Department of Electronic and Telecommunication Engineering

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EN4603 - Digital IC Design

Laboratory Experiment 1
RTL Synthesis

Laboratory Report

Submitted by

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Note:
All the materials related to the report can also be found at https://github.com/bimalka98/Digital-IC-Design

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List of Abbreviations

ASIC Application Specific Integrated Circuit

GPDK Generic Process Design Kit

HDL Hardware Description Language

RTL Register-Transfer Level

RX Receiver

TCL Tool Command Language

TX Transmitter

UART Universal Asynchronous Receiver Transmitter

1 Introduction

1.1 Practical

In this practical, we will be using *Cadence Genus - Ver. 18.10* to synthesize an example RTL design, a UART transceiver (shown in Figure 1). As inputs to Genus, we will provide

1. Source Verilog files
2. Technology libraries provided by the fabrication plant (here, 45 *nm* educational Generic Process Design Kit (GPDK) given by Cadence) : `(.lib, .lef, .tch)`
   - Library Timing (.lib) files specify timing (cell delay, cell transition time, setup and hold time requirement) and power characteristics of standard cells. Slow and fast libraries characterize standard cells with maximum and minimum signal delays, which could occur from process variations.
   - Tch files are binary files that accurately characterize library elements, that include capacitance and resistance.
   - Library Exchange Format (LEF) specify design rules, metal capacitances, layer information. . . etc.
3. Timing constraints

and will obtain the synthesized netlist (Verilog files) and further timing constrains `(.sdc)` as output. We will then analyze the area, timing and power of the synthesized design.

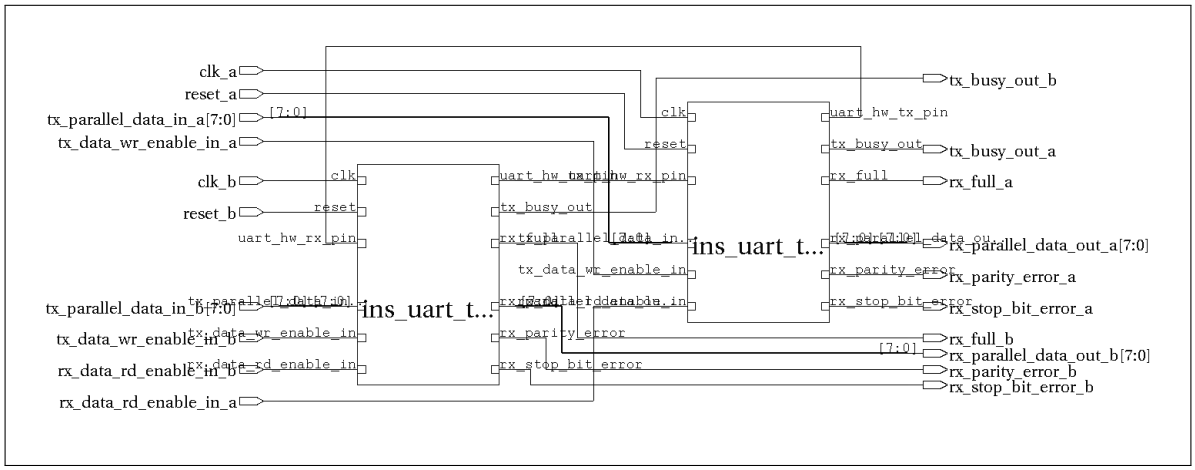

Figure 1: Top level diagram of the UART design

1.2 RTL Synthesis

In the context of digital hardware design, RTL synthesis is the process of converting an RTL description of a digital circuit into an optimized gate-level design.

The RTL description of a digital circuit is written in a Hardware Description Language (HDL) such as Verilog or VHDL. It specifies the digital circuit in terms of the flow of digital signals between registers, and the logical operations that are performed on those signals as they are transferred between the registers.

During RTL synthesis, an RTL compiler reads the RTL description of the digital circuit and generates an optimized gate-level representation of the circuit. This gate-level representation is a description of the digital circuit in terms of gates and interconnections between them. Figure 2 illustrates an overview of an RTL synthesis flow.

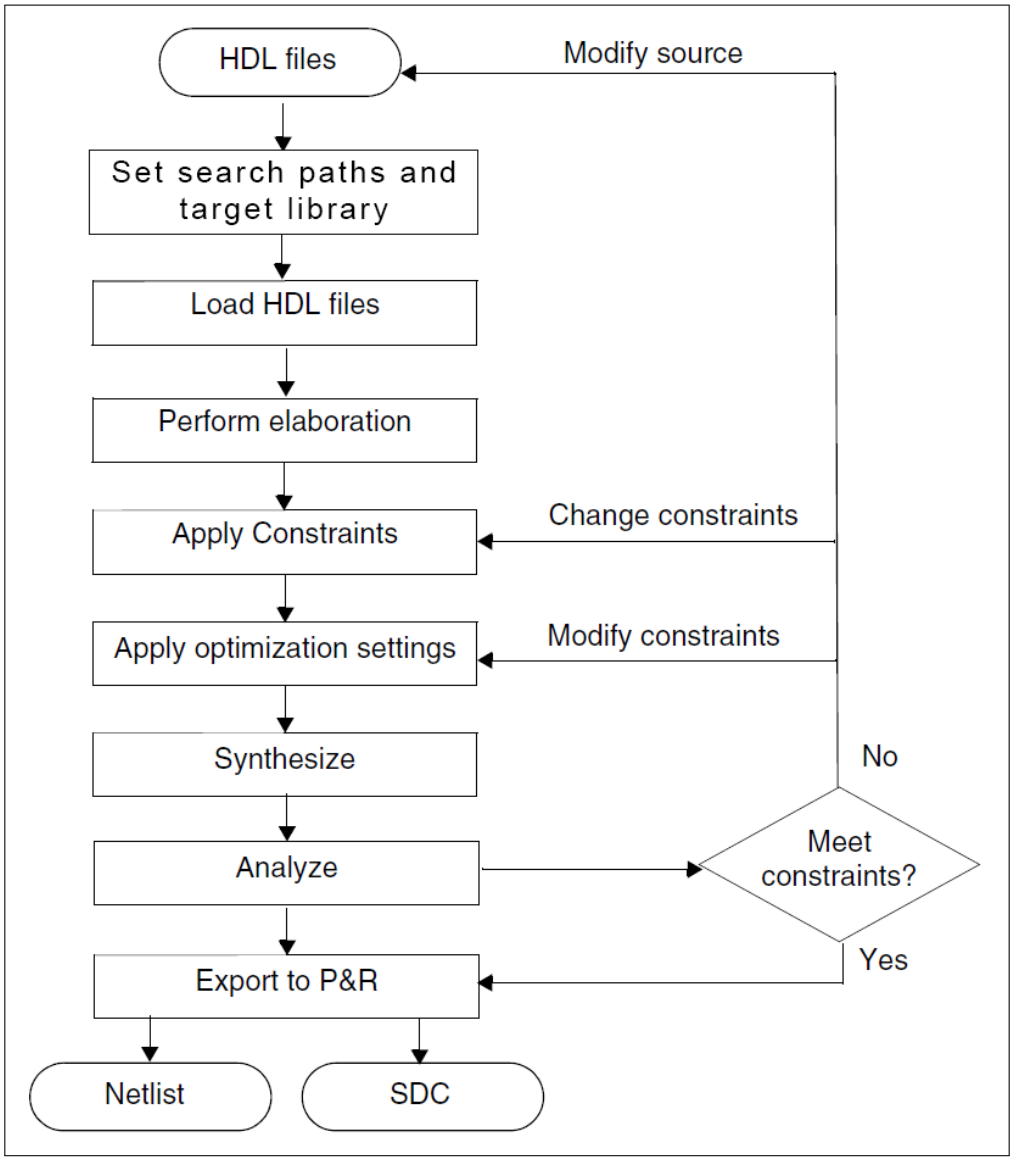

Figure 2: Overview of RTL synthesis flow of Cadence Genus software[1].

1.3 Associated Genus Commands

Note: *Genus is a Tool Command Language (TCL) based tool and therefore* `.tcl` *scripts can be created to execute a series of commands instead of typing each command individually. The entire interface of Genus is accessible through TCL, and true TCL syntax and semantics are supported.*

Followings are the commands used in this lab, and the entire script could be executed once using a single `.tcl` file. However, it was encouraged to execute the commands one-by-one in order to understand the process of synthesizing an RTL design.

```
# 1. Link Technology Library
set_db init_lib_search_path [list ../input/libs/gsclib045/lef
    ../input/libs/gsclib045/timing ../input/libs/gsclib045/qrc/qx]
set_db library {slow_vdd1v0_basicCells.lib fast_vdd1v0_basicCells.lib}
set_db lef_library {gsclib045_tech.lef gsclib045_macro.lef
    gsclib045_multibitsDFF.lef}
set_db qrc_tech_file gpdk045.tch

# 2. Read HDLs
read_hdl [glob ../input/rtl/*.v]

# 3. Elaborate the top module
elaborate uart_top

# 4. Check Design
check_design > ../log/check_design.log

# 5. Uniquifies the instances under the specified design or subdesign.
uniquify uart_top

# 6. Set constraints
source ../input/constraints.tcl

# 7. Synthesize
synthesize -to_mapped -effort m

# 8. Write netlist
write -mapped > ../output/uart_top.v
write_sdc > ../output/uart_top.sdc

# 9. Reports
report_area > ../report/area.log
report_timing  -nworst 10 > ../report/timing.log
report_constraint > ../report/constraint.log
report_port * > ../report/ports_final.log
report_power > ../report/power.log
```

2 Exercise

This section documents the observations made in step 4 and 5 of the practical guide, with screenshots and explanations.

2.1 System Clocks & Resets

2.1.1 System Clocks

The specifications related to the system clocks and other constraints are defined in the `constraints.tcl` script file, which can be executed once using the Genus software. The units of the clocks, and the other parameters related to timings are in nanoseconds (ns) scale, as defines in the Verilog source files by `timescale 1ns/1ps`.

The command `create_clock`[2] is used to define the clocks, and the necessary parameters related to them.

```
create_clock -name clk_a -period 10 [get_ports clk_a] -waveform {0 5}
create_clock -name clk_b -period 10 [get_ports clk_b] -waveform {0 5}
```

The clocks specified in the constraints file has the properties described in the Table 1. In addition to those properties, constraints related to the clock network uncertainty is also defined in the same file. In practical Application Specific Integrated Circuit (ASIC) design, ideal clock networks do not exist and clock signal arrival time may differ from cell to cell. In order to facilitate this, a parameter known as ***clock uncertainty*** is defined. It takes into account all the possible variations of the clock signal such as 1. ***jitter***, which is caused by the physical properties of the clock source, and 2. ***skew***, which is due to the routing length variations.

The `set_clock_uncertainty`[2] command is used to define the clock uncertainty as below.

```
set_clock_uncertainty 0.5 [all_clocks]
```

Table 1
Properties of the system clocks. (time unit = ns)

Name	Period	Rise Time	Fall Time	Clock Uncertainty
`clk_a`	10	0	5	0.5
`clk_b`	10	0	5	0.5

2.1.2 System Resets

Two system reset signals are defined in the top module `uart_top.v` Verilog source file, as `reset_a` and `reset_b`. Both resets are synchronous and active high.

```
always@(posedge clk) begin
    if (reset) begin
      some statements;
    end
end
```

2.1.3 Derived Clocks

A *derived clock* (a new clock signal) can be created from the clock waveform of a given pin in the design using the command `create_generated_clock`[2]. Howevr, the given design for this lab does not in cooperate any derived clocks.

2.2 Design Log Files

2.2.1 Area

The `area.log` file in the `report` directory carries the information shown in the Figure 3. It provides a breakdown of the area usage by design hierarchy and by instance, which can be helpful in identifying specific modules that are contributing to the overall area of the design. Specifically it provides the below information[2].

i. **Cell Count** : The total count of cells mapped against the hierarchical blocks in the current design.

ii. **Cell Area** : The combined cell area in each of the blocks and the top level design (hierarchical breakup)

iii. **Net Area** : The estimated post-route net area, which is based on the minimum wire widths defined in the LEF and capacitance table files and the area of the design blocks.

iv. **Total Area** : Simply combines the 'Cell Area' and the 'Net Area'

Instance	Module	Cell Count	Cell Area	Net Area	Total Area
uart_top		772	2220.948	946.493	3167.441
ins_uart_transceiver_B	uart_transceiver_CLOCK_IN_MHZ100_TX_WORD_LENGTH8_T	386	1110.474	423.318	1533.792
ins_rx_wrapper	rx_wrapper_NO_OF_WORS_IN_BUFFER1_NO_OF_DATA_BITS8_	197	621.072	209.103	830.175
ins_rx_buffer	rx_buffer_WORD_SIZE8_NO_OF_WORDS1_1	67	292.068	61.047	353.115
ins_rx_fsm	rx_fsm_NO_OF_DATA_BITS8_PARITY_ENABLED32h54525545_	74	180.918	77.867	258.785
ins_sampling_tick_generator	sampling_tick_generator_BAUD115200_CLOCK_IN_MHZ100	56	148.086	62.149	210.235
ins_tx_wrapper	tx_wrapper_NO_OF_WORDS_IN_BUFFER1_NO_OF_DATA_BITS8	189	489.402	214.215	703.617
ins_tx_fsm	tx_fsm_NO_OF_DATA_BITS8_PARITY_ENABLED32h54525545_	94	210.330	103.544	313.874
ins_tx_buffer	tx_buffer_WORD_SIZE8_NO_OF_WORDS1_1	53	146.718	52.247	198.965
ins_sampling_tick_generator	sampling_tick_generator_BAUD115200_CLOCK_IN_MHZ100	42	132.354	46.412	178.766
ins_uart_transceiver_A	uart_transceiver_CLOCK_IN_MHZ100_TX_WORD_LENGTH8_T	386	1110.474	423.318	1533.792
ins_rx_wrapper	rx_wrapper_NO_OF_WORS_IN_BUFFER1_NO_OF_DATA_BITS8_	197	621.072	209.103	830.175
ins_rx_buffer	rx_buffer_WORD_SIZE8_NO_OF_WORDS1	67	292.068	61.047	353.115
ins_rx_fsm	rx_fsm_NO_OF_DATA_BITS8_PARITY_ENABLED32h54525545_	74	180.918	77.867	258.785
ins_sampling_tick_generator	sampling_tick_generator_BAUD115200_CLOCK_IN_MHZ100	56	148.086	62.149	210.235
ins_tx_wrapper	tx_wrapper_NO_OF_WORDS_IN_BUFFER1_NO_OF_DATA_BITS8	189	489.402	214.215	703.617
ins_tx_fsm	tx_fsm_NO_OF_DATA_BITS8_PARITY_ENABLED32h54525545_	94	210.330	103.544	313.874
ins_tx_buffer	tx_buffer_WORD_SIZE8_NO_OF_WORDS1	53	146.718	52.247	198.965
ins_sampling_tick_generator	sampling_tick_generator_BAUD115200_CLOCK_IN_MHZ100	42	132.354	46.412	178.766

Figure 3: Area log file

2.2.2 Power

The `power.log` file in the `report` directory carries the details shown in the Figure 4. It provides the information related to the power consumption; however, the returned information depends on the current position in the design hierarchy and on the specified objects. If no objects are specified, the report is given for the design or instance at the current position in the design hierarchy[2].

i. **Leakage Power** refers to the power that is consumed by the circuit even when it is in a quiescent or standby state. This type of power consumption is caused by the leakage current flowing through the transistors and other components in the circuit.

ii. **Dynamic Power** refers to the power that is consumed by the circuit when it is actively switching or performing computations. This type of power consumption is caused by the charging and discharging of the load capacitance at the inputs and outputs of the transistors.

iii. **Total Power** is the sum of leakage power and dynamic power, it is the overall power consumed by the circuit.

Instance	Cells	Leakage Power(nW)	Dynamic Power(nW)	Total Power(nW)
uart_top	772	60.819	172490.052	172550.870
ins_uart_transceiver_B	386	30.415	87250.682	87281.098
ins_rx_wrapper	197	19.437	60900.810	60920.247
ins_rx_buffer	67	11.235	44449.732	44460.967
ins_rx_fsm	74	5.135	11368.789	11373.924
ins_sampli..ick_generator	56	3.067	5082.288	5085.355
ins_tx_wrapper	189	10.979	26349.873	26360.851
ins_tx_fsm	94	5.124	14188.375	14193.500
ins_tx_buffer	53	3.228	7822.657	7825.885
ins_sampli..ick_generator	42	2.626	4338.840	4341.466
ins_uart_transceiver_A	386	30.403	80046.763	80077.167
ins_rx_wrapper	197	19.422	54041.240	54060.663
ins_rx_buffer	67	11.223	37609.104	37620.327
ins_rx_fsm	74	5.146	12300.830	12305.977
ins_sampli..ick_generator	56	3.053	4131.306	4134.359
ins_tx_wrapper	189	10.981	26005.523	26016.504
ins_tx_fsm	94	5.117	13676.204	13681.321
ins_tx_buffer	53	3.232	8467.156	8470.388
ins_sampli..ick_generator	42	2.632	3862.163	3864.795

Figure 4: Power log file

2.2.3 Timing

The `timing.log` file in the `report` directory carries the details shown in the Figure 5. The command given below was used to generate this timing report. '`-nworst 10`' argument in the command specifies that, the maximum number of paths to report to each endpoint is 10[2].

```
report_timing  -nworst 10 > ../report/timing.log

Warning : Possible timing problems have been detected in this design. [TIM-11]
: The design is 'uart_top'.
: Use 'report timing -lint' for more information.
```

In addition, below constraints are defined in the `constraints.tcl` to be used for the synthesis. Here the input delay is constrained to 6 $ns = 6000\ ps$, and this information is also available in the timing report shown in the Figure 5.

```
set_input_delay  6 -clock clk_a  $design_inputs_a
set_input_delay  6 -clock clk_b  $design_inputs_b
set_output_delay 6 -clock clk_a $design_outputs_a
set_output_delay 6 -clock clk_b $design_outputs_b
```

According to the information found on the timing log file, **the most critical path** (Path 1 in Figure 5) has a positive slack time of 2539 ps. This is the least slack time of the given design. This indicates that, there is no timing violations in the design.

```
Path 1: MET (2539 ps) Setup Check with Pin ins_uart_transceiver_B/ins_rx_wrapper/ins_rx_buffer/buffer_full_counter_reg[2]/CK->D
          Group: clk_b
     Startpoint: (F) rx_data_rd_enable_in_b
          Clock: (R) clk_b
       Endpoint: (R) ins_uart_transceiver_B/ins_rx_wrapper/ins_rx_buffer/buffer_full_counter_reg[2]/D
          Clock: (R) clk_b

                     Capture       Launch
        Clock Edge:+   10000            0
        Drv Adjust:+       0            0
       Src Latency:+       0            0
       Net Latency:+       0 (I)        0 (I)
           Arrival:=   10000            0

             Setup:-     168
       Uncertainty:-     500
     Required Time:=    9332
      Launch Clock:-       0
       Input Delay:-    6000
         Data Path:-     793
             Slack:=    2539

Exceptions/Constraints:
  input_delay             6000             in_del_19_1

#--------------------------------------------------------------------------------------------------------------------------------------------
#                               Timing Point                                  Flags    Arc   Edge   Cell       Fanout Load Trans Delay Arrival Instance
#                                                                                                                      (fF)  (ps)  (ps)   (ps)  Location
#--------------------------------------------------------------------------------------------------------------------------------------------
  rx_data_rd_enable_in_b                                                      -        -     F      (arrival)       9 11.4     0     0    6000    (-,-)
  ins_uart_transceiver_B/ins_rx_wrapper/ins_rx_buffer/g598/Y                  -        B->Y  R      NOR2BX1         3  4.4   216   132    6132    (-,-)
  ins_uart_transceiver_B/ins_rx_wrapper/ins_rx_buffer/g593/Y                  -        B->Y  F      NOR2X1          2  2.9   123   181    6312    (-,-)
  ins_uart_transceiver_B/ins_rx_wrapper/ins_rx_buffer/g574/Y                  -        B0->Y R      OAI21X1         1  2.0   144   104    6416    (-,-)
  ins_uart_transceiver_B/ins_rx_wrapper/ins_rx_buffer/g560/Y                  -        A1->Y F      AOI22X1         1  1.9   190   206    6623    (-,-)
  ins_uart_transceiver_B/ins_rx_wrapper/ins_rx_buffer/g555/Y                  -        B->Y  R      NOR2X1          1  1.9   127   171    6793    (-,-)
  ins_uart_transceiver_B/ins_rx_wrapper/ins_rx_buffer/buffer_full_counter_reg[2]/D -   -     R      DFFHQX1         1    -     -     0    6793    (-,-)
#--------------------------------------------------------------------------------------------------------------------------------------------
```

Figure 5: Timing log file

Note: Slack is a measure of the timing margin available in a design. It is the difference between the *Required Time* and the *Arrival Time* of a signal at a specific endpoint. Positive slack indicates that the design meets the timing constraints and there is extra time available, while negative slack indicates that the design does not meet the timing constraints and the path is considered to be in violation. **The paths with the least slack are the most critical paths**. A design with a high slack value has more margin for manufacturing variations, temperature changes, and other factors that can affect the timing of the system.

2.2.4 Ports

The `ports_final.log` file in the `report` directory carries the details related to the ports of the current design. By default, the report gives information on port direction, external delays, exception objects and their types, driver, slew, fanout load, pin capacitance and wire capacitance for the ports[2]. Figure 6 illustrates the 'External Delays & Exceptions' section of the ports log file.

```
          External Delays & Exceptions
          ----------------------------
                                         Rise     Fall                 Ext Delay                 Exception
            Port              Dir  Clock  Delay    Delay                 Object                  Object/Type
--------------------------------------------------------------------------------------------------------------
 clk_a                        in   clk_a      0.0  no_value  create_clock_delay_domain_1_clk_a_R_0         N/A
                                   clk_a  no_value      0.0  create_clock_delay_domain_1_clk_a_F_0
 reset_a                      in   N/A        N/A       N/A  N/A                                            N/A
 tx_parallel_data_in_a[7]     in   clk_a   6000.0    6000.0  in_del                                         N/A
 tx_parallel_data_in_a[6]     in   clk_a   6000.0    6000.0  in_del_1_1                                     N/A
 tx_parallel_data_in_a[5]     in   clk_a   6000.0    6000.0  in_del_2_1                                     N/A
 tx_parallel_data_in_a[4]     in   clk_a   6000.0    6000.0  in_del_3_1                                     N/A
 tx_parallel_data_in_a[3]     in   clk_a   6000.0    6000.0  in_del_4_1                                     N/A
 tx_parallel_data_in_a[2]     in   clk_a   6000.0    6000.0  in_del_5_1                                     N/A
 tx_parallel_data_in_a[1]     in   clk_a   6000.0    6000.0  in_del_6_1                                     N/A
 tx_parallel_data_in_a[0]     in   clk_a   6000.0    6000.0  in_del_7_1                                     N/A
 tx_data_wr_enable_in_a       in   clk_a   6000.0    6000.0  in_del_8_1                                     N/A
 rx_data_rd_enable_in_a       in   clk_a   6000.0    6000.0  in_del_9_1                                     N/A
```

Figure 6: External Delays & Exceptions section of the ports log file

2.3 Changing the Top Level Designs Parameters

In this part of the exercise, the `uart_top.v` Verilog source file was modified according to the instructions, and synthesis process was re-run. After the modification, top level design parameters will be as follows. Note that word lengths of the Transmitter (TX) and the Receiver (RX) are changed from 8 bits to 32 bits.

```
module uart_top #(
    parameter  CLOCK_IN_MHZ  =100,

    parameter  TX_WORD_LENGTH =32,  // # of UART-tramsmit data bits ; 6,7,8
    parameter  TX_NO_OF_WORDS =1,   // Transmitter buffer size in words.
    // Actual buffer size= TX_WORD_LENGTH * TX_NO_OF_WORDS  ; 1,2...
    ,
    parameter  RX_WORD_LENGTH =32,  // # of UART-receive data bits ; 6,7,8
    parameter  RX_NO_OF_WORDS =1    // Receiver buffer size in words.
    // Actual buffer size= RX_WORD_LENGTH * RX_NO_OF_WORDS  ; 1,2.....
)
```

2.3.1 Area Reports Comparison

After changing the word length of the TX and the RX, the produced area report is shown in the Figure 7.

Instance	Module	Cell Count	Cell Area	Net Area	Total Area
uart_top		1054	3339.972	1348.581	4688.553
ins_uart_transceiver_B	uart_transceiver_CLOCK_IN_MHZ100_TX_WORD_LENGTH32_	527	1669.986	571.450	2241.436
ins_rx_wrapper	rx_wrapper_NO_OF_WORS_IN_BUFFER1_NO_OF_DATA_BITS32	277	999.666	282.389	1282.055
ins_rx_buffer	rx_buffer_WORD_SIZE32_NO_OF_WORDS1_1	166	729.828	156.722	886.550
ins_sampling_tick_generator	sampling_tick_generator_BAUD115200_CLOCK_IN_MHZ100	56	143.982	61.788	205.770
ins_rx_fsm	rx_fsm_NO_OF_DATA_BITS32_PARITY_ENABLED32h54525545	55	125.856	55.839	181.695
ins_tx_wrapper	tx_wrapper_NO_OF_WORDS_IN_BUFFER1_NO_OF_DATA_BITS3	250	670.320	289.060	959.380
ins_tx_buffer	tx_buffer_WORD_SIZE32_NO_OF_WORDS1_1	140	394.668	149.595	544.263
ins_tx_fsm	tx_fsm_NO_OF_DATA_BITS32_PARITY_ENABLED32h54525545	67	147.744	71.633	219.377
ins_sampling_tick_generator	sampling_tick_generator_BAUD115200_CLOCK_IN_MHZ100	43	127.908	47.154	175.062
ins_uart_transceiver_A	uart_transceiver_CLOCK_IN_MHZ100_TX_WORD_LENGTH32_	527	1669.986	571.450	2241.436
ins_rx_wrapper	rx_wrapper_NO_OF_WORS_IN_BUFFER1_NO_OF_DATA_BITS32	277	999.666	282.389	1282.055
ins_rx_buffer	rx_buffer_WORD_SIZE32_NO_OF_WORDS1	166	729.828	156.722	886.550
ins_sampling_tick_generator	sampling_tick_generator_BAUD115200_CLOCK_IN_MHZ100	56	143.982	61.788	205.770
ins_rx_fsm	rx_fsm_NO_OF_DATA_BITS32_PARITY_ENABLED32h54525545	55	125.856	55.839	181.695
ins_tx_wrapper	tx_wrapper_NO_OF_WORDS_IN_BUFFER1_NO_OF_DATA_BITS3	250	670.320	289.060	959.380
ins_tx_buffer	tx_buffer_WORD_SIZE32_NO_OF_WORDS1	140	394.668	149.595	544.263
ins_tx_fsm	tx_fsm_NO_OF_DATA_BITS32_PARITY_ENABLED32h54525545	67	147.744	71.633	219.377
ins_sampling_tick_generator	sampling_tick_generator_BAUD115200_CLOCK_IN_MHZ100	43	127.908	47.154	175.062

Figure 7: Area log file after changing the word length of TX and RX

When comparing the new area report with the previous area report showed in the Figure 3, observations reported in the Table 2 can be made. Below is a summary of the most significant changes between two designs.

- `ins_rx_buffer` cell count and the total area has been increased by nearly 2.5 times. This change is predictable as the buffer size equals to `RX_WORD_LENGTH * RX_NO_OF_WORDS`, and we have increased the RX word length by four times.
- `ins_tx_buffer` cell count and the total area has been increased by nearly 1.5 times. This change is also predictable as the buffer size equals to `TX_WORD_LENGTH * TX_NO_OF_WORDS`, and we have increased the TX word length by four times.

These increase of TX and RX buffer sizes have contributed to a significant area increase (nearly 1.5 times) in the overall design.

TABLE 2
AREA COMPARISON: CELL COUNT AND THE TOTAL AREA

Instance	Cell Count 8 bit design	Cell Count 32 bit design	Total Area 8 bit design	Total Area 32 bit design
uart_top	772	1054	3167.441	4688.553
-ins_uart_transceiver_B	386	527	1533.792	2241.436
---ins_rx_wrapper	197	277	830.175	1282.055
-----ins_rx_buffer	67	166	353.115	886.550
-----ins_sampling_tick_generator	74	56	258.785	205.770
-----ins_rx_fsm	56	55	210.235	181.695
---ins_tx_wrapper	189	250	703.617	959.380
-----ins_tx_buffer	94	140	313.874	544.263
-----ins_tx_fsm	53	67	198.965	219.377
-----ins_sampling_tick_generator	42	43	178.766	175.062

2.3.2 Timing Reports Comparison

After changing the word length of the TX and the RX, the produced timing report is shown in the Figure 8.

```
Path 1: MET (3080 ps) Setup Check with Pin ins_uart_transceiver_B/ins_rx_wrapper/ins_rx_buffer/buffer_full_counter_reg[4]/CK->D
          Group: clk_b
     Startpoint: (R) rx_data_rd_enable_in_b
          Clock: (R) clk_b
       Endpoint: (F) ins_uart_transceiver_B/ins_rx_wrapper/ins_rx_buffer/buffer_full_counter_reg[4]/D
          Clock: (R) clk_b

                     Capture       Launch
        Clock Edge:+   10000            0
        Drv Adjust:+       0            0
       Src Latency:+       0            0
       Net Latency:+       0 (I)        0 (I)
           Arrival:=   10000            0

             Setup:-      16
       Uncertainty:-     500
     Required Time:=    9484
      Launch Clock:-       0
       Input Delay:-    6000
         Data Path:-     404
             Slack:=    3080

Exceptions/Constraints:
  input_delay             6000             in_del_67_1

#--------------------------------------------------------------------------------------------------------------------------------------------------------------
#                              Timing Point                                        Flags    Arc    Edge   Cell       Fanout Load Trans Delay Arrival Instance
#                                                                                                                          (fF)  (ps)  (ps)   (ps)  Location
#--------------------------------------------------------------------------------------------------------------------------------------------------------------
  rx_data_rd_enable_in_b                                                            -       -      R     (arrival)      1  1.9     0     0    6000    (-,-)
  ins_uart_transceiver_B/ins_rx_wrapper/ins_rx_buffer/drc_buf_sp1335/Y              -       A->Y   R     BUFX2         33 46.5   161   104    6104    (-,-)
  ins_uart_transceiver_B/ins_rx_wrapper/ins_rx_buffer/g1309/Y                       -       A->Y   F     INVX1          3  4.3    60    70    6174    (-,-)
  ins_uart_transceiver_B/ins_rx_wrapper/ins_rx_buffer/g1266/Y                       -       A1->Y  F     AO21X1         2  3.0    24    49    6222    (-,-)
  ins_uart_transceiver_B/ins_rx_wrapper/ins_rx_buffer/g1201/Y                       -       B0->Y  F     AO21X1         2  2.9    23    42    6264    (-,-)
  ins_uart_transceiver_B/ins_rx_wrapper/ins_rx_buffer/g1166/Y                       -       B0->Y  F     AO21X1         2  2.9    23    42    6306    (-,-)
  ins_uart_transceiver_B/ins_rx_wrapper/ins_rx_buffer/g1161/Y                       -       B0->Y  F     AO21X1         1  2.0    17    39    6345    (-,-)
  ins_uart_transceiver_B/ins_rx_wrapper/ins_rx_buffer/g1154/Y                       -       B1->Y  R     AOI32X1        1  2.1    47    33    6378    (-,-)
  ins_uart_transceiver_B/ins_rx_wrapper/ins_rx_buffer/g1150/Y                       -       B->Y   F     NOR2X1         1  2.0    24    26    6404    (-,-)
  ins_uart_transceiver_B/ins_rx_wrapper/ins_rx_buffer/buffer_full_counter_reg[4]/D -       -      F     DFFHQX1        1    -     -     0    6404    (-,-)
#--------------------------------------------------------------------------------------------------------------------------------------------------------------
```

Figure 8: Timing log file after changing the word length of TX and RX

It can be observed that the least slack time which corresponds to the most critical path, has been increased to 3080 *ps*. This positive slack time indicates that there is no timing violations in the given design even after the made changes.

2.4 Changing Constraints

In this part of the exercise, the changes were made to the `constraints.tcl` file, to meet the below criteria.

a. Change the system clocks of both A and B transceivers to operate at $50MHz$.

b. Change the duty cycle of both clocks to 40%

c. Introduce 180° phase shift to clock B

d. Increase the pin load by 5pF and check the timing violations

2.4.1 Changing the System Clocks

The units of the clocks, and the other parameters related to timings are in nanoseconds (ns) scale, as defines in the Verilog source files by `ṭimescale 1ns/1ps`. Therefore in order to generate a clock operating at 50 MHz, the clock period must be 20 ns. Argument '`-period 20`' will do this change as follows.

```
create_clock -name clk_a -period 20 [get_ports clk_a] -waveform {0 10}
create_clock -name clk_b -period 20 [get_ports clk_b] -waveform {0 10}
```

2.4.2 Changing the Duty Cycle

Duty cycle of the clock can be changed as necessary by changing the parameters of the '`-waveform`' argument. Since the clock period is 20 ns, in order to have a 40% duty cycle, clock should remain high for 8 ns. Therefore, the rise time of the clock will be at time unit 0 and fall time will be at time unit 8.

$$high\ time = 20\ ns \times \frac{40}{100} = 8\ ns$$

```
create_clock -name clk_a -period 20 [get_ports clk_a] -waveform {0 8}
create_clock -name clk_b -period 20 [get_ports clk_b] -waveform {0 8}
```

2.4.3 Phase Shifting Clock B

The necessary phase shift can also be given to any clock by changing the rise time and the fall time of the clock. Since we need 180° phase shift in clock B, with respect to the clock A, we need to give a shift worth half of the period to the clock B. This is equal to the rise time and fall time increment by 10 time units.

```
create_clock -name clk_a -period 20 [get_ports clk_a] -waveform {0 8}
create_clock -name clk_b -period 20 [get_ports clk_b] -waveform {10 18}
```

2.4.4 Increasing Pin Loads

Pin load is specified by the below command. Previously it was 0.2 units and in order to make it 5.2 pF the necessary change was made.

```
set_load        5.2 $design_outputs
```

2.4.5 Area Reports Comparison

After changing the design constraints as described previously, the produced area report is shown in the Figure 9.

```
           Instance                              Module                          Cell Count  Cell Area  Net Area   Total Area
-----------------------------------------------------------------------------------------------------------------------------
uart_top                                                                              1128   3732.588  1384.730     5117.318
  ins_uart_transceiver_B         uart_transceiver_CLOCK_IN_MHZ100_TX_WORD_LENGTH32_    564   1866.294   602.163     2468.457
    ins_rx_wrapper               rx_wrapper_NO_OF_WORS_IN_BUFFER1_NO_OF_DATA_BITS32    305   1170.666   307.895     1478.561
      ins_rx_buffer              rx_buffer_WORD_SIZE32_NO_OF_WORDS1_1                  199    888.858   190.933     1079.791
      ins_sampling_tick_generator sampling_tick_generator_BAUD115200_CLOCK_IN_MHZ100    48    145.350    51.221      196.571
      ins_rx_fsm                 rx_fsm_NO_OF_DATA_BITS32_PARITY_ENABLED32h54525545     58    136.458    57.702      194.160
    ins_tx_wrapper               tx_wrapper_NO_OF_WORDS_IN_BUFFER1_NO_OF_DATA_BITS3    259    695.628   294.268      989.896
      ins_tx_buffer              tx_buffer_WORD_SIZE32_NO_OF_WORDS1_1                  146    405.612   154.043      559.655
      ins_tx_fsm                 tx_fsm_NO_OF_DATA_BITS32_PARITY_ENABLED32h54525545     66    153.900    69.790      223.690
      ins_sampling_tick_generator sampling_tick_generator_BAUD115200_CLOCK_IN_MHZ100    47    136.116    50.118      186.234
  ins_uart_transceiver_A         uart_transceiver_CLOCK_IN_MHZ100_TX_WORD_LENGTH32_    564   1866.294   602.163     2468.457
    ins_rx_wrapper               rx_wrapper_NO_OF_WORS_IN_BUFFER1_NO_OF_DATA_BITS32    305   1170.666   307.895     1478.561
      ins_rx_buffer              rx_buffer_WORD_SIZE32_NO_OF_WORDS1                    199    888.858   190.933     1079.791
      ins_sampling_tick_generator sampling_tick_generator_BAUD115200_CLOCK_IN_MHZ100    48    145.350    51.221      196.571
      ins_rx_fsm                 rx_fsm_NO_OF_DATA_BITS32_PARITY_ENABLED32h54525545     58    136.458    57.702      194.160
    ins_tx_wrapper               tx_wrapper_NO_OF_WORDS_IN_BUFFER1_NO_OF_DATA_BITS3    259    695.628   294.268      989.896
      ins_tx_buffer              tx_buffer_WORD_SIZE32_NO_OF_WORDS1                    146    405.612   154.043      559.655
      ins_tx_fsm                 tx_fsm_NO_OF_DATA_BITS32_PARITY_ENABLED32h54525545     66    153.900    69.790      223.690
      ins_sampling_tick_generator sampling_tick_generator_BAUD115200_CLOCK_IN_MHZ100    47    136.116    50.118      186.234
```

Figure 9: Area log file after changing the design constraints

When comparing the new area report with the previous area report showed in the Figure 7, observations reported in the Table 3 can be made. However, there is no significant change in the area of the design, although the design constraints are modified.

TABLE 3
AREA COMPARISON AFTER CHANGING THE DESIGN CONSTRAINTS: CELL COUNT AND THE TOTAL AREA

Instance	Cell Count (old)	Cell Count (new)	Total Area (old)	Total Area (new)
`uart_top`	1054	1128	4688.553	5117.318
`-ins_uart_transceiver_B`	527	564	2241.436	2468.457
`---ins_rx_wrapper`	277	305	1282.055	1478.561
`-----ins_rx_buffer`	166	199	886.550	1079.791
`-----ins_sampling_tick_generator`	56	48	205.770	196.571
`-----ins_rx_fsm`	55	58	181.695	194.160
`---ins_tx_wrapper`	250	259	959.380	989.896
`-----ins_tx_buffer`	140	146	544.263	559.655
`-----ins_tx_fsm`	67	66	219.377	223.690
`-----ins_sampling_tick_generator`	43	47	175.062	186.234

2.4.6 Timing Violations

After making the above changes to the constraints of the design, the produced timing report is shown in the Figure 10.

```
Path 1: MET (9126 ps) Late External Delay Assertion at pin rx_stop_bit_error_b
          Group: clk_b
     Startpoint: (R) ins_uart_transceiver_B/ins_rx_wrapper/ins_rx_fsm/stop_bit_error_reg/CK
          Clock: (R) clk_b
       Endpoint: (F) rx_stop_bit_error_b
          Clock: (R) clk_b

                     Capture       Launch
        Clock Edge:+   30000        10000
       Src Latency:+       0            0
       Net Latency:+       0 (I)        0 (I)
           Arrival:=   30000        10000

      Output Delay:-    6000
       Uncertainty:-     500
     Required Time:=   23500
      Launch Clock:-   10000
         Data Path:-    4374
             Slack:=    9126

Exceptions/Constraints:
  output_delay             6000            ou_del_416_1

#------------------------------------------------------------------------------------------------------------------------------------------
#                          Timing Point                                Flags    Arc   Edge   Cell       Fanout  Load  Trans Delay Arrival Instance
#                                                                                                                (fF)   (ps)  (ps)   (ps)  Location
#------------------------------------------------------------------------------------------------------------------------------------------
  ins_uart_transceiver_B/ins_rx_wrapper/ins_rx_fsm/stop_bit_error_reg/CK -         -     R     (arrival)    153      -     0     -   10000    (-,-)
  ins_uart_transceiver_B/ins_rx_wrapper/ins_rx_fsm/stop_bit_error_reg/Q  -       CK->Q F     DFFHQX1        2    4.6   126   253   10253    (-,-)
  ins_uart_transceiver_B/ins_rx_wrapper/ins_rx_fsm/drc_bufs2976/Y        -       A->Y  F     CLKBUFX20      1 5201.6  7071  4085   14338    (-,-)
  rx_stop_bit_error_b                                                    -         -     F     (port)         -      -     -     0   14374    (-,-)
#------------------------------------------------------------------------------------------------------------------------------------------
```

Figure 10: Timing log file after changing the design constraints

It can be observed that the least slack time which corresponds to the most critical path, has been increased to 9126 *ps*. This positive slack time indicates that there is no timing violations in the given design even after the made changes. An increase in slack time on the critical path means that the design has more flexibility to accommodate changes or delays without causing a timing violation.

Bibliography

[1] "Genus User Guide for Legacy UI," version 19.1, November 2019, published by *Cadence Design Systems, Inc.*

[2] "Genus Command Reference," version 19.1, November 2019, published by *Cadence Design Systems, Inc.*