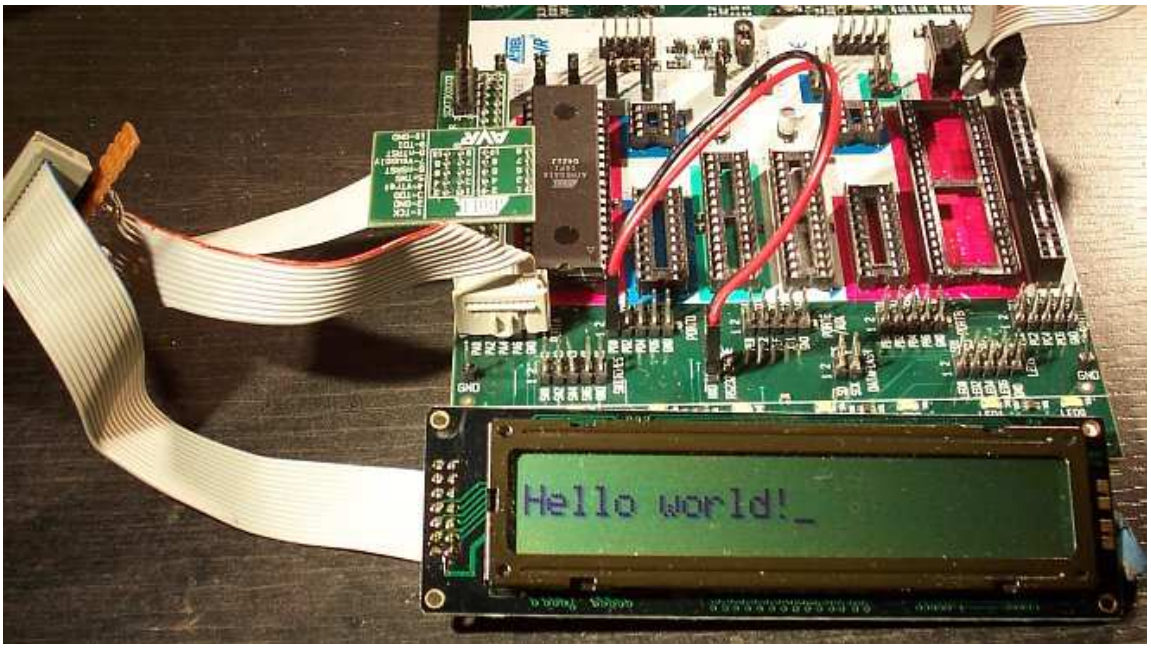
FYS3240: Mandatory exercise 3

Human-Machine interface and communication

Part 1

In the first part of this exercise you are supposed to play with a small screen, or display if you like. This is one step up from the General Purpose IO ports of mandatory exercise 2, but in principle just more of the same. But in this exercise you will have to take timing into account. That is, the sequence of port strobing.

The screen is a Liquid Crystal Display [LCD] of the passive or STN variety. This is the same kind found on home stereos, security systems and the like. But unlike the very naked displays mounted in this kind of home appliances, this display will be equiped with a dedicated display(micro)controller and thus, more to be considered a display module. This display controller will be a Hitachi HD44780U or equivalent protocol compatible clones like SANYO LC7985N or Samsung KS0066U.



Loads of datasheets can be found here, whilst this homepage offers a lot of help on the subject. All of these LCD controllers may drive a LCD display at a maximum of 1×80 or 2×40 `[lines×characters]`, limited only by the amount of on-chip ***D**ata **D**isplay **RAM*** of 80 characters. The display controller has built-in support for 1 or 2 lines in its' firmware. But there is little stopping the manufacturers of these display modules physically (electronically) wrapping each line of the glass in two effectively producing a 4×20 character module. Even so, these modules will from a software point of view still look like a 2×40 character module. There are also 4×40 character modules on sale — these sport *two* display controllers with one separate *enable* `[E]` line each. Our module is primarily inteded for pure text, specifically two lines of 16 characters each. The display controller may scroll text longer than 16 characters (up to a maximum of 40 characters,) each line by its' own. The display controller will take care of rendering the text. Our display module comes at a cost of about twice the AVR microcontroller.

What you are supposed to do is feeding the display controller with strings of text. The SRAM based data memory of the ATmega323is rather limited. You are therefore to refer the strings of text to the FLASH based program memory and copy these constant strings from there into data memory as needed, scrapping them afterwards. A problem you will encounter in doing this is the fact that AVR is a so called

Harvard architecture meaning that the data- and program storage is completely separated with separate address spaces. To gain access to program memory you will have to perform specialised "`Load Program Memory`" instructions in assembly language. It can also be done from within AVR-GCC by means of a set of compiler extensions. These extensions are declared in the headerfile ("#include <avr/pgmspace.h>") Do note that ATmega323 program space is not writeable runtime, with the consequence that any data to be placed there must be placed there compile time. This problem can easily be solved by the following code extract:

```
#include "HD44780U.h"                                                    // User supplied
#include <inttypes.h>                                                    // (u)int8/16/32_t
#include <avr/pgmspace.h>                                                // "(E)LPM" C routi

/*** DEPRECATED: ***/
// const uint8_t              /* progmem */ *sofar;                     // Z-register point
// const uint8_t __attribute__ ((progmem))   Hello[] = "Hello World!";  // Const string to

PGM_P        sofar;                                                      // Z-register point
prog_uint8_t Hello[] = "Hello World!";                                   // Const string to

uint8_t character;

int main(void){
  LCD_init( /* mode flags */ );

  sofar = Hello;                                                         // Initiate Z-point
  while ((character = pgm_read_byte(sofar)) && \                         // Read single char
         (LCD_putch(character) >= 0)) sofar++;                           // Output character
}
```

No use looking for the headerfile "`HD44780U.h`" of the above example. You are supposed to write that yourself. Alternatively you may include all LCD routines in one and the same sourcefile together with the rest of the program. This is however an exellent opportunity to practise some "project management" where multiple source code files with corresponding headerfiles are to be linked together to the final program memory image. E.g. the already mentioned "`HD44780U.h,`" the accompanying "`HD44780U.c`" plus the main file "`Oblig3a.c`"

Seize the opportunity to remind you that all source files will be compiled *each by itself* into *corresponding* object files, that in the last stage are linked together into the final image. Refer the GCC flow diagram. This is exactly the reason we need headerfiles for declarations (*not* defenitions) of resources shared between source files. A headerfile *exports* symbols from one source file to the next. Any source file will therefor normally *not* import its' own accompanying headerfile. Consider the headerfil the card of the source file. — contact information to be shared. If access to actual data is to be shared, then the declarations in the headerfile must be prefixed by a '`extern`' keyword. The defenition proper is to reside in the source file as before. But you are to present a really good reason to share actual data (as opposed to methods,) or I will come smack your fingers. Declarations of functions are on the other hand and inconsequently implied '`extern`' by nature in the **C** programming language. But then again it is the latter that is *supposed* to be shared between source files, not data. This is the foundation of object oriented programming — share the methods data can be manipulated with, not the actual data.

The text strings you are to feed the display controller with is to be represented by a 8-bit character set that is defined in the datasheet of the display controller. The lower 7 bits of this character set is loosely to be considered ISO-646-US-ASCII (American National Standard Code for Information Interchange) or equivalently ECMA-006.

ASCII is a seven bit wide character set that goes all the way back to the age of the teletype/telex. Seven bit equals a table of 128 charcters or letters if you like. ASCII covers the English alphabet with both Capital and lowercase letters plus the numbers 0-9. The rest is used for control characters, exclamation, period, etc. plus currency symbols. ASCII also represents the lower 7 bits of most western character sets in use, like the Norwegian DOS CP850 / CP865, Windows CP1252 and UNIX ISO/IEC 8859-1. The GCC compiler both expect and produce ASCII. Plain text should therefore not be a problem. To use specialised charcters you will have to employ the **C** language escape sequences ("`\xYY`") embedded into your strings. To speed things up a bit, the LCD font table is as follows wrt. character *number:*

```
Either { Function Set[F=0] }
[0x00..0x07]    => Eight user defined 5×7(8)-pixel bitmap characters stored in CGRAM.
[0x08..0x0F]    => Duplicate (alias) of above

Or { Function Set[F=1] }
```

```
[0x00..0x03]    => Four user defined 5×10(11)-pixel bitmap characters stored in CGRAM.
[0x04..0x07]    => Duplicate (alias) of above
[0x08..0x0C]    => Duplicate (alias) of above
[0x0D..0x0F]    => Duplicate (alias) of above

Then 160 entries of 5×7(8)-pixel bitmap characters stored in CGROM
[0x20..0x2F]    => [ASCII] <SPACE> ! " # $ % & ' ( ) * + , - .
[0x30..0x39]    => [ASCII] 0 1 2 3 4 5 6 7 8 9
[0x3A..0x40]    => [ASCII] : ; < = > ? @
[0x41..0x5A]    => [ASCII] A B C D E F G H I J K L M N O P Q R S T U V X Y Z
[0x5B..0x60]    => [ASCII] [ ¥ ] ^ _ `
[0x61..0x7A]    => [ASCII] a b c d e f g h i j k l m n o p q r s t u v x y z
[0x7B..0x7F]    => [ASCII] { | } -> <-
[0x80..0xDF]    => Non-printable, non-standard characters. (Ref Datasheet)

Lastly 32 entries of 5×10(11)-pixel bitmap characters stored in CGROM
[0xE0..0xFF]    => Non-printable, non-standard characters. (Ref Datasheet)
```

The display module will from a hardware point of view behave like a readable- and writeable external memory (RAM.) Unfortunately, this bus protocol does not conform to the AVR external bus interface protocol. We will therefore fall back to bit-banging, in whitch the display is attached to two somewhat arbitrarily choosen GPIO ports of the AVR microcontroller. One port is in full to be dedicated data bus - `DATA[7..0]` - whilst three bits of the other GPIO port is dedicated control bus signals. These signals are "`Register Selct [RS], Read/NotWrite [R/~W]`" and "`Enable [E]`" There are printed cicuit boards to be fond in the lab featuring an LCD module and cicuitry for direct attachment to STK500 GPIO ports. The essencew of the schematics is as follows:

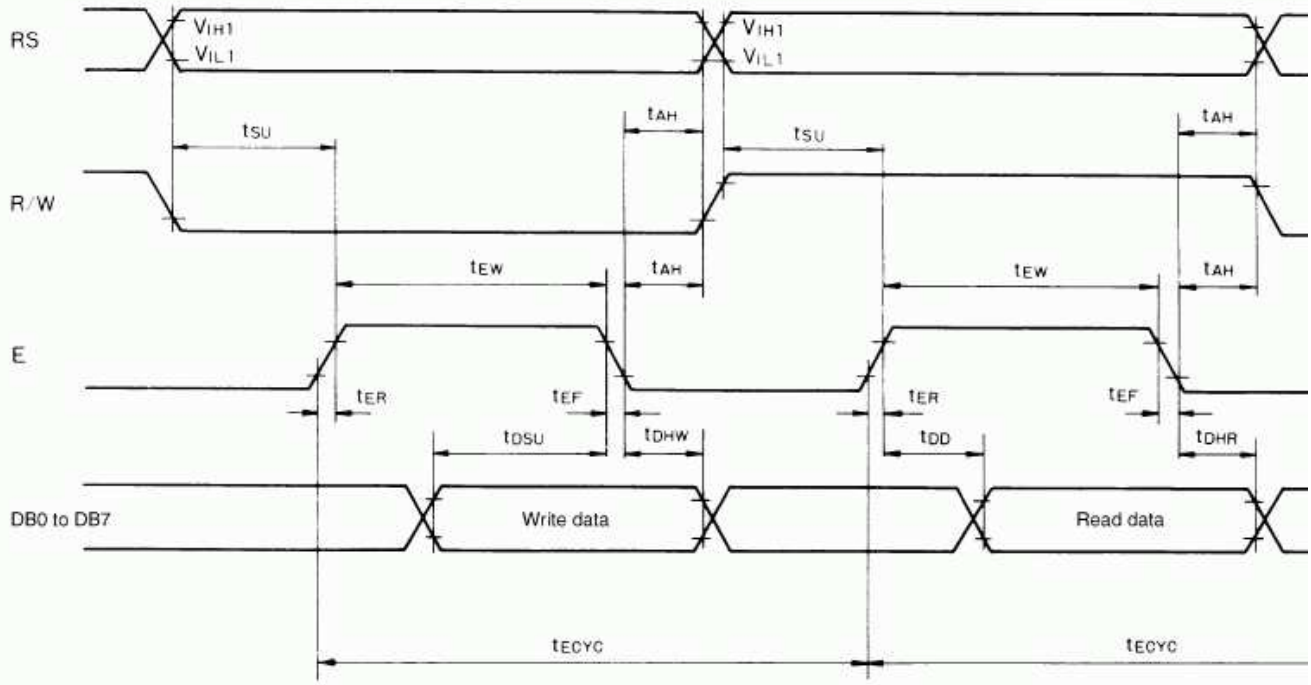
```
LCD_DATA[7..0] <=> PORTA[7..0]

LCD_RS         <=> PORTB[5]
LCD_RW         <=> PORTB[6]
LCD_EN         <=> PORTB[7]
```

The data on the data bus (including direction) and the three control signals must be steered in the correct sequence. Study the timing diagram in the datasheet of the display controller. The most important diagram is reproduced below. Not that this diagram covers two full bus cycles — first a write cycle, then a read cycle.

LC7985NA, LC7985ND

Read/write cycle timing



You are to emulate the LCD display bus protocol by steering ATmega323 GPIO-ports as if the were the control signals of the LCD bus. What text to write to the display is up to you. But it should be strings of more than 16 characters and both lines of the display is to be in use.

The task is simpler than it sounds as there is no upper limit to long a time you may use strobing the control lines. But you must not do it any *faster* as what is staed in the dispaly controller datasheet. Most noteworthy is the relatively long delay *between* two consecutive cycles. This delay is repeated in the last column of the below table. AVR performs one instruction per clock cycle. At standard STK500 clock frequency for target MCU of **3,68640 MHz** one clock cycle lasts **271 ns** It should now be possible to come up with a approximation for delay loops. Alternatively 'somebody' has already done these calculations for you in the form of ("`#include <avr/delay.h>`") Which in case requires you to declare correct clock frequency. And beware of optimalization above level "`-O1`" as such (useless) delay loops then will be optimized out of existance.

LCD module Instruction	Instruction Code										Description	Execution time
	RS	R/W	DB7	DB6	DB5	DB4	DB3	DB2	DB1	DB0		
Clear Display	0	0	0	0	0	0	0	0	0	1	Clears all of **DDRAM** to "`0x20`" and resets DDRAM Address Counter `[AC]` to "`0x00 (0x80)`"	1.53 ms

Return Home	0	0	0	0	0	0	0	0	1	-	Resets Address Counter [AC] to start of DDRAM "0x00(0x80)" and moves cursor to upper-left position. The content of DDRAM is not affected.	1.53 ms
Entry Mode Set	0	0	0	0	0	0	0	1	I/D	SH	Address Counter [AC] auto Increment/Decrement [I/D] and Display Shift (scroll) [SH] control.	39 µs
Display ON/OFF Control	0	0	0	0	0	0	1	D	C	B	Display [D], Cursor [C], and cursor Blinking [B] on/off control bits.	39 µs
Shift Display or Cursor	0	0	0	0	0	1	S/C	R/L	-	-	An explicit single charcter Display Shift or Cursor move [S/C] to the Right or Left [R/L] Neither [AC] nor DDRAM content is affected.	39 µs
Function Set	0	0	0	0	1	DL	N	F	-	-	Interface data width (DL: **8-bits** / 4-bits) Number of display lines (N: **2-lines** / 1-line) and the CGRAM Font size (F: 5×10(11) [4 psc.] / 5×7(8) [8 psc.] dots)	39 µs
Set CGRAM Address	0	0	0	1	AC5	AC4	AC3	AC2	AC1	AC0	Places a **CGRAM** address [0x40..0x7F] into the Address Counter [AC] register.	39 µs
Set DDRAM Address	0	0	1	AC6	AC5	AC4	AC3	AC2	AC1	AC0	Places a **DDRAM** address [0x80..0xFF] into the Address Counter [AC] register.	39 µs
Read Busy Flag and Address	0	1	BF	AC6	AC5	AC4	AC3	AC2	AC1	AC0	Busy flag indicates pending operation. The contents of the Address Counter [AC] register is also returned.	0 µs
Write Data to RAM	1	0	D7	D6	D5	D4	D3	D2	D1	D0	Write data into the internal **DDRAM/CGRAM** memory location currently pointed to by the Address Counter [AC] register.	43 µs
Read Data from RAM	1	1	D7	D6	D5	D4	D3	D2	D1	D0	Read data from the internal **DDRAM/CGRAM** memory location currently pointed to by the Address Counter [AC] register.	43 µs

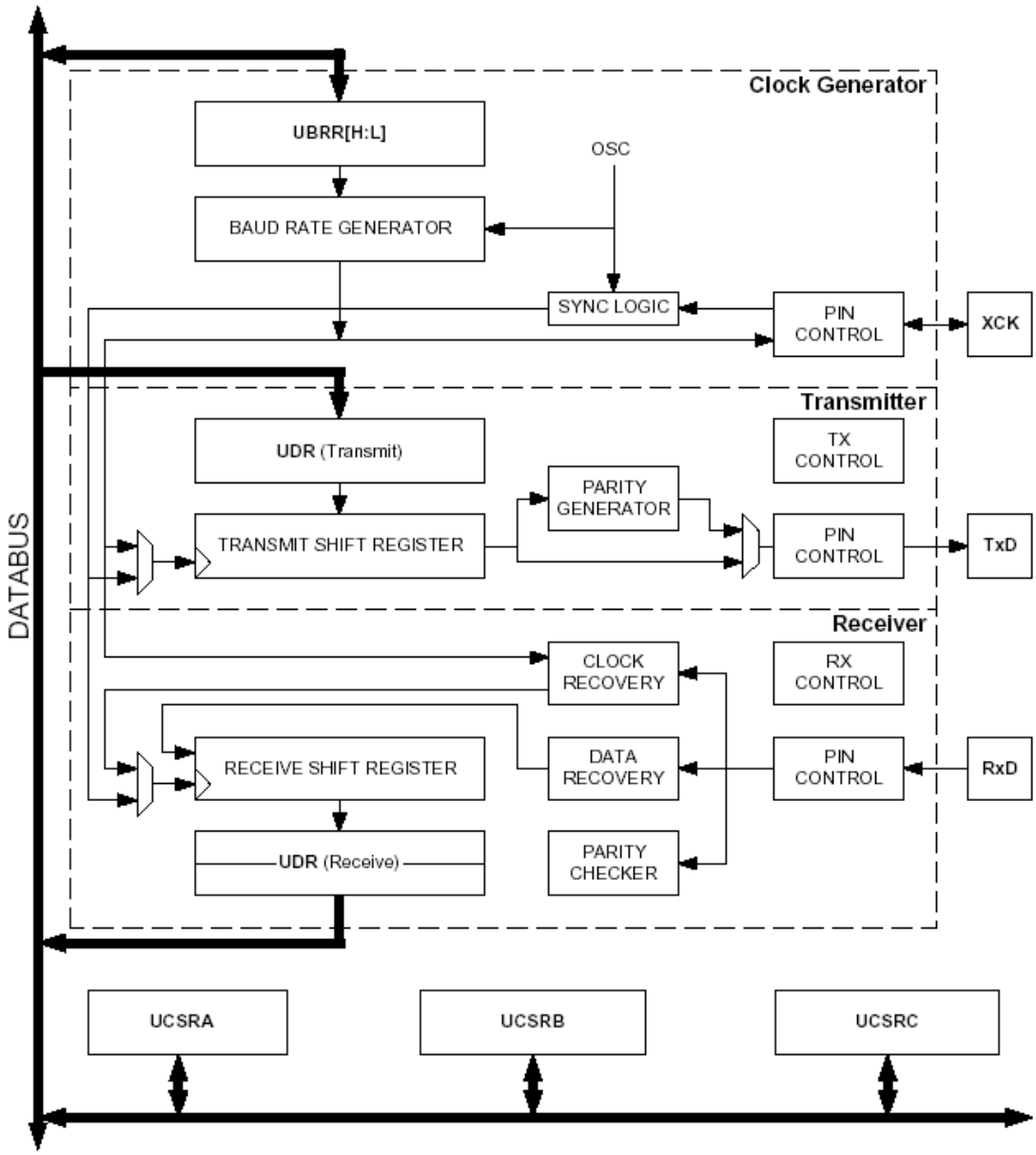
Part 2

In this part we will continue feeding the LCD panel, but no longer by predefined text. We will instead read this text from the serial port - or more precisely the "**Universal Asynchronous Reciver/Transmitter**" port of the AVR micro controller. Serial data to and from the U(S)ART will have to pass through a levelshifter that translates the signal level from [0..5]VDC TTL level as found within the STK500 and up to ±[10..15]VDC RS232 level more suitable for long streches of cable. There is a MAX202 levelshifter onboard the STK500 for this purpose. To utilize this levelshifter we will have to connect a strap from "`PORTD[1..0]`" onto the "`TxD/RxD`" pins on the STK500. This strap is visible in the picture in a black and red.

We attach a serial cable to the connector marked "`RS232 SPARE`" on the STK500. The other end of this cable is of cause to be attached to the host computer [PC] How you manage to get data out of the host computer is irrelevant, but the simplest way is to use a so called terminal emulator. We have installed Tera Term Pro on the lab computers for just this purpose. Also note that RS232 goes back to the youth of computing and as such is completely free of protocol or operating system intervention. WYSIWYG is the rule, and excatly this absence of complicating elements is what makes RS232 such a useful tool for microcontroller purposes - RS232 is available for de casual developer.

Our ATmega323 is equiped with a **USART**. This is nothing but a UART with the addition of a dedicated clock line making this port capable of synchronous communication. We are to ignore this capability. It might therefore pay to read the shorter explanation of the UART in the datasheet of the AT90S8535 predecessor. All bits not found on the UART are to be left alone or set to zero on the USART. All registers of the ATmega323 not mirrored in the AT90S8535 is best left untouched.

Figure 45. USART Block Diagram



UART is another step up from pure GPIO-ports as UART must be configured and then be enabled to be used. A UART is nothing but a set of parallel-to-serial shift registers with implied clock generation. With is just a fancy way of saying that sender and reciver has agreed upon a 'baudrate.' Synchronisation of clocks is obtained by means of dedicated start- and stop bits embedded into the data stream. This is handled transparently by HW. UART is equiped with three interrupt request vectors - one for recieve, one for transmit and one for data register empty. The latter is useful for buffered transmission. Each and every interrupt vector of the ATmega323 is tabulated in the ("`#include <avr/iom323.h>`") header file

```
/* Interrupt vectors */

#define SIG_INTERRUPT0          _VECTOR(1)
#define SIG_INTERRUPT1          _VECTOR(2)
#define SIG_INTERRUPT2          _VECTOR(3)
#define SIG_OUTPUT_COMPARE2     _VECTOR(4)
#define SIG_OVERFLOW2           _VECTOR(5)
#define SIG_INPUT_CAPTURE1      _VECTOR(6)
#define SIG_OUTPUT_COMPARE1A    _VECTOR(7)
#define SIG_OUTPUT_COMPARE1B    _VECTOR(8)
#define SIG_OVERFLOW1           _VECTOR(9)
```

```
#define SIG_OUTPUT_COMPARE0     _VECTOR(10)
#define SIG_OVERFLOW0           _VECTOR(11)
#define SIG_SPI                 _VECTOR(12)
#define SIG_UART_RECV           _VECTOR(13)
#define SIG_UART_DATA           _VECTOR(14)
#define SIG_UART_TRANS          _VECTOR(15)
#define SIG_ADC                 _VECTOR(16)
#define SIG_EEPROM_READY        _VECTOR(17)
#define SIG_COMPARATOR          _VECTOR(18)
#define SIG_2WIRE_SERIAL        _VECTOR(19)
```

The UART of the AT90S8535 is a classic peripherial meaning that the UART is controlled through three(four) registers: A data register `[UDR]`, a control register `[UCR]` and a status register `[USR]` In addition the UART has a configuration register, the Baudrate dividend register `[UBRR]`. Atmel has messed up this on the ATmega323 renaming `[UCR]` control register B `[UCRB]`, while the status register `[USR]` is renamed into control register A `[UCRA]`. In additon Atmel has introduced a third control register C `[UCRC]`. The latter is best ignored.

The Baudrate dividend register [UBRR(High/Low)] specify the number the system clock [3,6864 MHz] has to be divided with to produce the approriate baudrate [**9600 bps**] Table 24 in the AT90S8535 datasheet lists multiple examples. Typically you will load the correct dividend into the `[UBRR(H/L)]` register (Hint: `UBRRL = 23`) wherafter you will unmask any necessary UART interrupt source (`[RXCIE]`) Then you turn on the parts of the UART (`[RXEN]`) you inted to use.

You will also have to write a Interrupt Service Routine (ISR) that will handle interrupts (IRQs) from the reciever. An ISR is much the same as an ordinary function, but has to be surrounded by a ISR declaration. ISRs is another extension added to the AVR backend of the AVR-GCC compiler. A consequence of this is that the optimizer — that belongs to the GCC frontend — has no concept of ISRs. Any data *shared* between ISRs and normal program flow *must* be declared as "`volatile`" The optimizer will then be prohibited from simply assuming that the data has not changed since last accesss. The required declarations you will find in ("`#include <avr/signal.h>`") and ("`#include <avr/interrupt.h>`") files dealing with ISRs with global interrupts masked and unmasked, respectively. (The interrupt-on-interrupt subject.)

```
#include <avr/signal.h>
#include <avr/interrupt.h>

volatile uit8_t character;

SIGNAL(SIG_UART_RECV){
  /* code */
  character = UDR;
}

void IO_init(void){ /* code */ }

int main(void){
  IO_init();

  sei();         // Global Interrupt Enable
  /* code */
  cli();         // Global Interrupt Disable
  /* code */
}
```

A ISR is to be called by hardware dirctly, and must as such *never* be called upon by software. ISRs simply do not conform to *C Calling Convention*. Within ISRs you have to remember to clear the flag that caused the interrupt, or else you will immediately reenter the ISR upon 'Return from ISR.' In the case of `[RXC]` this is as simple as reading the data register `[UDR]`, which you are supposed to do anyway. Implement as KISS a solution as possible.

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geirfrs** ved **fys** punkt **uio** punkt **no