

# **S4\_VHDL Specifications**



Circuit Design (WS2020/21)  
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## **History - Change Log**

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17.01.2021	Repository added
17.01.2021	Program Design added
15.01.2021	Testbanches added
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06.11.2020	General description added
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# **Chapter 1**

## **General description**

IC4 is a single chip based application containing processing capabilities to detect and keep track of the amount of people in one room. It is part of a system solution to fulfill the covid-19-restrictions and regulate the amount of people in an area. This solution is only meant for a chamber with only one doorway available to enter or to exit.

The IC4 is designed on a FPGA prototype-board Max1000 with 10M16SAU169C8G device on board.

# Chapter 2

## Requirements

ID	Requirement	Priority	Verifiable	Description
<b>General</b>				
G01	Gen.: #persons	High	Testbench	The number of persons in a room must be known.
G02	Gen.: max	High	Testbench	The number of persons in a room must not exceed a given limit.
G03	Gen.: only one pers.	High	N/A	Only one person can either enter or leave the room at a time.
G04	Gen.: three light sensors	Medium	Testbench	Along the doorway, there are three light-curtains to allow directiontracking of possible visitors.
G05	Gen.: only one door	High	N/A	Only one door exists.
<b>Sound</b>				
S01	Sound: entered	High	N/A	A person entered the room, play a unique sound.
S02	Sound: left	High	N/A	A person left the room, play a unique sound.
S03	Sound: stop	High	N/A	The room is full, play a unique sound.
<b>LED</b>				
LED01	LED: red	High	Testbench	The maximal number of persons reached.
LED02	LED: green	High	Testbench	The maximal number of persons not reached.

<b>ID</b>	<b>Requirement</b>	<b>Priority</b>	<b>Verifiable</b>	<b>Description</b>
<b>UART</b>				
UART01	UART: 9600 baud	High	Testbench	The speed of the serial transmission should be set to 9600 baud.
UART02	UART: 8 bit	High	Testbench	The data width of the serial transmission should be set to 8 bit.
UART03	UART: no parity	High	Testbench	The serial transmission should not be checked with a parity bit.
UART04	UART: one stop bit	High	Testbench	The serial transmission should have only one stop bit.
UART06	UART: #persons	High	Testbench	The #persons should be transmitted to a PC.
<b>PC</b>				
PC01	PC: language	Medium	N/A	Information should be displayed on a PC, the language is C++.
PC02	PC: timestamp	Low	N/A	Every event should have a unique timestamp.
<b>IC_S3</b>				
IC01	IC_S3: interface	Low	Testbench	Use a three wire IF.
IC02	IC_S3: events	Low	Testbench	All events should be transmitted via the three wire IF.
IC03	IC_S3: #persons	Low	Testbench	The #persons should be transmitted via the three wire IF.

# **Chapter 3**

## **Architecture Concepts**

### **Clock Cycle - Trigger**

This project uses a 12MHz clock with a rising edge trigger signal. This allows to synchronize the modules within the IC\_S4. Each block has the same clock cycle starting with the rising edge event.

### **Reset**

To reset the whole project an active low is required. That is due to FPGA board, which has buttons with active low signals built in.

### **FSM**

The FSMs (Finite State Machines) in this project are 3 process FSMs. This allows to easily construct and modify them quickly if needed.

# Chapter 4

## Top Level View

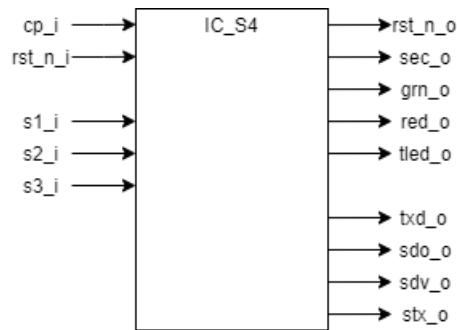


Figure 4.1: IC\_S4 Top View

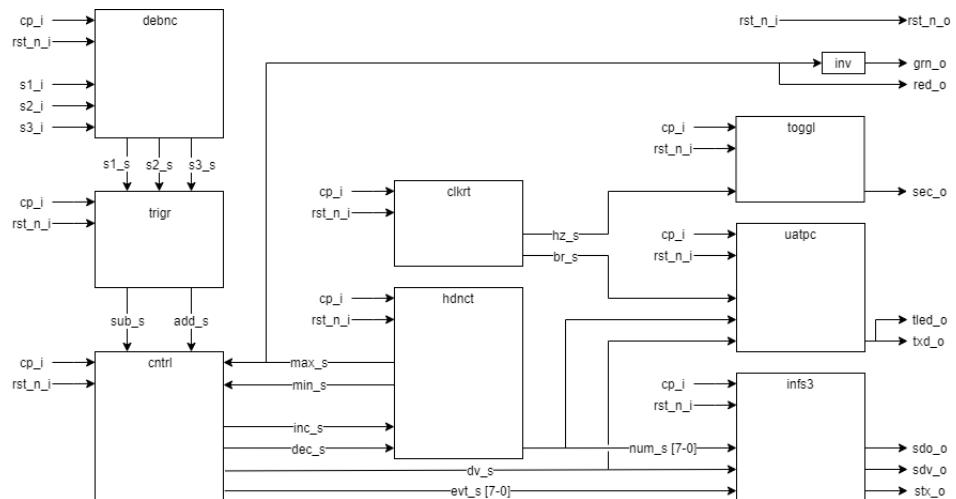


Figure 4.2: Top Level Block Diagram

<b>Signal</b>	<b>Pin</b>	<b>Direction</b>	<b>Description</b>
rst_n_i	E6	IN	Reset, active low
cp_i	H6	IN	Syscp, @ 12MHz
s1_i	L12	IN	Sensor 1
s2_i	J12	IN	Sensor 2
s3_i	J13	IN	Sensor 3
rst_n_o	A8	OUT	Reset state LED
sec_o	A9	OUT	Pulse LED
grn_o	A11	OUT	Green LED, go ahead
red_o	A10	OUT	Red LED, stop, access denied
tled_o	B10	OUT	Transmission LED
txd_o	K11	OUT	Transmission RS-232-driver, 9k6,8N2,ASCII,to PC
sdi_o	K12	OUT	S3 data value
sdv_o	J10	OUT	S3 data valid
stx_o	H10	OUT	S3 transmission active

<b>Internal Signal</b>	<b>Width</b>	<b>Description</b>
br_s	1	9600 baud rate signal
hz_s	1	1Hz signal
add_s	1	trigger signal that someone entered
sub_s	1	trigger signal that someone left
inc_s	1	increment headcount signal
dec_s	1	decrement headcount signal
min_s	1	headcount reached min
max_s	1	headcount reached max
num_s	8	contains the headcount number
evh_s	8	contains the current event (ASCII)

# Functionality

When some one passes the sensors, the IC\_S4 will recognize if the person passing enters the room or leaves it. According to the event the headcounter gets adjusted (either increased or decreased). With a red LED is indicated that the maximum amount of people in the room is reached. Else a green LED indicates otherwise.

## Assumptions:

- Everyone completes the enter/leave process compleatly.
- No one enters, when the room is full.
- No one leaves, when room is already empty.

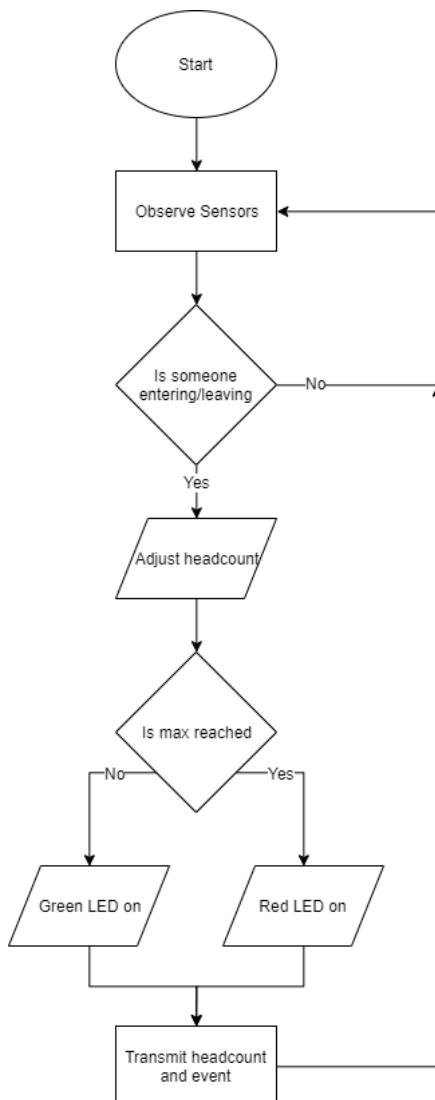


Figure 4.3: Flowchart

# Chapter 5

## VHDL Design

### 5.1 debnc: Signal Debouncing

This module debounces three incoming signals into unbounced pulsed signals. To do that it uses the module dbpul three times.

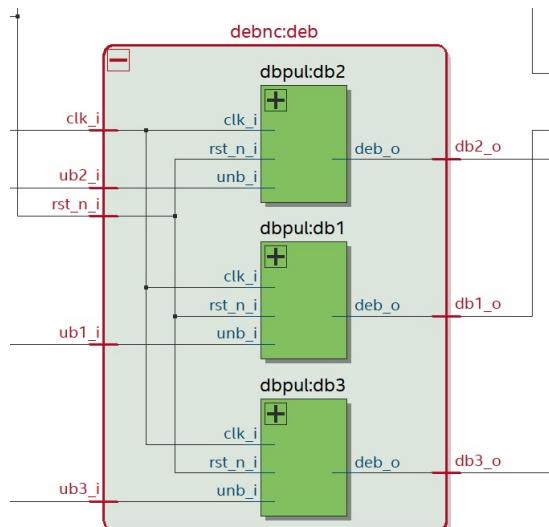


Figure 5.1: debnc\_deb

Signal	Direction	Width	Description
rst_n_i	IN	1	Reset, active low
clk_i	IN	1	Syscp, @ 12MHz
ub1_i	IN	1	Unbounced Input 1
ub2_i	IN	1	Unbounced Input 2
ub3_i	IN	1	Unbounced Input 3
db1_o	OUT	1	Debounced Output 1
db2_o	OUT	1	Debounced Output 2
db3_o	OUT	1	Debounced Output 3

### 5.1.1 dbpul: Pulse Debouncer

An unbounced signal from e.g. a Button can create multiple signals when once pressed. To get a more reliable signal the input needs to be debounced. Therefor the module waits a specified amount of time when a change happens, until the signal is in a static state. Then this module creates a single one clock cycle pulse.

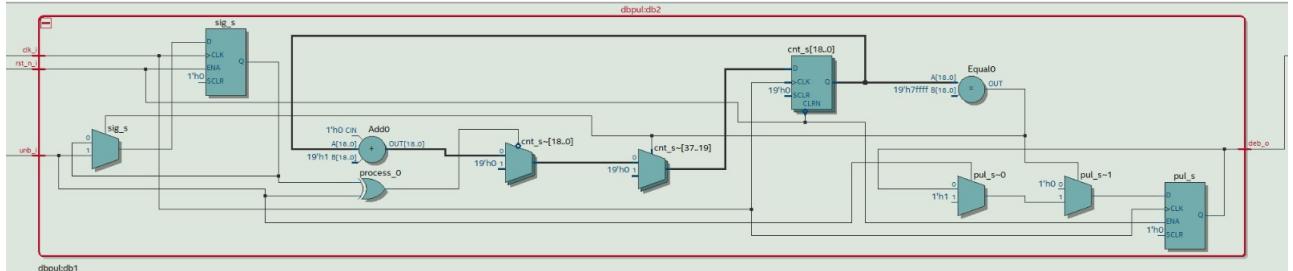


Figure 5.2: dbpul\_db2

Signal	Direction	Width	Description
<code>rst_n_i</code>	IN	1	Reset, active low
<code>clk_i</code>	IN	1	Syscp, @ 12MHz
<code>unb_i</code>	IN	1	Unbounced Input
<code>deb_o</code>	OUT	1	Debounced Output

Generic	Type	Description
<code>dbc_width</code>	integer	Duration of debouncing (vector size)

## 5.2 togg|: Signal Toggle

This module works as a flipflop. Every time it gets a impulse the output toggles. It creates the heartbeat LED pulse from the 1Hz clock signal.

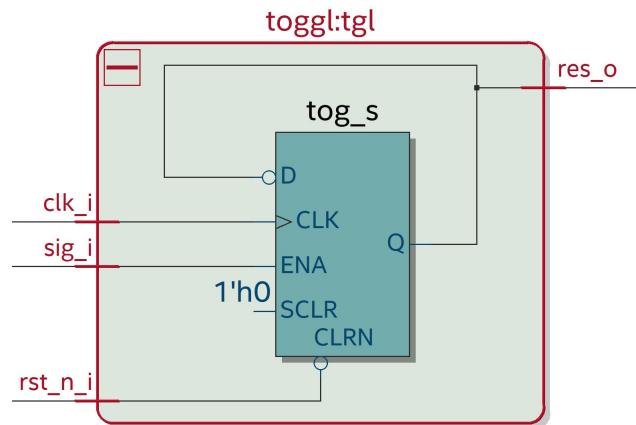


Figure 5.3: toggle\_tgl

Signal	Direction	Width	Description
<code>rst_n_i</code>	IN	1	Reset, active low
<code>clk_i</code>	IN	1	Syscp, @ 12MHz
<code>sig_i</code>	IN	1	Pulseing signal
<code>res_o</code>	OUT	1	Toggled output

## 5.3 clkrt: Clock Rate Generator

This module generates an 1Hz signal as well as an 9600Hz baud rate. To generate those it uses the module clkgn two times.

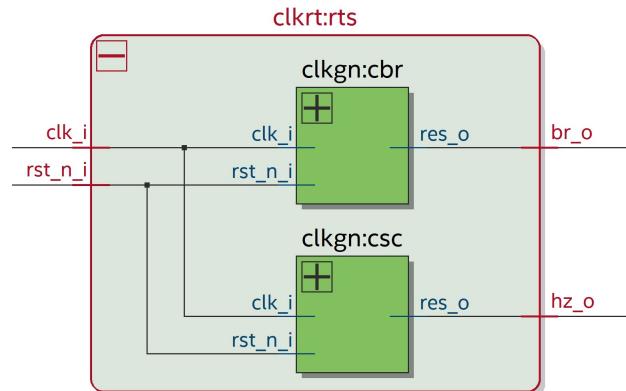


Figure 5.4: clkrt\_rts

Signal	Direction	Width	Description
rst_n_i	IN	1	Reset, active low
clk_i	IN	1	Syscp, @ 12MHz
br_o	OUT	1	Baud Rate @9600Hz
hz_o	OUT	1	Alive Pulse @1Hz

### 5.3.1 clkgn: Clock Generator

This module has a counter, which counts the clock cycles. When the pre-set amount of clock cycles is counted a pulsed is released.

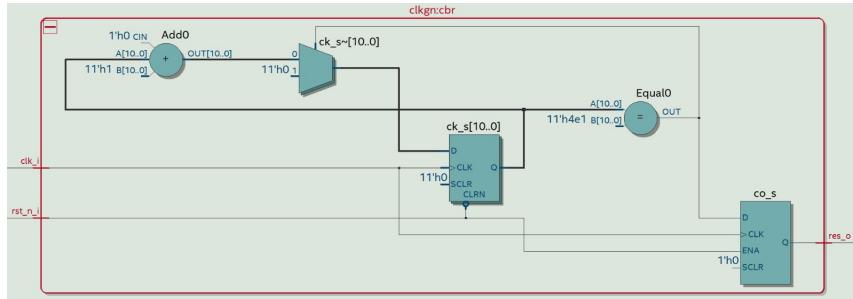


Figure 5.5: clkgn\_cbr

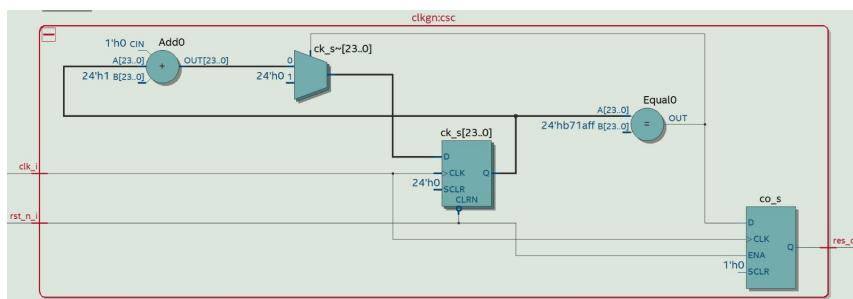


Figure 5.6: clkgn\_csc

Signal	Direction	Width	Description
rst_n_i	IN	1	Reset, active low
clk_i	IN	1	Syscp, @ 12MHz
res_o	OUT	1	Resulting Ticks

Generic	Type	Description
cnt_width	integer	Counter bit vector
div_cnt	integer	Clock cycle durations

## 5.4 trigr: Sensor Handling

This module handles the debounced and pulsed sensor inputs and detects the events. It can recognize if someone is entering or leaving the room. According to the detection a signal is send.

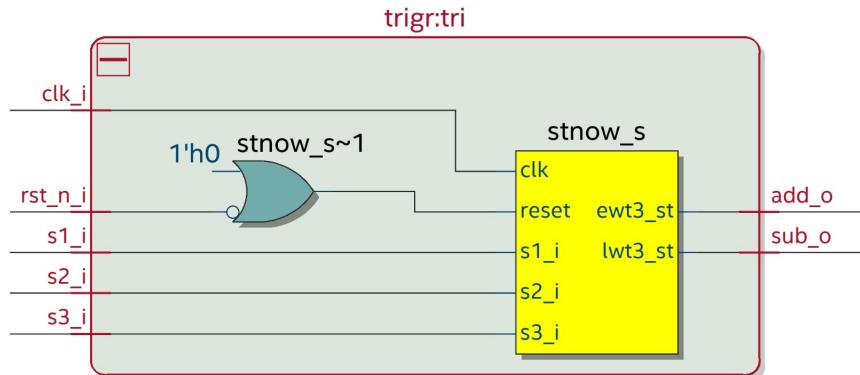


Figure 5.7: trigr\_tri

Signal	Direction	Width	Description
rst_n_i	IN	1	Reset, active low
clk_i	IN	1	Syscp, @ 12MHz
s1_i	IN	1	Sensor 1
s2_i	IN	1	Sensor 2
s3_i	IN	1	Sensor 3
add_o	OUT	1	Person entered
sub_o	OUT	1	Person left

## trigr - Finite State Machine

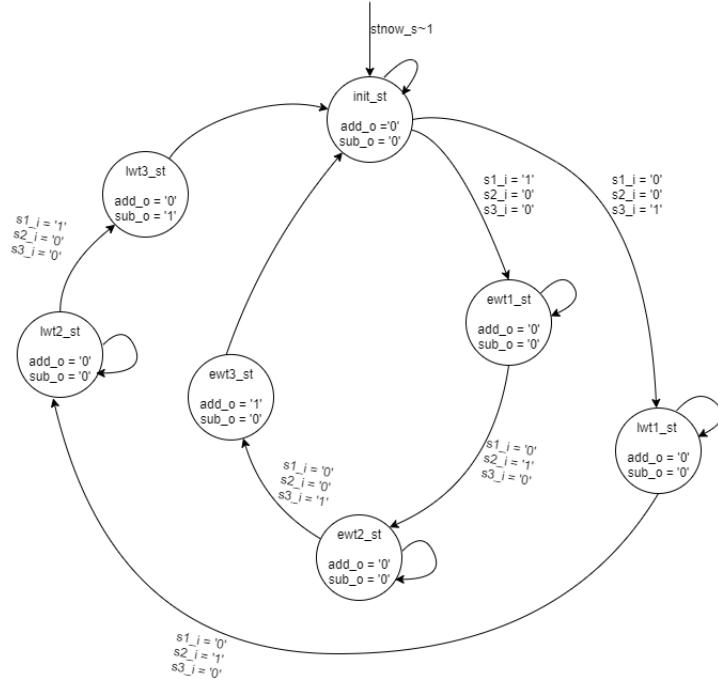


Figure 5.8: Trigger FSM

State Name	Description
init_st	wait for either sensor 1 or sensor 2 triggered
ewt1_st	someone entering, sensor 1 triggered wait for sensor 2
lwt1_st	someone leaving, sensor 3 triggered wait for sensor 2
ewt2_st	someone entering, sensor 2 triggered wait for sensor 3
lwt2_st	someone leaving, sensor 2 triggered wait for sensor 1
ewt3_st	someone entering, sensor 3 triggered -i back to init
lwt3_st	someone leaving, sensor 1 triggered -i back to init

## 5.5 hdcnt: HeadCounter

This module stores the current number of people in the room. It increments or decrements the number if needed. Additionally it indicates if min or max number of people is reached.

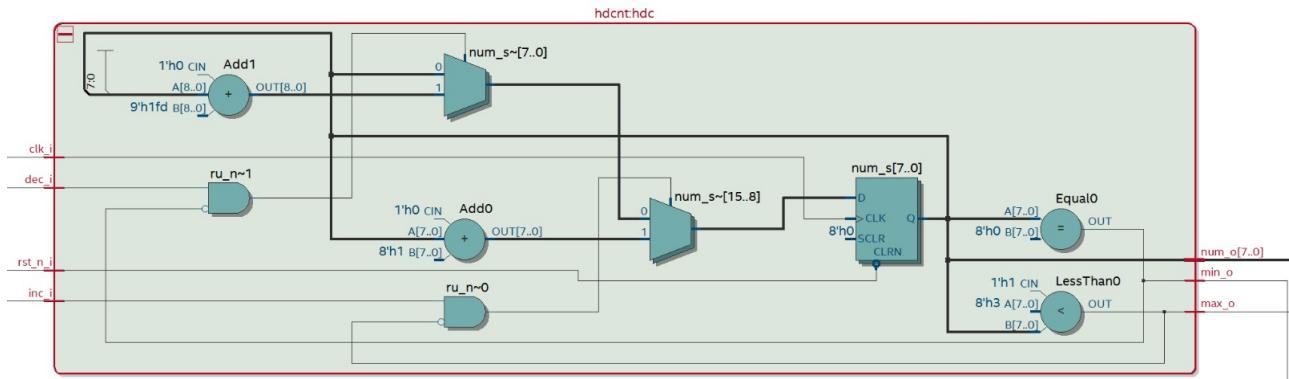


Figure 5.9: hdcnt\_hdc

Signal	Direction	Width	Description
rst_n_i	IN	1	Reset, active low
clk_i	IN	1	Syscp, @ 12MHz
inc_i	IN	1	Increment Counter Signal
dec_i	IN	1	Decrement Counter Signal
min_o	OUT	1	Min persons in room
max_o	OUT	1	Max persons in room
num_o	OUT	8	Contains the number

Generic	Type	Description
cnt_width	integer	Counter bit vector size
max_cnt	integer	Trigger number

## 5.6 cntrl: Controller

This module controls the whole system and decides what to do next according to the inputs and the current states.

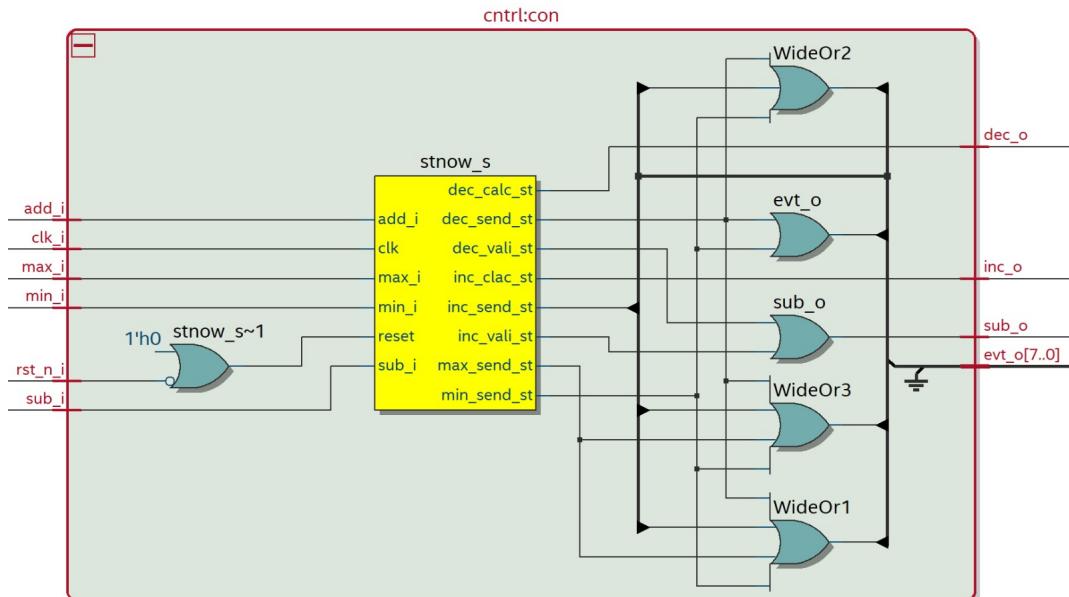


Figure 5.10: `cntrl_con`

Signal	Direction	Width	Description
<code>rst_n_i</code>	IN	1	Reset, active low
<code>clk_i</code>	IN	1	Syscp, @ 12MHz
<code>add_i</code>	IN	1	Person entered
<code>sub_i</code>	IN	1	Person left
<code>min_i</code>	IN	1	Min persons in room
<code>max_i</code>	IN	1	Max persons in room
<code>inc_o</code>	OUT	1	Increment Counter Signal
<code>dec_o</code>	OUT	1	Decrement Counter Signal
<code>evt_o</code>	OUT	8	Happened event char
<code>sub_o</code>	OUT	1	Submitt/Send Data

## cntrl - Finite State Machine

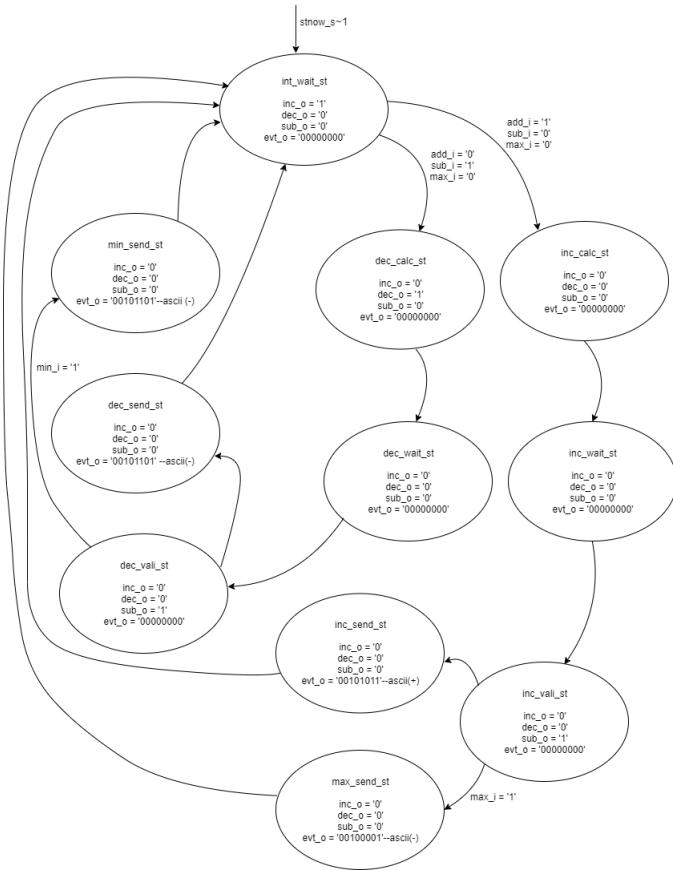


Figure 5.11: Control FSM

State Name	Description
ini_wait_st	wait until
inc_clac_st	send increase signal to headcounter
dec_calc_st	send decrease signal to headcounter
inc_wait_st	wait until headcount calculated
dec_wait_st	wait until headcount calculated
inc_vali_st	done calculating, check if max
dec_vali_st	done calculating, check if min
inc_send_st	start sending num and ascii
dec_send_st	start sending num and ascii
min_send_st	start sending num and ascii
max_send_st	start sending num and ascii

## 5.7 uatpc: UART to PC

This module connects the IC\_S4 to a PC via the RS232. It uses a 9600 baud rate, 8 bit, no parity and 1 stop bit. When the send/data valid bit is received it starts to send the number bit by bit.

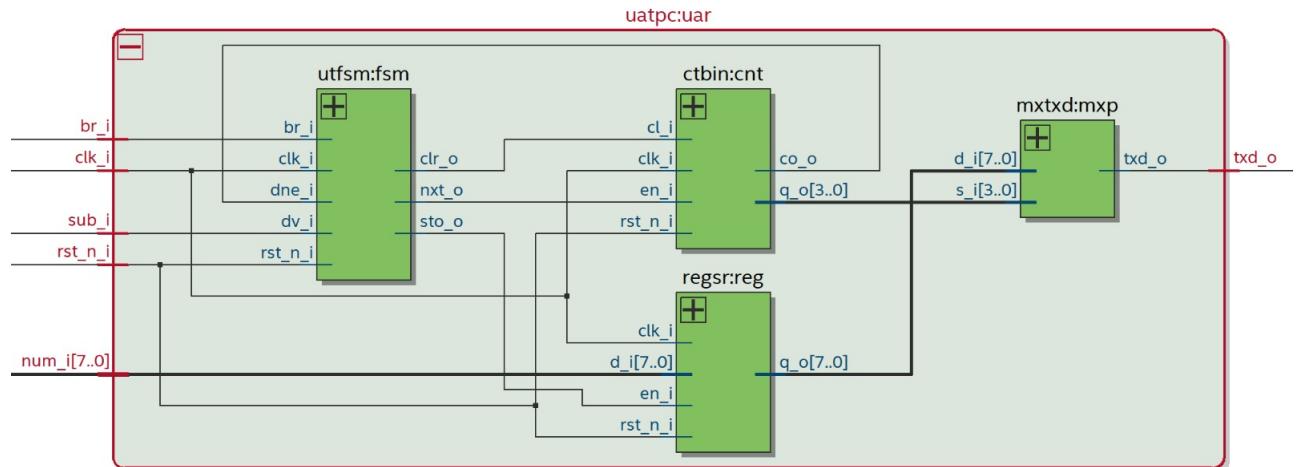


Figure 5.12: uatpc\_uar

Signal	Direction	Width	Description
rst_n_i	IN	1	Reset, active low
clk_i	IN	1	Syscp, @ 12MHz
br_i	IN	1	Baud rate
sub_i	IN	1	Submitt/Send Data
num_i	IN	8	Headcount number
txd_o	OUT	1	Serial output

## UART transmission - Output

UART with 8 Databits, 1 Stopbit and no Parity

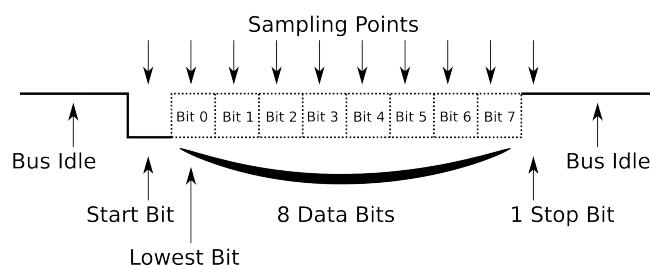


Figure 5.13: Uart FSM

### 5.7.1 regsr: Register to store bits

To secure the number it gets loaded and stored in the register until something new is stored.

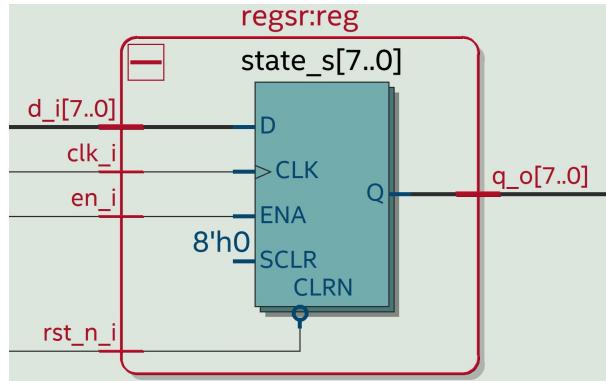


Figure 5.14: regsr\_reg

Signal	Direction	Width	Description
rst_n_i	IN	1	Reset, active low
clk_i	IN	1	Syscp, @ 12MHz
en_i	IN	1	Store Data
d_i	IN	1	Input Data
q_o	OUT	1	Stored Data

Generic	Type	Description
dta_width	integer	Data bit vector size

## 5.7.2 ctbin: Binary Counter

This binary counter counts until a pre-set value. It increments, when an enable counter signal is received. The current number and the carry can always be seen.

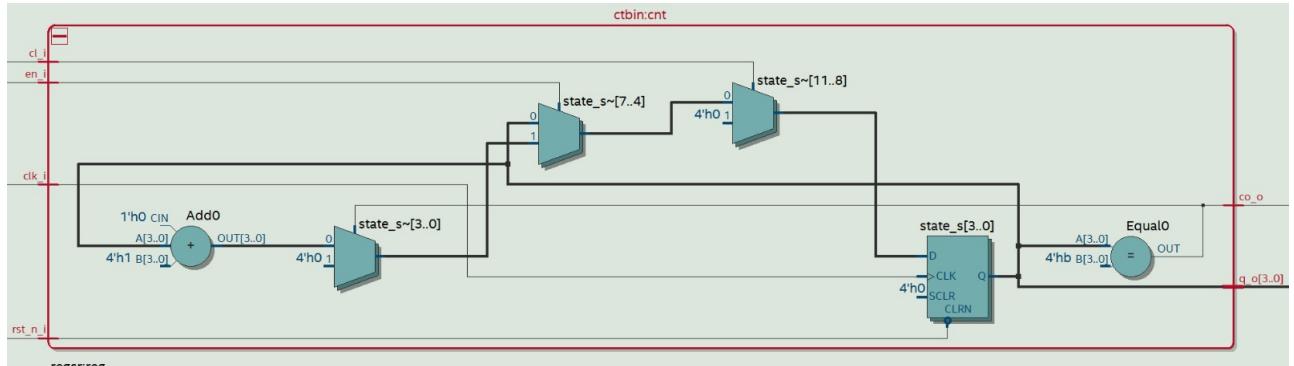


Figure 5.15: ctbin\_cnt

Signal	Direction	Width	Description
rst_n_i	IN	1	Reset, active low
clk_i	IN	1	Syscp, @ 12MHz
en_i	IN	1	Enable Count
cl_i	IN	1	Clear Counter
co_o	OUT	1	Carry Out
q_o	OUT	4	Counter Value

Generic	Type	Description
cnt_width	integer	Counter bit vector size
cnt_max	integer	Trigger number

### 5.7.3 mxtxd: Multiplexer for TXD

This multiplexer has some special states, where it has the required stopbit and initial state, for the UART transmission build in. In total it pushes 10 bits one by one.

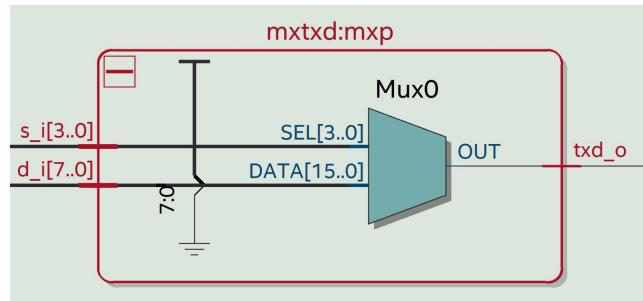


Figure 5.16: mxtxd\_mxp

Signal	Direction	Width	Description
s_i	IN	4	Bit position
d_i	IN	8	Bit vector
txd_o	OUT	1	Txd, Serial Output

### 5.7.4 utfsm: FSM for UART

This module contains the FSM for the UART.

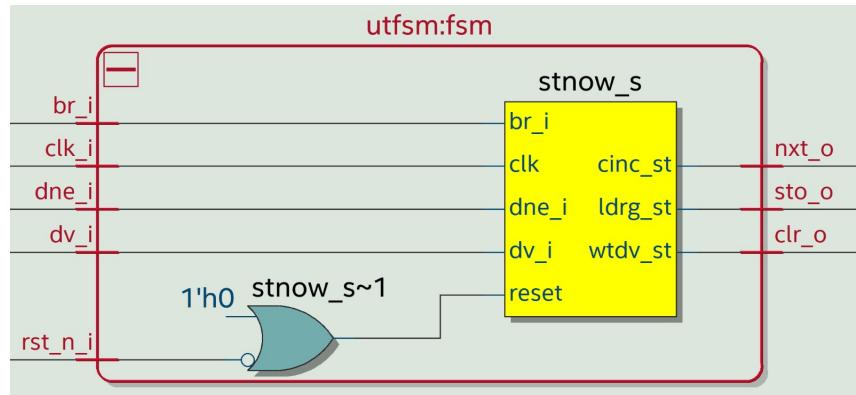


Figure 5.17: utfsm\_fsm

Signal	Direction	Width	Description
rst_n_i	IN	1	Reset, active low
clk_i	IN	1	Syscp, @ 12MHz
dv_i	IN	1	Have new RTC or GPS-Data
br_i	IN	1	Baud-Rate to ena Counter
dne_i	IN	1	Last Bit transmitted
sto_o	OUT	1	enable register load
clr_o	OUT	1	clear Bit-Counters
nxt_o	OUT	1	next Bit, inc count

## utfsm - Finite State Machine

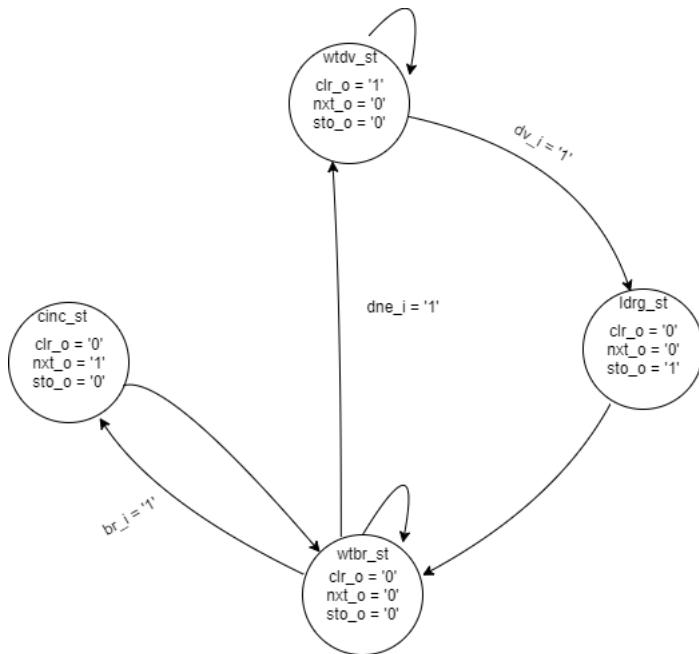


Figure 5.18: Uart FSM

State Name	Description
wtdv_st	wait until data valid
ldrg_st	load data in register
wtbr_st	wait till baud rate is 1 or goto wtdv when done transmitting
cinc_st	get next bit (increment counter)

## 5.8 inf3: Interface to S3

This module connects the IC\_S4 to a IC\_S3 via a 3-wire-interface. It passes the current event as well as the number of people in the room.

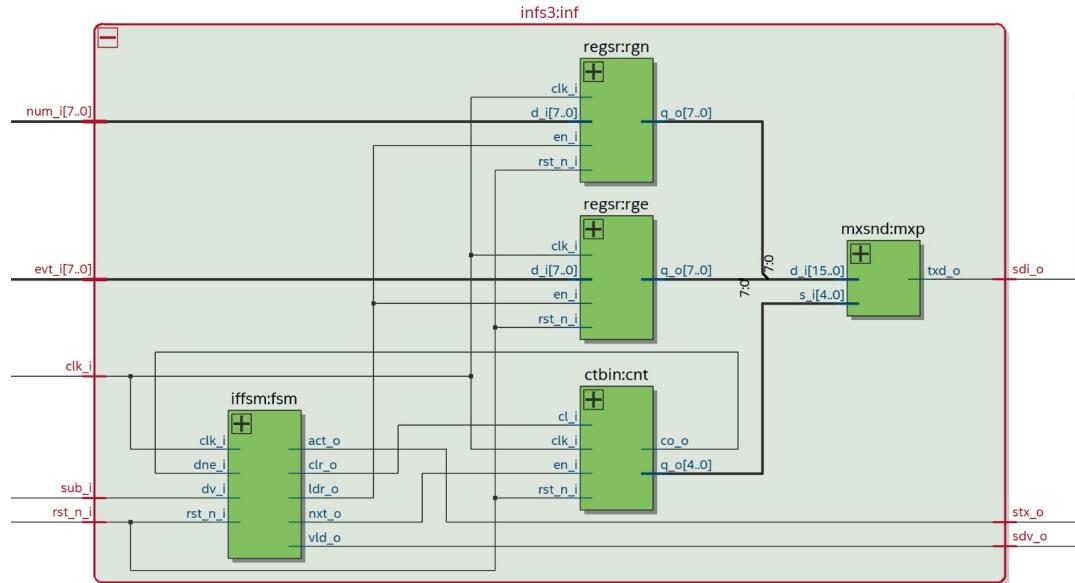


Figure 5.19: inf3.inf

Signal	Direction	Width	Description
rst_n_i	IN	1	Reset, active low
clk_i	IN	1	Syscp, @ 12MHz
sub_i	IN	1	Submitt/Send Data
evt_i	IN	8	Occured event char
num_i	IN	8	Head count number
sdi_o	OUT	1	S3 data value
sdv_o	OUT	1	S3 data valid
stx_o	OUT	1	S3 transmission active

## 3-Wire-Interface transmission - Output

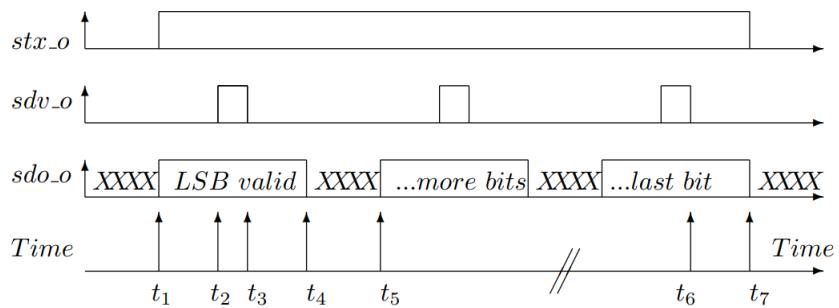


Figure 5.20: Uart FSM

### 5.8.1 regsr: Register to store bits

To secure the number and the event they get loaded and stored in a register until something new is stored.

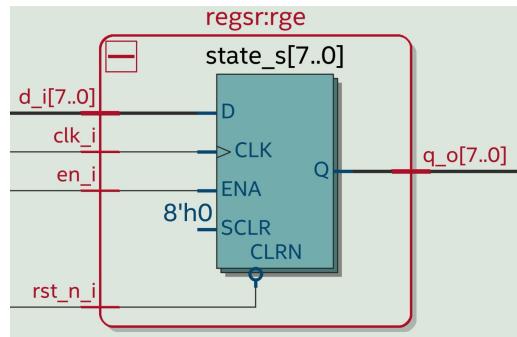


Figure 5.21: regsr\_rge

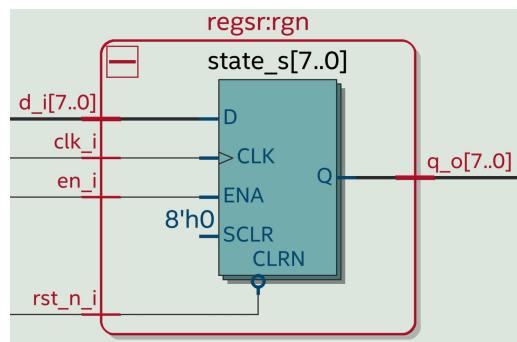


Figure 5.22: regsr\_rgn

Signal	Direction	Width	Description
rst_n_i	IN	1	Reset, active low
clk_i	IN	1	Syscp, @ 12MHz
en_i	IN	1	Store Data
d_i	IN	8	Input Data
q_o	OUT	8	Stored Data

Generic	Type	Description
dta_width	integer	Data bit vector size

## 5.8.2 ctbin: Binary Counter

This binary counter counts until a pre-set value. It increments, when an enable counter signal is received. The current number and the carry can always be seen.

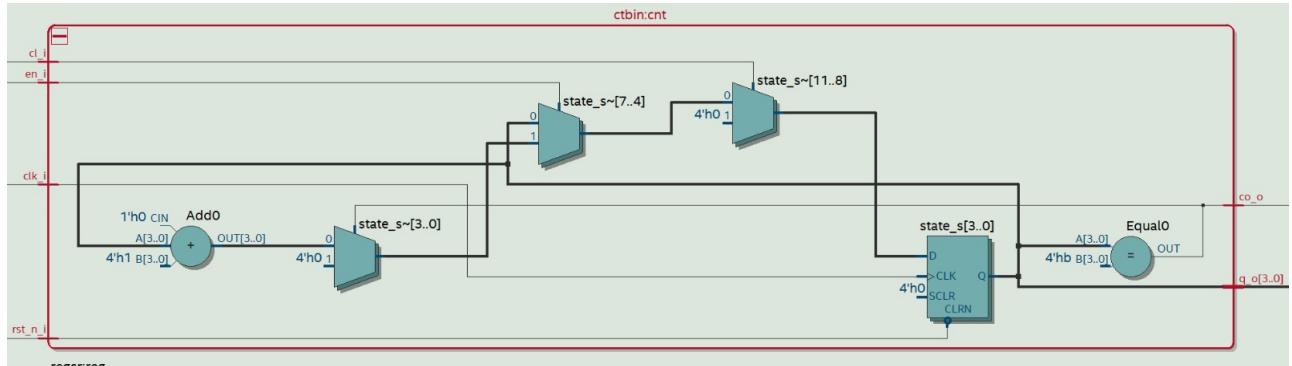


Figure 5.23: ctbin\_cnt

Signal	Direction	Width	Description
rst_n_i	IN	1	Reset, active low
clk_i	IN	1	Syscp, @ 12MHz
en_i	IN	1	Enable Count
cl_i	IN	1	Clear Counter
co_o	OUT	1	Carry Out
q_o	OUT	5	Counter Value

Generic	Type	Description
cnt_width	integer	Counter bit vector size
cnt_max	integer	Trigger number

### 5.8.3 mxsnd: Multiplexer for Interface to S3

This multiplexer has in total 17 bits to push one by one. One of them is a initial 0 bit.

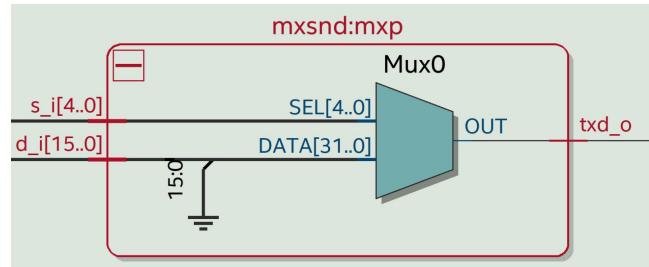


Figure 5.24: mxsnd\_mxp

Signal	Direction	Width	Description
s_i	IN	5	Bit position
d_i	IN	16	Bit vector
txd_o	OUT	1	txd, Serial Output

### 5.8.4 iffsm: FSM for Interface to S3

This module contains the FSM for the 3-wire-interface to S3.

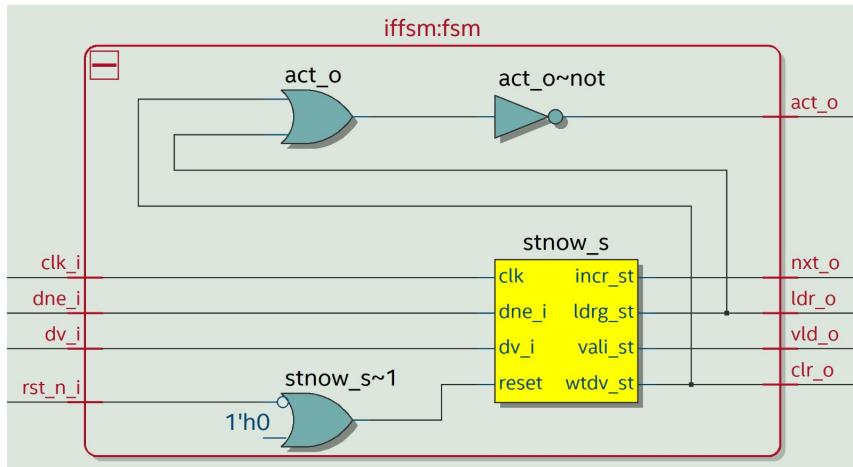


Figure 5.25: iffsm\_fsm

Signal	Direction	Width	Description
rst_n_i	IN	1	Reset, active low
clk_i	IN	1	Syscp, @ 12MHz
dv_i	IN	1	Have new RTC or GPS-Data
dne_i	IN	1	Last Bit transmitted
ldr_o	OUT	1	Enable register load
act_o	OUT	1	Transmission active
vld_o	OUT	1	Data Bit valid
clr_o	OUT	1	Clear Bit-Counters
nxt_o	OUT	1	Next Bit, inc count

## ifs3 - Finite State Machine

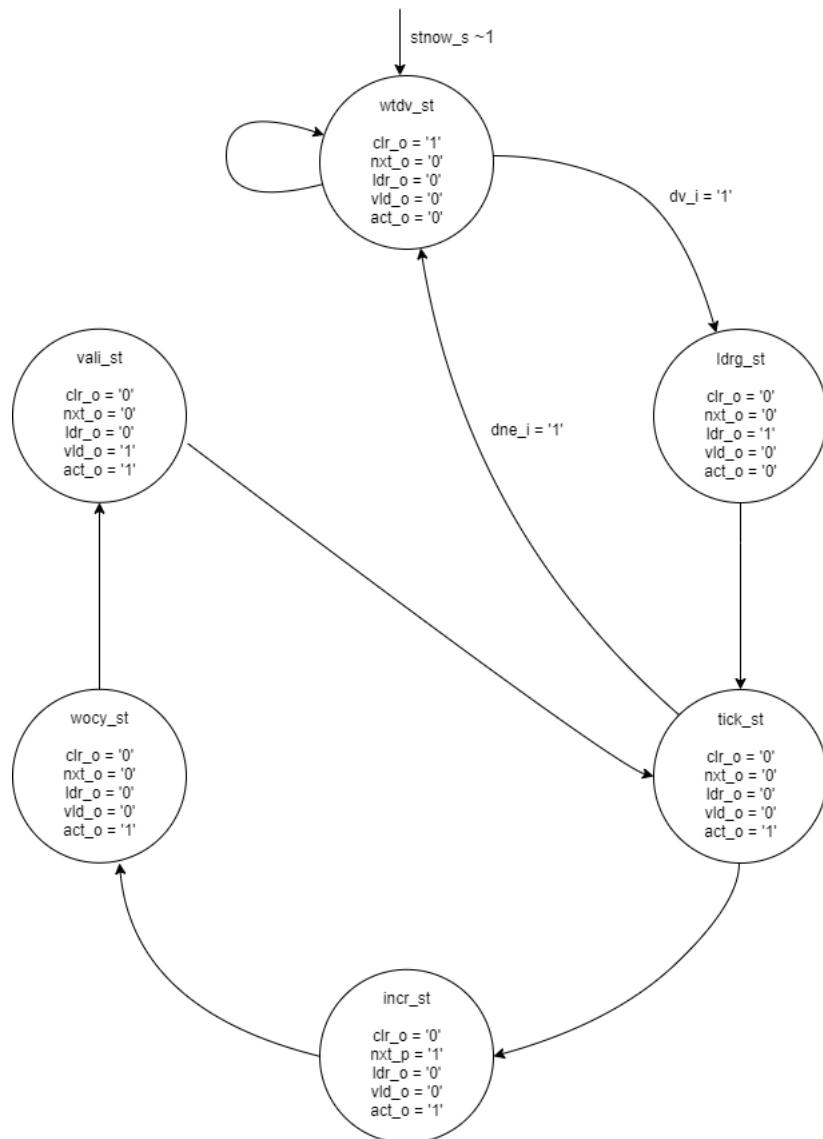


Figure 5.26: ifs3 FSM

State Name	Description
wtdv_st	wait until data valid
ldrg_st	load data in register
tick_st	check if done, else go on
incr_st	get next bit (increment counter)
wocyst	wait one clock cycle
vali_st	send validation bit

# **Chapter 6**

## **Testbenches**

Testbenches are a great tool to test if the requirements are met. Our Project contains multiple testbenches to test the important and complex modules. The trivial modules aren't tested directly, but they are tested in testbenches of modules with higher hierarchy aswell.

### **Testbenches:**

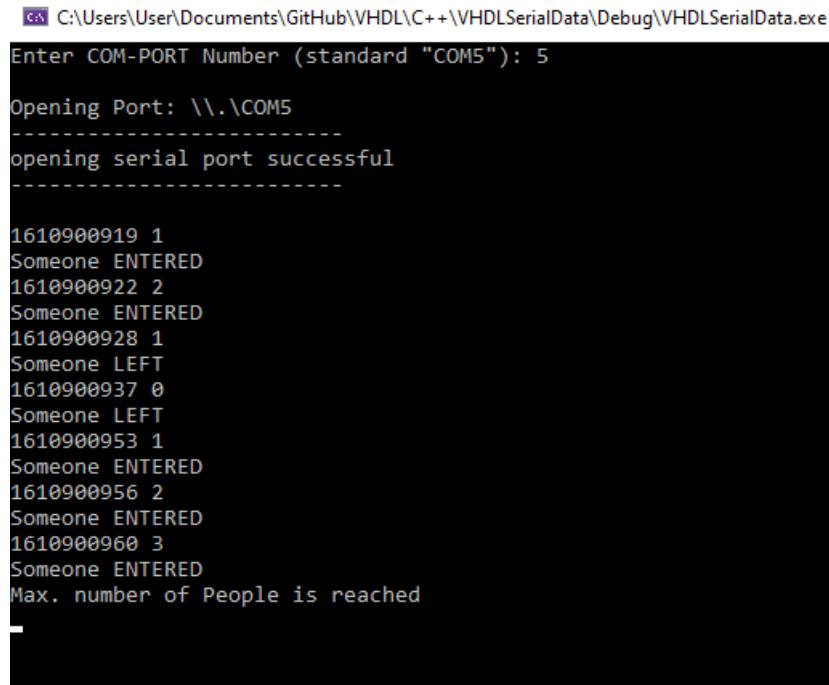
- TB-top
- TB-clkgn
- TB-cntrl
- TB-dbpu
- TB-hdcnt
- TB-infs3
- TB-toggl
- TB-trigr
- TB-uatpc

# Chapter 7

## Program Design

The pc program is written in C++. It monitors a chosen COM-Port and receives the current number of people in the room when it changes.

The program is asking for a port number (between 0 and 10) and tries to open the serial connection afterwards. When an invalid number is entered, it tries to open the serial connection at the standard port COM5.



```
C:\Users\User\Documents\GitHub\VHDL\C++\VHDLSerialData\Debug\VHDLSerialData.exe
Enter COM-PORT Number (standard "COM5"): 5
Opening Port: \\.\COM5
-----
opening serial port successful
-----
1610900919 1
Someone ENTERED
1610900922 2
Someone ENTERED
1610900928 1
Someone LEFT
1610900937 0
Someone LEFT
1610900953 1
Someone ENTERED
1610900956 2
Someone ENTERED
1610900960 3
Someone ENTERED
Max. number of People is reached
```

Figure 7.1: C++ Program Console

Event	Beep One	Beep Two	Description
Enter	LOW	HIGH	Someone entered the room
Leave	HIGH	LOW	Someone left the room
Stop	MEDIUM	MEDIUM	The room is full

# **Chapter 8**

## **Repository - Download**

The repository includes:

- VHDL source code
- VHDL testbenches
- C++ source code
- Documentation/Specification

The lastest version of this project can be downloaded directly from <https://github.com/nlsy/VHDL>.