



# Serial Receiver

## Labor Digital Design

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## 1 | Goals

This lab aims to practice the design of synchronous digital circuits using an [Finite State Machine \(FSM\)](#). It focuses on the implementation of a serial RS232-type receiver, including:

- Understanding the principles of asynchronous serial communication.
- Designing and implementing a shift register and a clock divider counter.
- Creating an [FSM](#) in HDL Designer to control the reception process.

Through this lab, students will gain hands-on experience in combining sequential logic ([FSM](#), counters) with data handling (shift registers) to realize a complete communication module.

The functionality of the receiver will be verified by decoding a message sent by the Xilinx [PicoBlaze](#)  $\mu$ Processor developed in previous labs.



The previous lab `$LABO_DIR/CNT` is a prerequisite. Make sure to have completed, fully tested and imported in your project.

## 2 | Serial Receiver

### 2.1 Serial Transmission

A serial receiver is a digital circuit that converts an incoming asynchronous serial data stream into parallel data suitable for further processing. The [Figure 1](#) shows the timing of the serial transmission of a data word, where the data is transmitted one bit at a time, starting with a start bit, followed by data bits ([Least Significant Bit \(LSB\)](#) first), and ending with one stop bit.

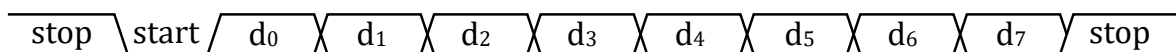


Figure 1 - Serial transmission

### 2.2 Circuit

The core of the design in [Figure 2](#) consist of:

- A shift register to collect the incoming bits and convert them to parallel format.
- A counter to divide the system clock and synchronize with the baud rate of the incoming data.
- A finite state machine ([FSM](#)) to control the reception process, detect the start bit, sample each data bit at the correct time, and validate the stop bit.

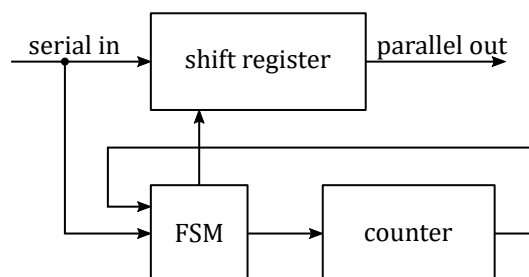


Figure 2 - Block diagram of the serial receiver

The [FSM](#) monitors the serial input line, detects the transition indicating the start of a frame (start bit), and triggers regular sampling pulses via the counter. Each sampled bit is shifted into the register until the complete byte is received. The output is then made available in parallel form for subsequent stages of the system.



Investigate the existing elements and signals in the bloc `COM/serialPortReceiver`.



## 3 | FSM

In the bloc **COM/receiverController**, an **FSM** implements the reception of serial data. The **FSM** manages the timing of the sampling of incoming bits, ensuring that each bit is read at the correct time relative to the baud rate of the incoming data stream.

### 3.1 FSM Elements

Multiple elements are already available and color coded in Figure 3:

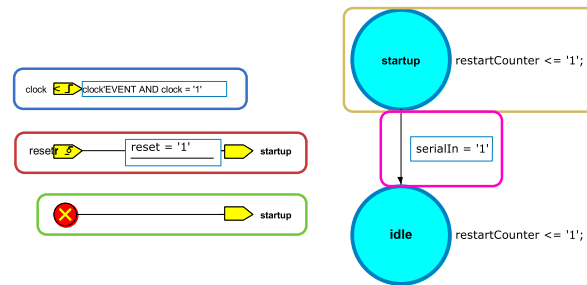


Figure 3 - Elements of the given **FSM**

1. Definition of the clock signal and its triggering condition. In this case, the clock event occurs on the rising edge of the **clock** signal.
2. Definition of the reset signal, reset condition, and the state after reset. In this case, the reset signal is named **reset**; when it is high, the system resets and transitions to the **startup** state.
3. The recovery state used when there is no other valid state assignment.
4. States of the **FSM**. Each state requires a unique name. The code on the right is executed while in the residing in that state (*code is optional*). In this case:

```

1 restartCounter <= '1';
2 -- ^ ^ ^ ^
3 -- | | | +-- Required end symbol of a statement
4 -- | | +---- Value to assign to the signal
5 -- | +----- Assignment symbol (be careful to use <= not =)
6 -- +----- Signal to assign a value to

```

Listing 1 - Code executed in the state **startup**

5. Transition condition to link states together (*conditions are optional*). In this case:

```

1 serialIn = '1'
2 -- ^ ^ ^ ^
3 -- | | | +-- No end symbol like ';' required since this is a condition
4 -- | | +---- Condition to take the transition
5 -- | +----- Comparison operator equals (be careful to use = not ==)
6 -- +----- Left side of the condition is in this case the signal `serialIn`

```

Listing 2 - Condition to take the transition between the states **startup** and **idle**

It can be translated to “if the signal **serialIn** is equal to '1', then the state will change”.



### 3.2 States and Transitions

The **FSM** has multiple states, each representing a specific phase of the reception process. The transitions between these states are triggered by events defined in the arrows. If the arrow has no trigger it means that the transition is always active and that the next clock cycle always jumps to the next state.

On top of the editor are several toolbars with all required functions to edit the **FSM**. The first toolbar Figure 4 allows you to create new **states** (blue circle) and **transitions** (black arrow).



Figure 4 - Toolbar to create new **states** or **transitions** in a **FSM**

### 3.3 Action code, Transition statements and Expression builder

For all actions or transition conditions you have to write **Very Highspeed Integrated Circuit Hardware Description Language (VHDL)** code. For this labo we only need to write simple **if** conditions for the transitions - see Listing 2 - or simple signal assignments for the states - see Listing 1 -.

The second toolbar contains the button to open the **expression builder** Figure 5, it allows you to create new expressions for the conditions of the transitions and code within the states.



Figure 5 - Toolbar open up the **expression builder**



To edit a state action or a transition condition, you can double-click on the state or transition in the editor. This opens a code editor where you can write/edit the **VHDL** code for the action or condition.

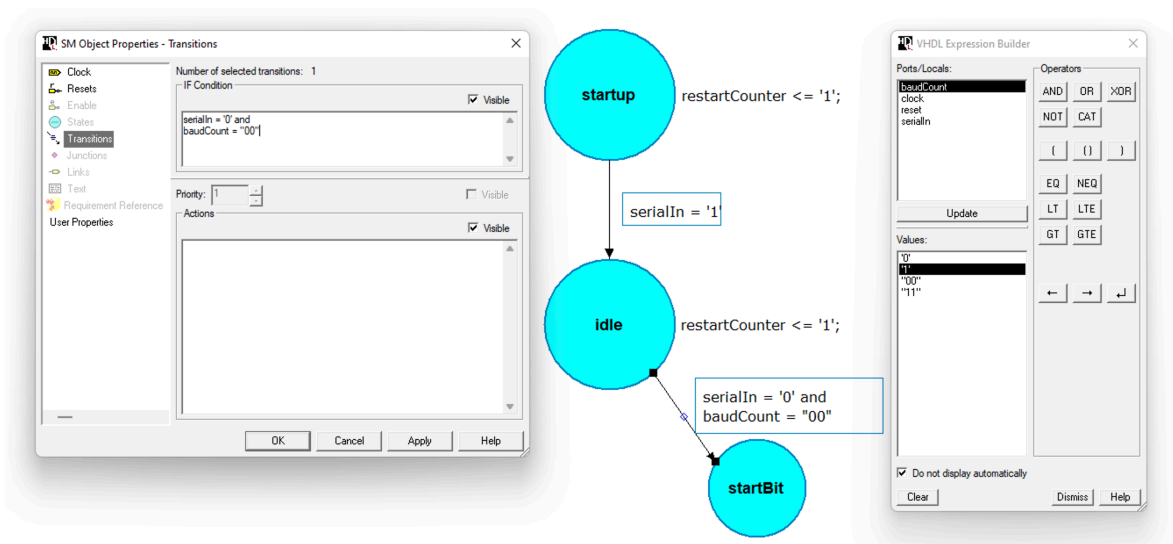


Figure 6 - Code editor for a state action or transition condition



A comparison with a single bit signal such as **serialIn** or a multiple bits signal such as **baudCount** is slightly different.

1. Comparison are not made with `==` as in other programming languages, but with only one `=`.
2. The comparison value for single bit signals is enclosed in single quotes `'` and for multiple bits in double quotes `"`.
3. You can combine multiple conditions together with boolean operators such as **and**, **or** and **not**.

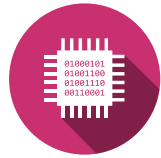


For example, to check if the serial input is low and the baud count is zero, you can write:

```

1  serialIn = '0' and baudCount = "00"
2  -- \      / ^ \      /
3  -- |      | |      +--- Comparison of a multibit signal
4  -- |      | |      +----- boolean operator
5  -- +----- Comparison of a single bit signal

```



## 4 Implementation

The three main components of the serial port receiver to be implemented are:

- **COM/shiftRegister** for collecting the incoming bits and converting them to parallel format.
- **COM/baudrateCounter** for dividing the system clock and synchronizing with the baud rate of the incoming data.
- **COM/receiverController** for controlling the reception process, detecting the start bit, sampling each data bit at the correct time, and validating the stop bit.

### 4.1 Analysis

In order to precisely control the reception of serial data, the timing of the received bits are crucial.

The sending on the serial port is done by the  $\mu$ Processor Picoblaze developed in the previous labors.

The code used is the linear one, without loops, as given under [Listing 3](#):

```

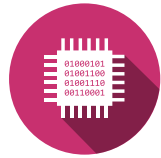
1  LOAD      s3, FF          ; load stop bit
2  OUTPUT    s3              ; output stop bit
3  LOAD      s3, s3          ; no operation
4  LOAD      s3, s3          ; no operation
5  LOAD      s3, s3          ; no operation
6  LOAD      s3, s3          ; no operation
7  LOAD      s0, 00          ; load start bit
8  OUTPUT    s0              ; output start bit
9  INPUT      s1              ; load word to send
10 OUTPUT    s1              ; output word, LSB is considered
11 SR0       s1              ; shift word, bit 1 -> LSB
12 OUTPUT    s1              ; output bit 1
13 SR0       s1              ; bit 2 -> LSB
14 OUTPUT    s1              ; output bit 2
15 SR0       s1              ; bit 3 -> LSB
16 OUTPUT    s1              ; output bit 3
17 SR0       s1              ; bit 4 -> LSB
18 OUTPUT    s1              ; output bit 4
19 SR0       s1              ; bit 5 -> LSB
20 OUTPUT    s1              ; output bit 5
21 SR0       s1              ; bit 6 -> LSB
22 OUTPUT    s1              ; output bit 6
23 SR0       s1              ; bit 7 -> LSB
24 OUTPUT    s1              ; output bit 7
25 LOAD      s3, s3          ; no operation
26 OUTPUT    s3              ; output stop bit

```

Listing 3 - Linear algorithm



Reading the given code [Listing 3](#), and looking at the **COM\_test/serialPortReceiver\_tb** block, determine which serial code is sent by the processor.



Determine the number of clock cycles required to send one bit.



For this, refer to the code [Listing 3](#), the baudrate calculation performed in the previous laboratory **CNT**, as well as the **serialOut** signal of the **COM\_test/serialPortReceiver\_tb** circuit when simulated with the file **\$SIMULATION\_DIR/COM.do**.

## 4.2 Development

With all the informations gathered in the previous section, you can now implement the three main components of the serial port receiver.

### 4.2.1 Shift register

Data comes in serially, one bit at a time, and needs to be collected and stored in a parallel format for further processing. A **shift register** is ideal for this purpose, as it can shift in each incoming bit on a control signal and output the complete byte in parallel.



Implement the shift register **COM/shiftRegister**. Each time the input must be shifted, the signal **shiftEn** is set to **1**.

### 4.2.2 Baudrate counter

To accurately sample the incoming serial data, a counter is needed to divide the system clock down to the baud rate of the incoming data. This block generates a count value which can be used to know when to sample the incoming bits, where we are in the received frame, and/or when to reset for the next frame...

When sampling a bit, it must be as close to the middle of the bit period as possible.



- Determine the number of bits required for the counter **COM/baudrateCounter** depending on how you will use it.
- Input the required number of bits in the system. For this, in the **COM/serialPortReceiver**, double click the **baudCounterBitNb** constant definition at the top left of the schematic and edit it in the newly open window under **User Declarations** as shown under [Figure 7](#) then click **Apply**:

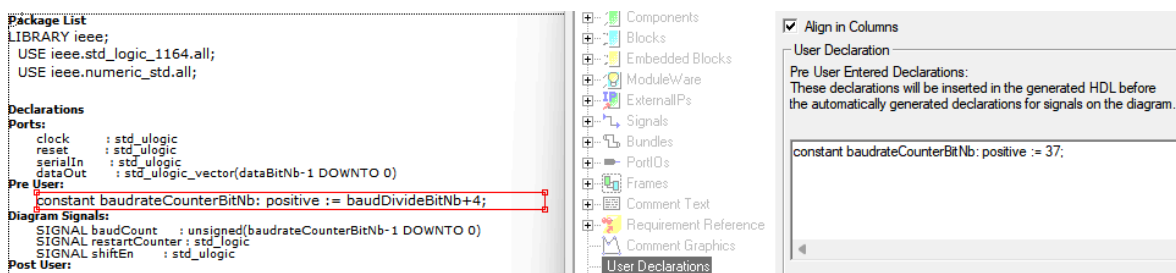
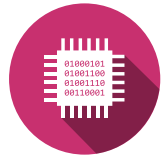


Figure 7 - Modify system counter bit number



Implement the counter **COM/baudrateCounter**.

- Do not forget to validate/change the number of bits of the signal **baudCount**.
- The counter needs to support a synchronous reset which sets it back to value **0** when the **restartCounter** is **1**.

#### 4.2.3 Receiver controller (FSM)

The finite state machine (**FSM**) is the brain of the serial port receiver. It monitors the serial input line, detects the transition indicating the start of a frame (start bit), and triggers regular sampling pulses based on the counter value. Each sampled bit is shifted into the register until the complete byte is received. The output is then made available in parallel form for subsequent stages of the system.



Implement the finite state machine **COM/receiverController**. It needs to detect the beginning and ending of a packet and generates the signals **restartCounter** as well as **shiftEn** accordingly.

### 4.3 Simulation

Once implemented, simulate the three components with the testbench **COM\_test/serialPortReceiver\_tb**. The  $\mu$ Processor Xilinx Picoblaze developed in the previous labors will be used to send the serial data to the **COM/serialPortReceiver**.



Simulate the testbench **COM\_test/serialPortReceiver\_tb** with the simulation file **\$SIMULATION\_DIR/COM.do**.

Validate that the various sent bytes are correctly decoded onto the **dataOut** signal.

### 4.4 System analysis

Now that the serial port receiver is implemented and simulated, answer the following questions:



1. How long does one bit take to be sent by the  $\mu$ Processor Picoblaze in terms of time (i.e. transmission bitrate)?
2. How long do two data take to be received ?
3. Why are the data bits sampled as close to the middle of the bit period as possible?
4. What happens if the baud rate of the sender does not match the baudrate of the receiver?





## 5 | Checkout

This is the end of the labo, you have successfully built a system with several different blocks. Before leaving the laboratory, ensure you have completed the following tasks:

- ☐ Theory
  - ☐ You understand how to create [FSM](#) in HDL Designer.
- ☐ Circuit Design
  - ☐ The three blocks **COM/shiftRegister**, **COM/baudrateCounter**, and **COM/receiverController** have been created and tested.
- ☐ Simulations
  - ☐ The data sent by the **COM/nanoprocessor** is correctly read and parallelized by the **COM/serialPortReceiver**.
  - ☐ The individual bits are read as close to the middle as possible.
- ☐ Analysis
  - ☐ You have answered the system analysis questions.
- ☐ Documentation and Project Files
  - ☐ Ensure all steps (design, simulations, comparison) are well documented in your lab report.
  - ☐ Save the project on a USB stick or in the shared network folder (**\\filer01.hevs.ch**).
  - ☐ Share the files with your lab partner to ensure continuity of work.



# Glossary

**FSM** – Finite State Machine [1](#), [1](#), [1](#), [2](#), [2](#), [3](#), [3](#), [3](#), [3](#), [4](#), [4](#), [4](#), [8](#), [9](#)

**LSB** – Least Significant Bit [2](#)

**PicoBlaze**: PicoBlaze is a small, 8-bit microcontroller designed by Xilinx for use in FPGAs. It is often used in educational settings to teach basic microcontroller concepts. [1](#)

**VHDL** – Very Highspeed Integrated Circuit Hardware Description Language [4](#), [4](#)