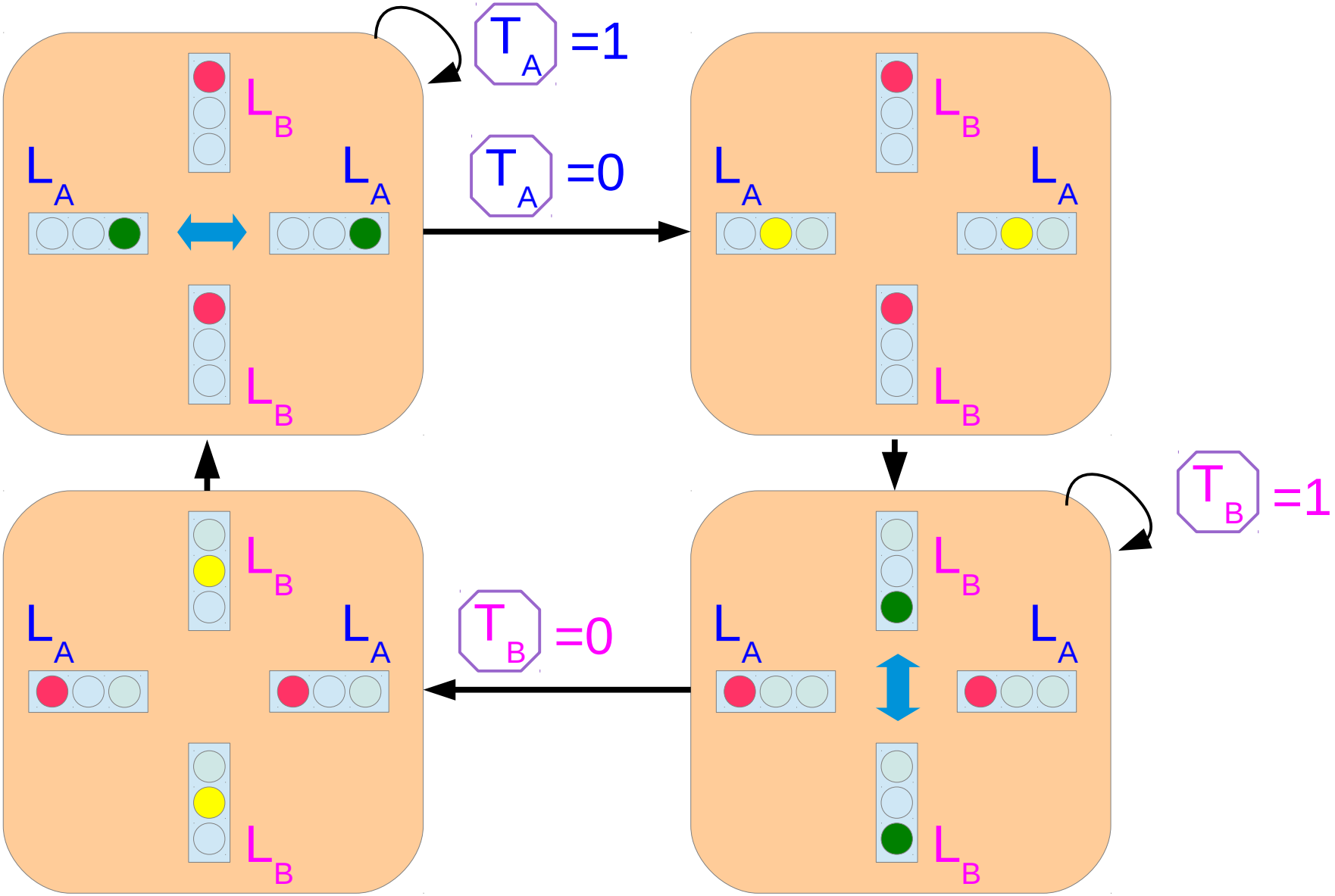
Traffic Lights - Outputs

L_A L_B

Sensor - Inputs

T_A T_B

States



Moore FSM State Transition Table

S_1	S_0	T_A	T_B	S'_1	S'_0
0	0	0	X	0	1
0	0	1	X	0	0
0	1	X	X	1	0
1	0	X	0	1	1
1	0	X	1	1	0
1	1	X	X	0	0

	S_1	S_0	T_A	T_B	S'_1
	0	0	0	X	0
	0	0	1	X	0
$\overline{S_1}S_0$ ⇨	0	1	X	X	1
$S_1\overline{S_0}\,\overline{T_B}$ ⇨	1	0	X	0	1
$S_1\overline{S_0}T_B$ ⇨	1	0	X	1	1
	1	1	X	X	0

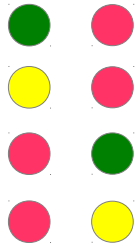
$$S'_1 = \overline{S_1}S_0 + S_1\overline{S_0} = S_1 \oplus S_0$$

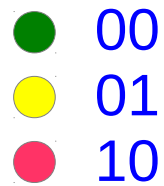
	S_1	S_0	T_A	T_B	S'_0
$\overline{S_1}\,\overline{S_0}\,\overline{T_A}$ ⇨	0	0	0	X	1
	0	0	1	X	0
	0	1	X	X	0
$S_1\overline{S_0}\,\overline{T_B}$ ⇨	1	0	X	0	1
	1	0	X	1	0
	1	1	X	X	0

$$S'_0 = \overline{S_1}\,\overline{S_0}\,\overline{T_A} + S_1\overline{S_0}\,\overline{T_B}$$

States

S_1	S_2	L_{A1}	L_{A0}	L_{B1}	L_{B0}
0	0	0	0	1	0
0	1	0	1	1	0
1	0	1	0	0	0
1	1	1	0	0	1





S_1	S_2	L_{A1}
0	0	0
0	1	0
1	0	1
1	1	1

$$L_{A1} = S_1$$

S_1	S_2	L_{A0}
0	0	0
0	1	1
1	0	0
1	1	0

$$L_{A0} = \overline{S_1} S_0$$

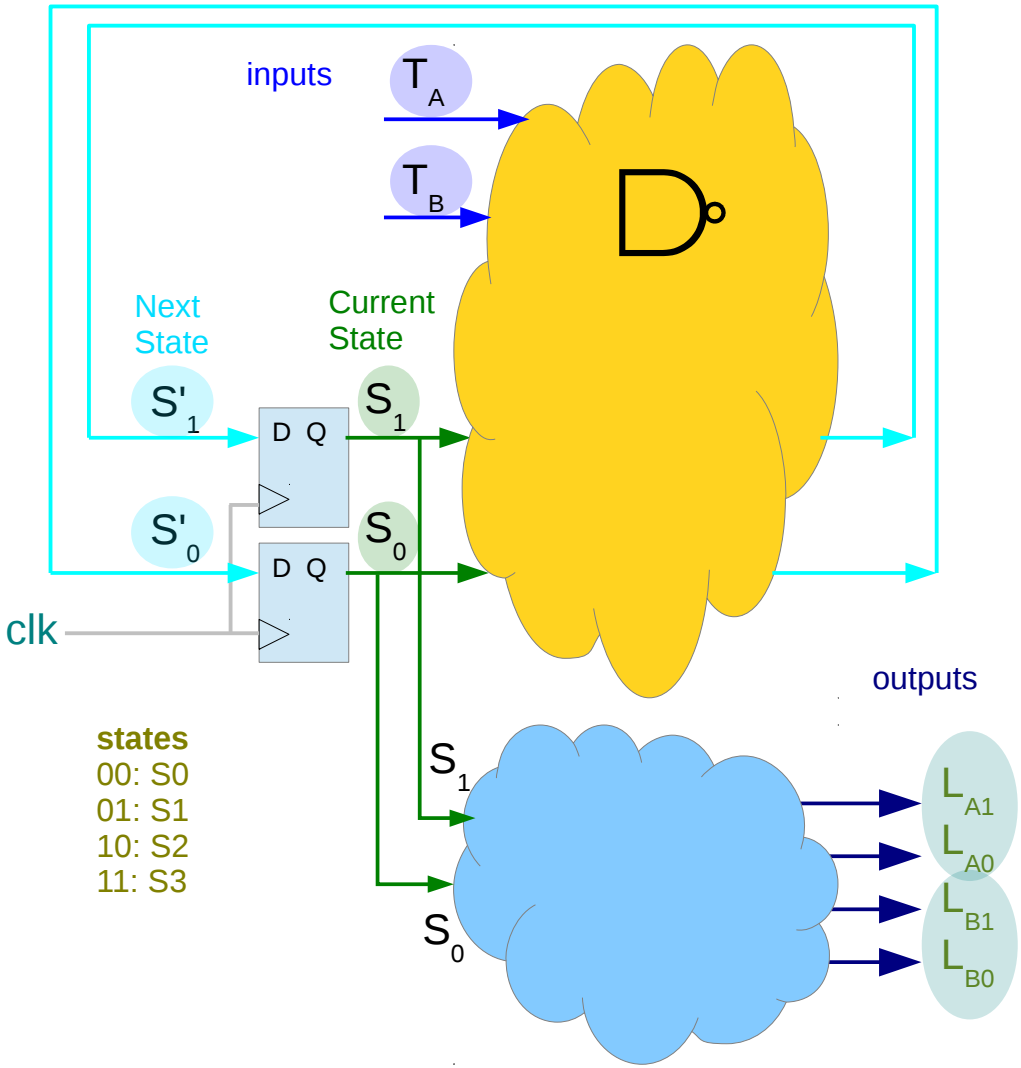
S_1	S_2	L_{B1}
0	0	1
0	1	1
1	0	0
1	1	0

$$L_{B1} = \overline{S_1}$$

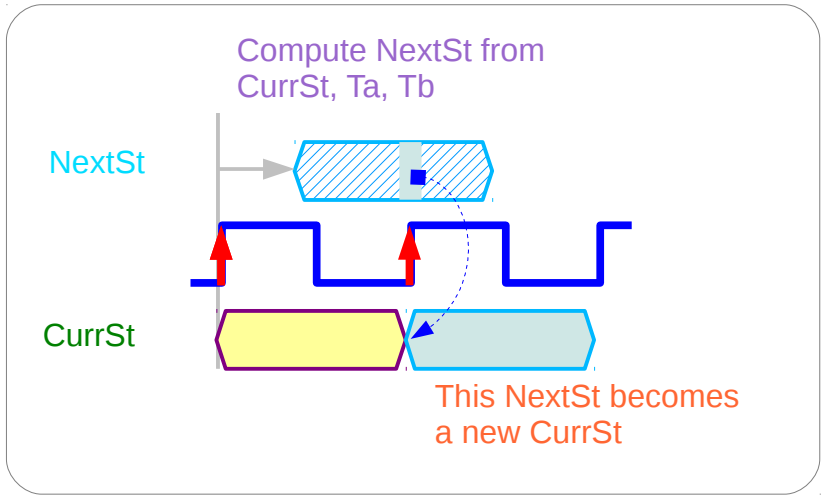
S_1	S_2	L_{B0}
0	0	0
0	1	0
1	0	0
1	1	1

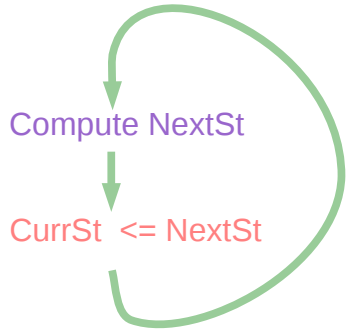
$$L_{A0} = S_1 S_0$$

Moore FSM (1)



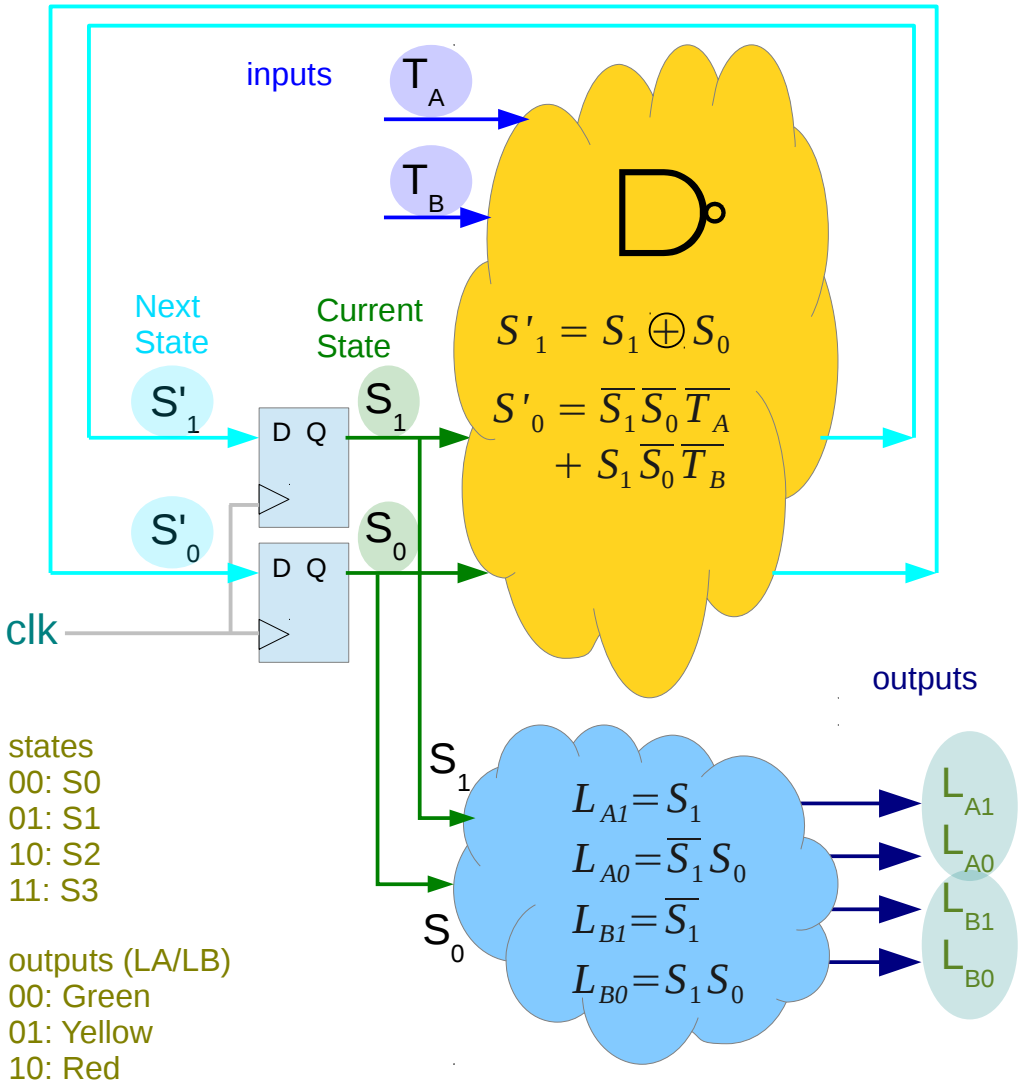
states
00: S0
01: S1
10: S2
11: S3





outputs (LA/LB)
00: Green
01: Yellow
10: Red
11: X

Moore FSM



Inputs T_A T_B

Current State S_1 S_0

Next States

$S'_1 = S_1 \oplus S_0$

$S'_0 = \overline{S_1}\,\overline{S_0}\,\overline{T_A} + S_1\,\overline{S_0}\,\overline{T_B}$

Current State S_1 S_0

Outputs

$L_{A1} = S_1$ $L_{B1} = \overline{S_1}$

$L_{A0} = \overline{S_1}\,S_0$ $L_{B0} = S_1 S_0$

Verilog Gate Level Design - testbench

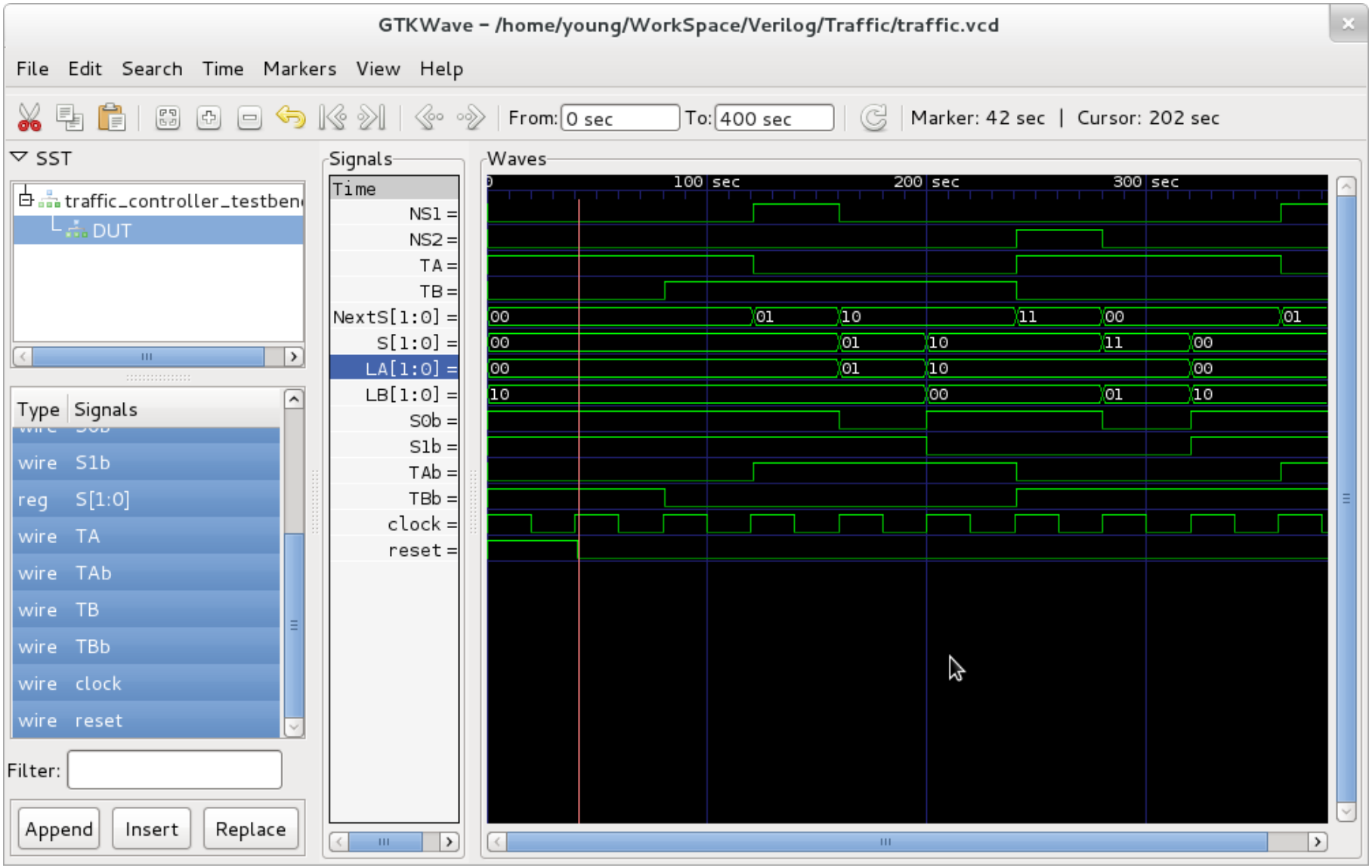
```
`timescale 1ns/100ps

module traffic_controller_testbench;

  parameter cycle = 40;

  reg clock;

  always
    begin
      #(cycle/2) clock=~clock;
    end


  traffic_controller DUT (.clock(clock),
                          .reset(reset),
                          .TA(TA),
                          .TB(TB),
                          .LA(LA),
                          .LB(LB) );

  reg       reset;
  reg       TA, TB;
  wire [1:0] LA, LB;
```

```
  initial
    begin
      clock = 1;
      reset = 1;
      TA = 1;
      TB = 0;

       #1;
      #(cycle)     reset = 0;
      #(cycle)     TB = 1;
      #(cycle)     TA = 0;
      #(cycle*3)   TA = 1;
                   TB = 0;
      #(cycle*3)   TA = 0;
    end

  initial
    begin
      $dumpfile("traffic.vcd");
      $dumpvars(0, DUT);
      #(cycle * 10);
      $finish;
    end

endmodule
```

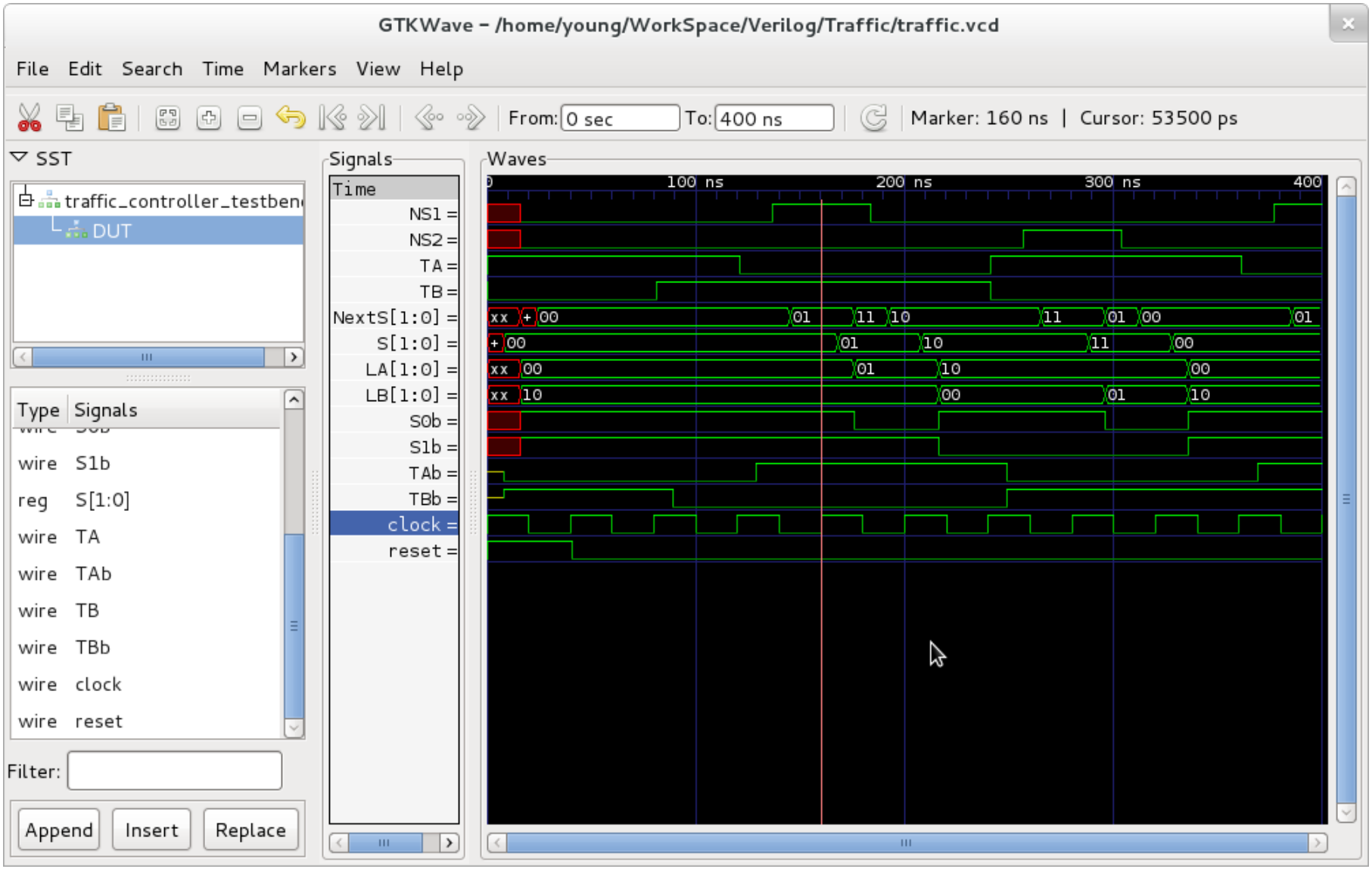
Verilog Gate Level Design – traffic_gate.v

```
module traffic_controller(clock, reset, TA, TB, LA, LB);
  input clock, reset;
  input TA, TB;
  output [1:0] LA, LB;

  reg    [1:0] S;
  wire   [1:0] NextS;

  always @(posedge clock)
    begin: SEQ
      if (reset)
        #8 S = 2'b00;
      else
        #8 S = NextS;
    end

    not #8 (S1b, S[1]);
    not #8 (S0b, S[0]);
    not #8 (TAb, TA);
    not #8 (TBb, TB);

    xor #8 (NextS[1], S[1], S[0]);
    or  #8 (NextS[0], NS1, NS2);
    and #8 (NS1, S1b,  S0b, TAb);
    and #8 (NS2, S[1], S0b, TBb);


    buf #8 (LA[1], S[1]);
    and #8 (LA[0], S1b, S[0]);
    not #8 (LB[1], S[1]);
    and #8 (LB[0], S[1], S[0]);

endmodule
```

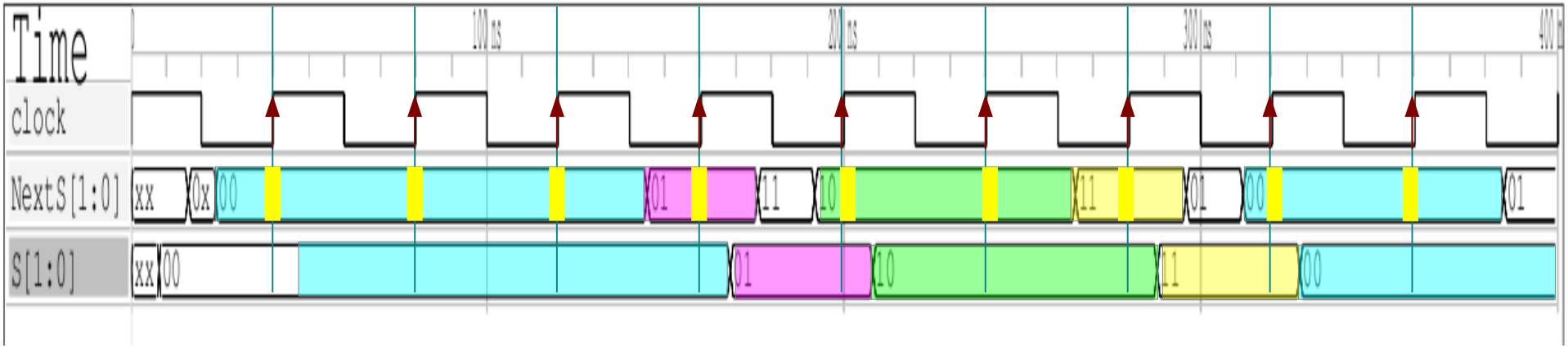
VCD Output with zero delay



VCD Output with gate delays

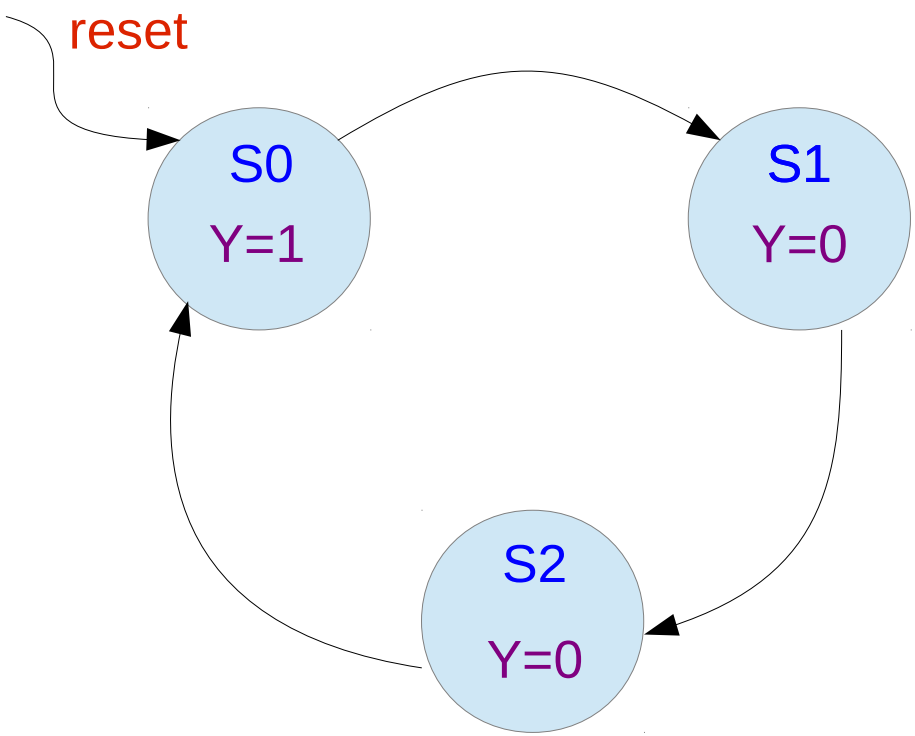


VCD Output with gate delays



Output Delay

Divide By N Counter FSM



Input: none

Output: Y=1 every 3 cycles

State Transition Table

Curr St	Next St
S0	S1
S1	S2
S2	S0

Output Table

Curr St	Output
S0	1
S1	0
S2	0

Encoding States

State Transition Table

Curr St	Next St
S0	S1
S1	S2
S2	S0

Output Table

Curr St	Output
S0	1
S1	0
S2	0

S_1	S_0	S'_1	S'_0
0	0	0	1
0	1	1	0
1	0	0	0

S_1	S_0	Y
0	0	1
0	1	0
1	0	0

$$S'_1 = \overline{S_1} S_0$$

$$S'_0 = \overline{S_1}\,\overline{S_0}$$

$$Y = \overline{S_1}\,\overline{S_0}$$

State Transition Table

Curr St	Next St
S0	S1
S1	S2
S2	S0

Output Table

Curr St	Output
S0	1
S1	0
S2	0

S_2	S_1	S_0	S'_2	S'_1	S'_0
0	0	1	0	1	0
0	1	0	1	0	0
1	0	0	0	0	1

S_2	S_1	S_0	Y
0	0	1	1
0	1	0	0
1	0	0	0

$$S'_2 = \overline{S_2} S_1 \overline{S_0} \quad \Rightarrow S_1$$

$$S'_1 = \overline{S_2}\,\overline{S_1} S_0 \quad \Rightarrow S_0$$

$$S'_0 = S_2 \overline{S_1}\,\overline{S_0} \quad \Rightarrow S_2$$

$$Y = \overline{S_2}\,\overline{S_1} S_0 \quad \Rightarrow S_0$$

References

[1] http://en.wikipedia.org/
[2] D.M. Harris, S. L. Harris, “Digital Design and Computer Architecture”