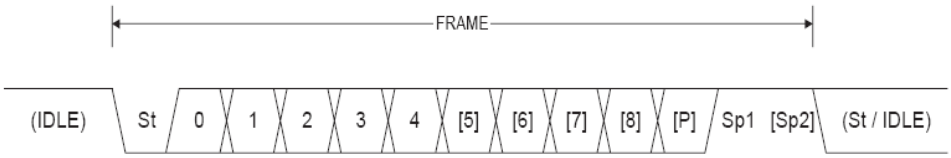
Exercise 2: Serial Communication

1 UART

Universal Asynchronous Receiver/Transmitter (UART) is a piece of hardware that translates data between parallel and serial data. UARTs are usually used in conjunction with other communication standards such as *EIA RS-232* (like in our case) to perform serial communication. The UART takes bytes of data and transmits the individual bits in a sequential fashion. At the destination, a second UART re-assembles the bits into complete bytes. Most microcontrollers today provide built-in UART functionality. In our target microcontroller, there is 1 UART port available.

In asynchronous transmitting, a UART frame consists of the following bits (figure 1):



St	Start bit, always low
(n)	Data bits (0 to 8)
P	Parity bit. Can be odd or even
Sp	Stop bit, always high
IDLE	No transfers on the communication line (RxD or TxD). An IDLE line must be high.

Figure 1: UART Frame Format

- Start bit: always 1 bit with the opposite polarity of the data line's idle state.
- Data bits: 5 to 8 bits, least significant bit first.
- Parity bits: optional (0 or 1 bit), odd parity mode and even parity mode supported.
- Stop bits: 1, 1.5, or 2 bits.

Some microcontrollers also support synchronous transmission mode (USART), in which the clock data is recovered separately from the data stream and no start/stop bits are used. This improves the efficiency of transmission on the channel. ATmega8515 also support it, but for reasons of simplicity, we will only use the asynchronous transmission (normal mode) in this lab course.

The UART settings (number of data bits, parity, number of stop bits) must be agreed between PC and target (the microcontroller in our case) before communication starts. At the target side, those settings are configured in special registers. Another key parameter that needs to be set before communication is the baud rate (transmission speed). For UART there are a set of predefined baud rate values that we can choose from.

Remember: Save each of the solutions to the exercises in this lab course as a separate *AVRStudio* project and send all the projects together with the answers to the questions to the organizers of the lab course when you are finished.

Exercise 2.1

a) Which pins serve for receiving data (RXD) and transmitting data (TXD) in ATmega8515, respectively? Connect the two-wire cable so that the corresponding pins and the UART connector (*RS232 SPARE*) are connected.

b) What is the difference between a baud and a bit? Do some research on the internet.

c) Start the *HyperTerminal* application (*Accessories* → *Communications* → *HyperTerminal* in the start menu). Enter an arbitrary profile name and select a valid COM port. Have a look at the available settings. List the standard baud rates that are available. Which of these baud rates are theoretically supported by ATmega8515 at a clock speed of 8 MHz? Read the ATmega8515 manual and calculate the possible baud rates.

d) Read the ATmega8515 manual to find out which register is used to configure the baud rate of the target. What value should we put into this register for a given baud rate? Write down the formula for asynchronous normal mode. Which bits of the UBRR value have to be put into which hardware register?

e) List the registers and the corresponding bit fields that are relevant for storing other UART related settings and data in ATmega8515.

2 Polling-based UART communication

Programming a microcontroller without a debugger is a painful task. In this section, we will try to build a UART based debugger on our own. The idea is to forward the standard output channel (written to by C functions like `putchar()`, `puts()`, `printf()`, etc.) via a UART connection to the PC and use a terminal application to visualize the output.

Exercise 2.2

a) Write a function `uart_init()` that initializes the UART of ATmega8515 using the following parameters: Asynchronous normal mode, 9600 baud, 8 data bits, no parity bit, 1 stop bit. Make sure your code is readable (i.e., not just calculate the register values in advance, but set each bit individually by using the shift operator and the bitwise OR operator).

b) Read the manual including sample C code and develop a function named `uart_putchar()` for sending a single character `c` to the terminal. The signature of the function should be (we will later see why):

```
int uart_putchar(char c, FILE* stream);
```

Let your function always return `0` and ignore the `stream` argument. Establish a *HyperTerminal* connection with the same baud rate, data bits, stop bits and parity mode as on the target and disable flow control. Test your `uart_putchar()` function.

c) Based on your `uart_putchar()` implementation, implement and test a `uart_puts()` function that can print a whole character string to the console. Always append a Windows line break (`"\r\n"`) at the end of the transmission. Test your implementation by sending `"Hello world!"`.

Hints

- There are two serial connectors on the development board. The one named *RS232 CTRL* is used to program the device and *RS232 SPARE* is used for normal communication (e.g., our debug console). We recommend to attach both serial cables to the host PC so that you do not need to reconnect the cable between programming and communicating. Each host PC should have an additional serial port connector below the VGA slot.
- In C language, strings are terminated with a special character '\0', which is automatically inserted by the compiler. For example, assume we define a string using the following statement:

  ```
  char str[13] = "Hello world!";
  ```

  Although the string only has a length of 12 characters, we need to request 13 bytes of memory to store `str`, because the last byte is used to store the terminator '\0'. The standard C `puts()` function continues to output a string until a terminator is detected. Try to implement your own `uart_puts()` function in the same way.
- The `uart_putchar()` and `uart_puts()` functions developed in this exercise will serve you well during the rest of the lab course as they facilitate debugging of the target device. Hence, you should make sure that they work properly before continuing.

Exercise 2.3

Up to now we can only print a constant string to the terminal. To build a debug console, it is important that we can print the current value of a certain variable. The C standard function `printf()` can be used to do this.

a) Familiarize yourself with the `printf()` function (e.g., by "Googling"). Write down some example format strings for formatting character strings, decimal integers and hexadecimal integers.

b) The standard C I/O functions (e.g., `puts()` and `printf()`) forward the output string to a predefined channel called `stdout`. On a PC, this channel is normally bound to a console window, a file or a different process. We will now replace `stdout` with the serial port, so that the output can be visualized at the host side. Add the following statements to your `main()` function (and include `<stdio.h>`):

```
/* File handle for standard output via UART */
static FILE uart_stdout = FDEV_SETUP_STREAM(uart_putchar, 0, _FDEV_SETUP_WRITE);
stdout = &uart_stdout;
```

In these statements, we created a *fake* file called `uart_stdout` and replace the standard `stdout` object with our own file. Now if you use `printf()` function, the characters are redirected to the serial port by calling the `uart_putchar()` function, which you have developed in the previous steps The reason why we chose the specific signature in exercise **2.2 b)** is that this function expects a pointer to a function with exactly that signature. Test whether the `printf()` function works as you expected using different format specifiers.

Hints

- To make formatting floating-point numbers using `printf()` work, you will need to tweak the project's *Configuration Options* a little bit: In the *Libraries* tab, add the objects `libm.a` and `libprintf_flt.a`. In the *Custom Options* tab, select the `[Linker Options]` item on the left and add the value `-Wl,-u,vfprintf` to the parameter list.

Exercise 2.4

a) Write a function `uart_getchar()` that waits until a single character is received on the serial port and returns that character. To prove that the function works, let the LEDs attached to `PORTB` display the (ASCII) character code of the received character. Find out the character code of a captial 'A' by sending it to the target and interpreting the status of the LEDs.

b) Write an *echo* application. Upon receiving any data from the host side, send back exactly the same data.

c) Create a generalized implementation of `uart_init()` named `uart_init2()` that takes the following parameters:

- Baud rate (as a numeric value)
- Mode (asynchronous normal, asynchronous double speed, synchronous master)
- Parity mode (none, even, odd)
- Number of stop bits (1, 2)
- Number of data bits (5, 6, 7, 8)

Use the enumerations from the `uart_params.h` file. Test your implementation with various settings on the target and the host side.

Hints

- Displaying the (ASCII) character code of the received character using the LEDs is actually very simple. Remember that characters are already treated as numbers internally. Do not forget to invert the bits because of the inverse logic of the LEDs.

Notes

- It is not a problem if you do not finish an exercise within one session. For reasons of structure, some exercises will be longer, others shorter. You can also work on the solutions in the next session. The following exercise is for those who are faster.

Exercise 2.5 (optional)

a) Optional: Generalize your set of UART functions so that they can handle 9 data bits (name them differently from the original functions so that you can still use the "normal" ones).

b) Optional: `printf()` is a *variable-argument function*, which means the it can take a variable number of input parameters. If you are interested (or have some spare time), ask the tutor to provide you a `printf()` implementation. This implementation works exactly the same as standard C. Have a look at the `printf()` implementation to find out how to declare and implement a variable-argument function.

Notes

- Regarding the increased flash memory consumption, you should not tend to use your generic `uart_init()` function in the subsequent exercises of this lab course. Use the dedicated function from exercise **2.2 a)** instead.