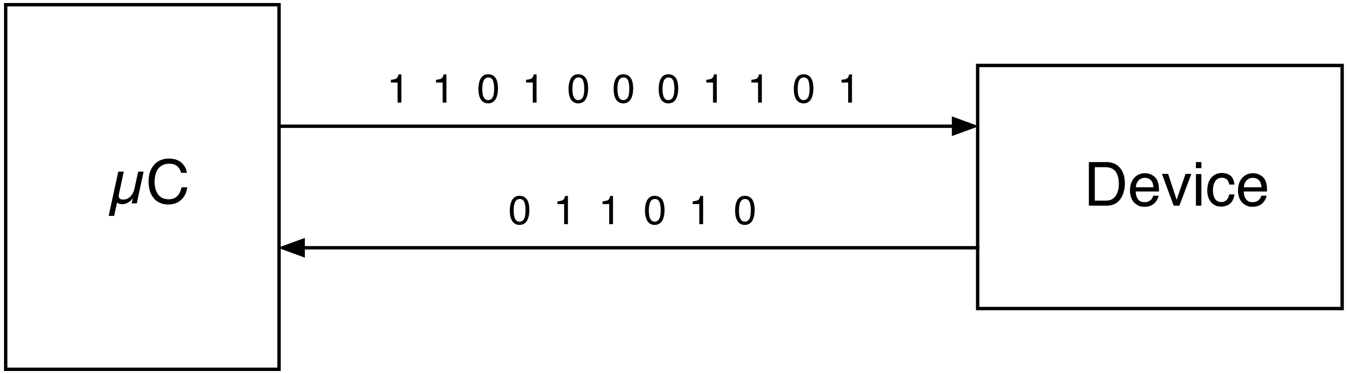
Serial Interfaces

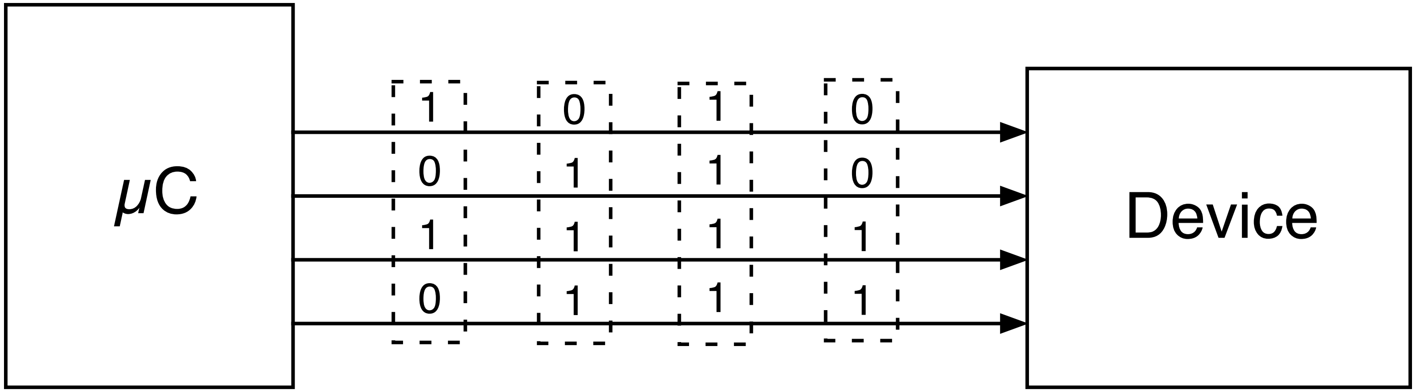
Serial Interfaces

- Embedded system often have to interface to several devices (sensors, actuators, memory, etc.)
- To help reduce the amount of wiring, many interfaces use a **serial interface** of some type.
- “Serial” implies that it sends or receives one bit at a time.



Serial Interfaces

- Different from a parallel interface that sends/receives multiple bits at a time.
- Example: The LCDs often use a 4-bit or 8-bit parallel interface to transfer commands and data.



- Serial interfaces: less hardware but slower
- Parallel interfaces: more hardware but faster

Pick Your Serial Interface

- Embedded systems can use a variety of serial interfaces.
  - Numerous manufacturers have developed interfaces
  - Some of these become "standards"
- Choosing which to use depends on several factors.
  - What interface is available on the device you need to talk to
  - Speed
  - Distance between devices
  - Cost of wiring and connectors
  - Complexity of software
- Common Serial Interfaces
  - RS-232, I^2C, SPI, 1-Wire, USB, SATA, PCIe, Thunderbolt

RS-232 Interface

- One-to-one topology
- Full duplex (if both devices are capable of it)
- Longer distances
  - Specs say 50 feet, but can often be much longer (>1000 ft) with proper cables and data rates.
- Very simple interface to implement in both hardware and software.
- Uses a minimum of three wires
  - Transmit
  - Receive
  - Ground
  - [Optional] handshake signals that are often not used.

RS-232 Interface

- Despite its age, RS-232 is still heavily used
  - Industrial devices
  - Data logging devices
  - “Headless” servers, for use during installation
  - Anything that needs a simple interface, often for configuration

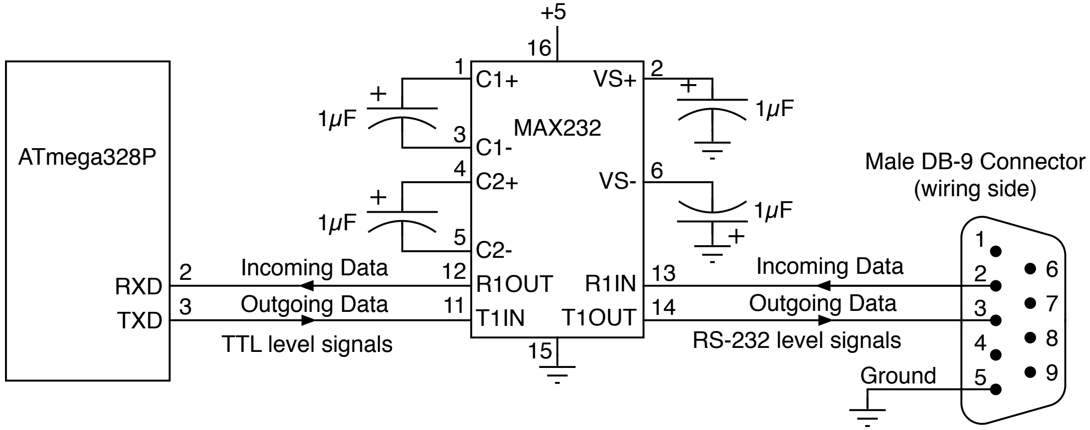
RS-232 Interface

- RS-232 uses bipolar voltages to signal 1's and 0's

  –3 to –15 Volts = 1

  +3 to +15 Volts = 0

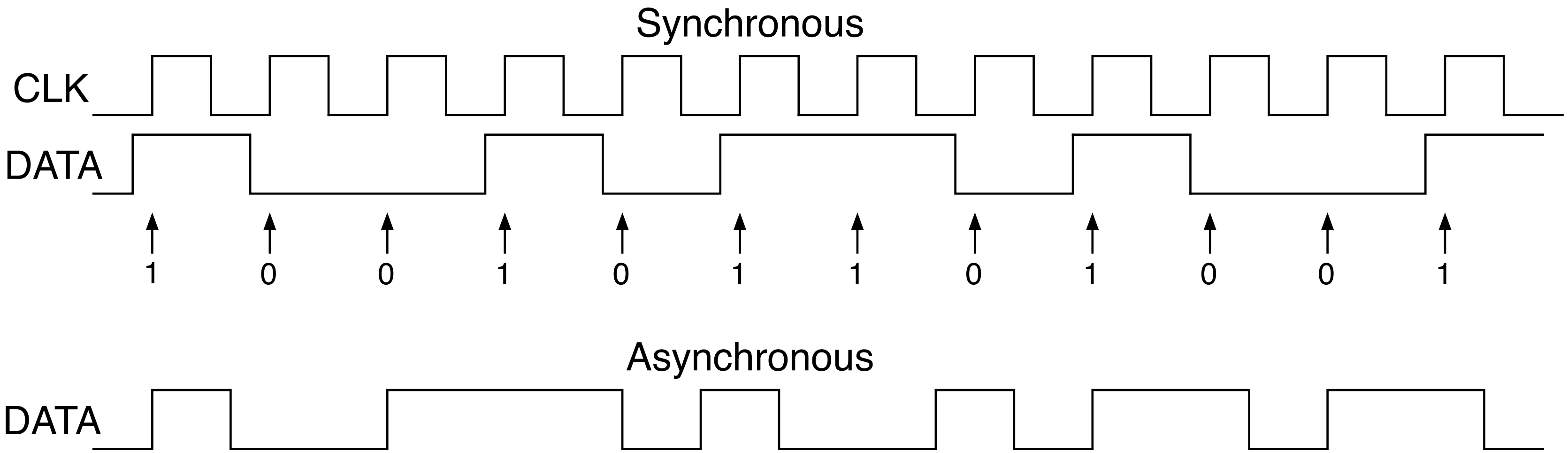
- MAX232 converts between 0-5V and bipolar signals



- Many devices used in EE459 projects with RS-232 interfaces work the just 0 and 5V signals ("TTL Serial")
  - Make sure you know which voltages are required.

RS-232 Interface

- An “asynchronous” interface
  - I²C and SPI are synchronous interfaces since there is clock signal
  - RS-232 only sends data, no clock signal accompanying the data
  - In order to correctly receive the data, the receiver must derive clocking information by examining the data

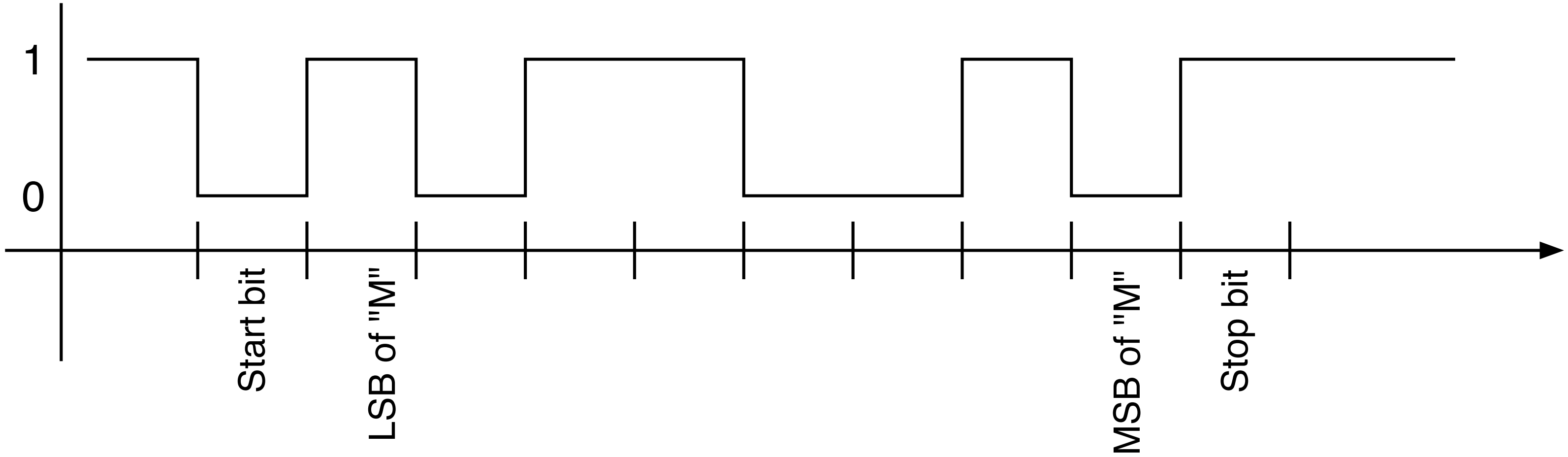


RS-232 Interface

- To correctly receive the data, the transmitter and receiver have to agree on how the data will be sent
- Must agree on data rate
  - Data rates given in bits/second or “baud rate”
  - Use any rate, as long as TX and RX devices agree on the rate
  - In most cases, standard rates are used:
    - 300, 2400, 9600, 28800, 57600, 115200, etc.
  - Many devices will specify that they can only communicate at one rate
- Must agree on the format of the data
  - How many data bits sent for each character?
  - Which comes first, the MSB or the LSB?
  - What other bits are sent along with the data?

RS-232 Interface

- To send a byte, the transmitter sends…
  - Start bit (a zero)
  - Data bits, LSB first, MSB last
  - Parity bits (optional)
  - Stop bits (a one, 1 or 2 of them)
- Example: to send an “M”
  - ASCII code = 0x4D = 01001101

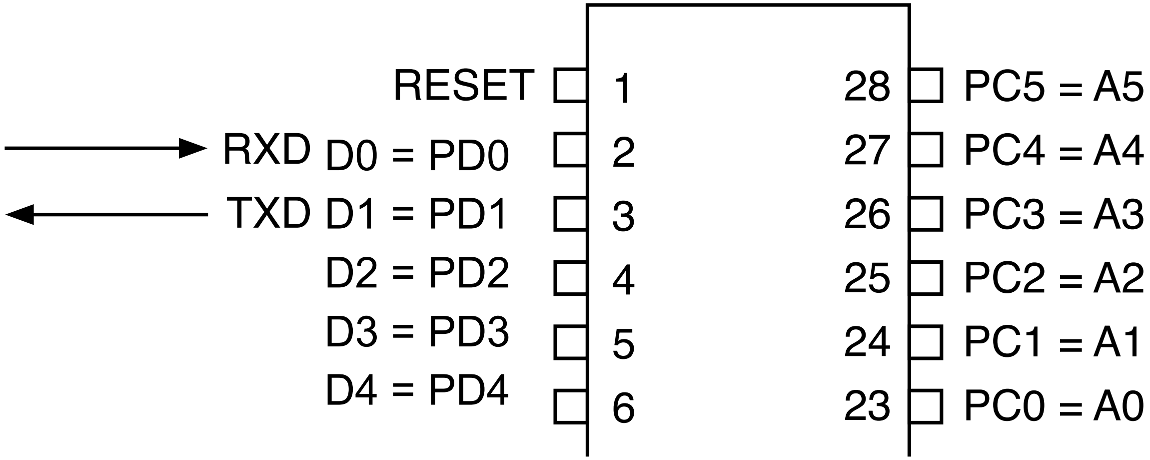


RS-232 Interface

- Parity bit – sent after the MSB to help detect errors
- Even parity
  - Transmitter adds a 0 or 1 so the number of ones sent is even
  - Receiver checks that an even number of ones was received
- Odd parity
  - Transmitter adds a 0 or 1 so the number of ones sent is odd
  - Receiver checks that an odd number of ones was received
- No parity
  - Don’t have to send parity if not needed
- If parity at received end is incorrect, a flag is set
- Transmitter and receiver must agree: odd, even or none

AVR USART0 Module

- Supports both asynchronous and synchronous modes
- Data lengths of 5, 6, 7, 8 or 9 bits, plus parity
- Interrupt generation on both transmit and receive
- Uses same pins as PORTD, bit 0 and 1
- If TX or RX enabled, can't use that pin for I/O



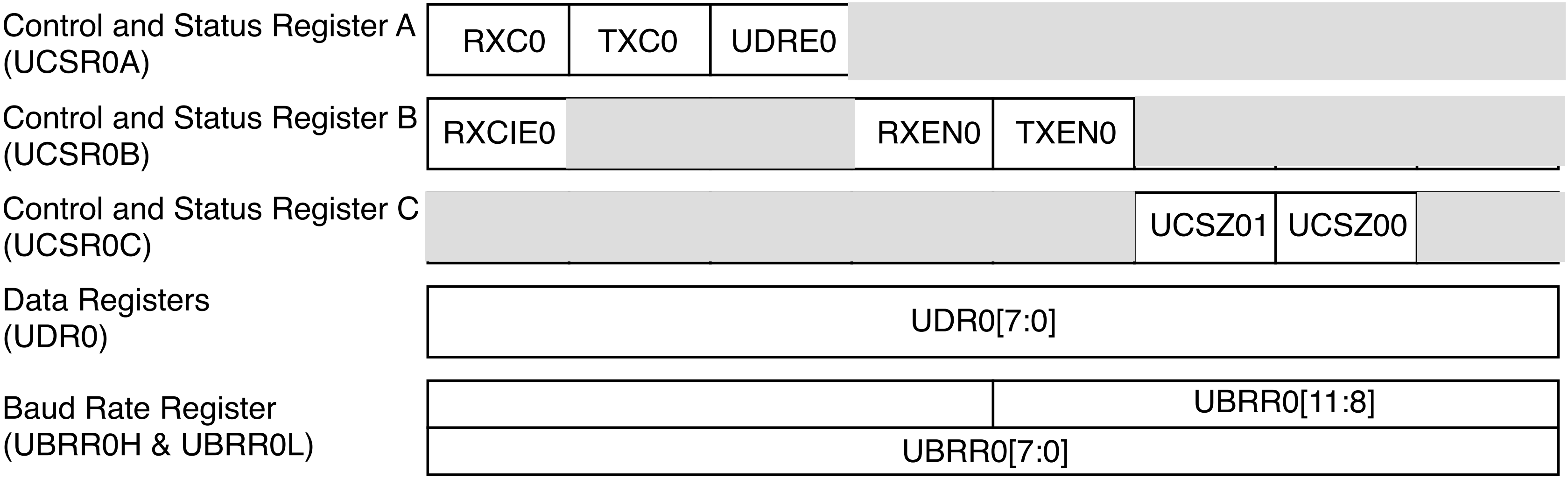
AVR USART0 Module

- Bad News: lots of registers and bits

Control and Status Register A (UCSR0A)	RXC0	TXC0	UDRE0	FE0	DOR0	UPE0	U2X0	MPCM0
Control and Status Register B (UCSR0B)	RXCIE0	TXCIE0	UDRIE0	RXEN0	TXEN0	USCZ02	RXB80	TRXB80
Control and Status Register C (UCSR0C)	UMSEL01	UMSEL02	UPM01	UPM00	USBS0	UCSZ01	UCSZ00	UCPOL0
Data Registers (UDR0)	UDR0[7:0]							
Baud Rate Register (UBRR0H & UBRR0L)					UBRR0[11:8]			
	UBRR0[7:0]							

AVR USART0 Module

- Good News: Can ignore most bits or leave as zero



Control and Status Register A (UCSR0A)	RXC0	TXC0	UDRE0					
Control and Status Register B (UCSR0B)	RXCIE0			RXEN0	TXEN0			
Control and Status Register C (UCSR0C)						UCSZ01	UCSZ00	
Data Registers (UDR0)	UDR0[7:0]							
Baud Rate Register (UBRR0H & UBRR0L)					UBRR0[11:8]			
	UBRR0[7:0]							

- UDR0 – received and transmitted data register
  - Actually two registers at the same address
  - Write to it ⇒ stores data to be transmitted
  - Read from it ⇒ gets data that has been received

RX and TX by polling

- First step, find the value to go in UBRR0 for the desired baud rate.

$$\mathrm{UBRR} = \frac{\mathrm{f_{osc}}}{16 \times BAUD} - 1$$

- The UBRR value must calculate to an integer to get the baud rate correct.
- Example:
  - An Arduino with a 16MHz clock trying to send at 9600 baud would need a UBRR value of 103.167
  - Using 103 gives a rate of 9615.4 baud which can cause errors.

RX and TX by polling

- For EE459 projects, clock oscillators are used that yield integer values to give correct baud rates
  - 7.3728Mhz, 9.8304Mhz

- Can use compiler directives to calculate the value

```
#define FOSC 7372800             // Clock frequency
#define BAUD 9600                // Baud rate used
#define MYUBRR (FOSC/16/BAUD-1)  // Value for UBRR0
```

- Store it in the UBRR0 register

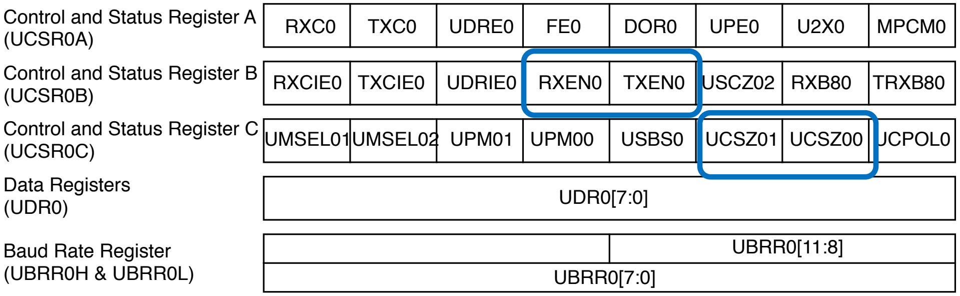
```
UBRR0 = MYUBRR;                 // Set baud rate
```

RX and TX by polling

- Second steps
  - Enable the receiver and/or transmitter
  - Set the values in UCSR0C for the desired communications settings
  - Most of the bits in UCSR0C can be left as zeros

```
UCSR0B |= (1 << TXEN0 | 1 << RXEN0);  // Enable RX and TX
UCSR0C = (3 << UCSZ00);               // Async., no parity,
                                      // 1 stop bit, 8 data bits
```

- The receiver and transmitter are now ready to go and waiting for data.



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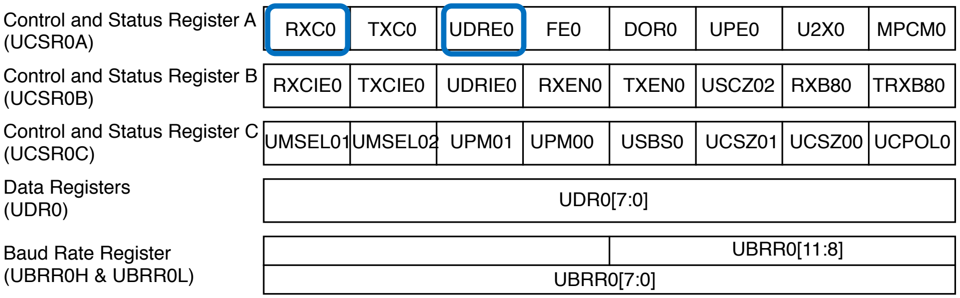
Data Registers (UDR0)	UDR0[7:0]							
Baud Rate Register (UBRR0H & UBRR0L)					UBRR0[11:8]			
	UBRR0[7:0]							

RX and TX by polling

- Routines for RX and TX
  - Receiver: checks RXC0 bit to find out when new data has come in.
  - Transmitter: checks UDRE0 bit to find out when transmitter is empty.

```
char rx_char()
{
    // Wait for receive complete flag to go high
    while ( !(UCSR0A & (1 << RXC0)) ) {}
    return UDR0;
}

void tx_char(char ch)
{
    // Wait for transmitter data register empty
    while ((UCSR0A & (1<<UDRE0)) == 0) {}
    UDR0 = ch;
}
```



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Data Registers (UDR0)	UDR0[7:0]							
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	UBRR0[7:0]							

RX and TX by polling

- Using interrupts can simplify serial communications
- The USART module can generate interrupts
  - Whenever data is received and is in UDR0
  - When the UDR0 register is empty and ready for the next data to be sent.
  - When the data being sent has finished being transmitted.

Control and Status Register A (UCSR0A)	RXC0	TXC0	UDRE0	FE0	DOR0	UPE0	U2X0	MPCM0
Control and Status Register B (UCSR0B)	RXCIE0	TXCIE0	UDRIE0	RXEN0	TXEN0	USCZ02	RXB80	TRXB80
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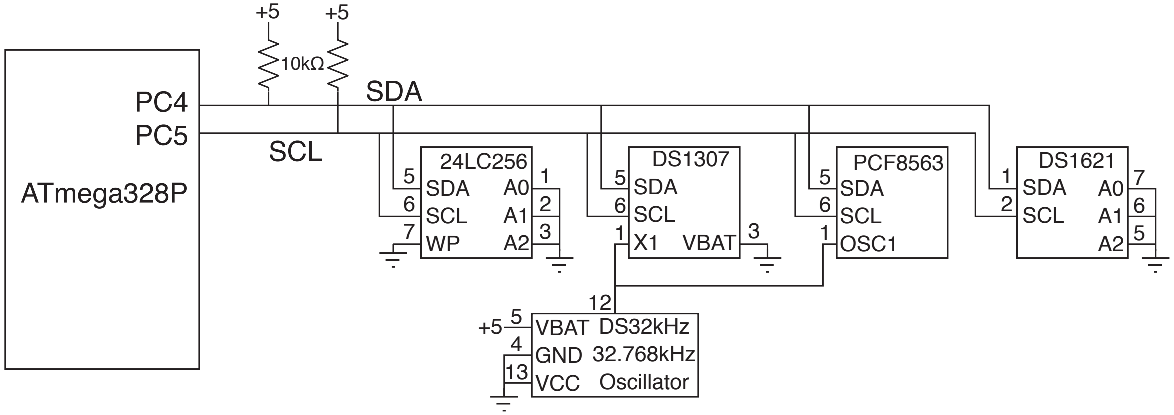
	UBRR0[7:0]							

I^2C Interface

- I^2C (Inter-Integrated Circuit) Interface
  - Also known as the “Two Wire Interface” (TWI)
- Most commonly used on a single PC board to transfer data between two or more ICs.
- Data rates are relatively slow (usually < 100 kb/sec)
- Example: A non-volatile memory IC stores configuration data used when a system powers up.
  - Reducing the amount of wiring is more important than speed
- Software interface is relatively complex
  - Many µC’s include I^2C hardware that simplify the task, a little.

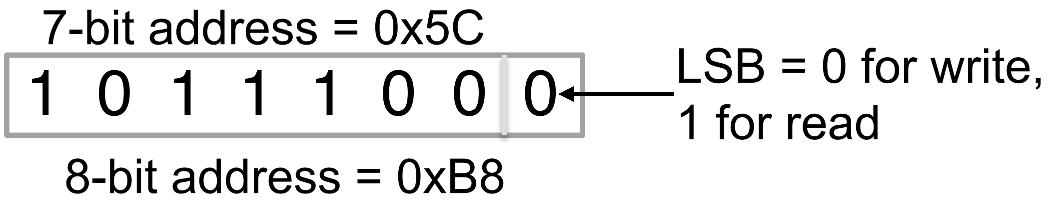
I^2C Interface

- Bus topology
  - One bus “master” can communicate with multiple “slave” devices over a single pair of wires.
- Clock and Data
  - Clock (SCL) generated by the master device
  - Data line (SDA) is bidirectional
- Half duplex
  - Master ⇒ slave, or slave ⇒ master, but not at the same time



I^2C Addresses

- Every slave device has a unique 7-bit address that is fixed by the manufacturer (see the datasheet).
  - Some I^2C devices allow the lower address bit(s) to be changed so multiple devices can be on the same bus.
- The 7-bit address is actually the upper 7-bits of an 8-bit address used on bus. LSB is used for read/write.



7-bit address = 0x5C

1 0 1 1 1 0 0 | 0

LSB = 0 for write,
1 for read

8-bit address = 0xB8

- Some vendors specify the 8-bit address, others the 7-bit.
  - The 8-bit address is the 7-bit address times 2 (shift the 7-bits over one place to the left).

I^{2}C Addresses

- Make sure you find the address before trying to write any software to communicate with a device!
- Some examples

I2C device	8-bit address
DS1307 real time clock	0xD0
PCF8563 real time clock	0xA2
24LC256 32kb EEPROM	0xA0
DS1631 temperature sensor	0x90
LIS3DH accelerometer	0x30
NHD-0420D3Z-NSW-BBW LCD	0x50
TSL2591 light sensor	0x52

I^{2}C Software

- Make sure you read the manfacturer’s datasheet to understand the sequence of steps that must be followed to work with an I^{2}C device.
- What needs to be done to initialize it?
  - Example: The DS1631 temperature sensor needs to be sent a 0xAC to load the configuration register, followed by the byte to go in that register
- What commands need to be written to it to perform operations?
- How do you read data back from the device?
  - Example: The DS1631 needs to be sent 0xAA ”Read Temperature” command, followed by a read of two bytes.

I^2C Software

- Some I2C devices are configured as a collection of registers, usually numbered from 0 on up.
- Writing to a device usually requires sending the address of the register first, then the data byte to go in that register.
  - If more data is sent those bytes go in the subsequent registers.
  - IMPORTANT: The I^2C **device address** is not the same as the **register address**
- For example, to load registers 4, 5 and 6 with the values 0x23, 0x52, 0xD5, the software would send four bytes
  - 0x04, 0x23, 0x52, 0xD5

I^2C Software

- Reading from an I^2C device with multiple registers usually requires writing to it first to tell which register you want to read data from, and then reading the data.
  - If more than one byte is read, they come from the subsequent registers
- For example, to read from registers 7, 8 and 9 in a device, the software would first write 0x07, and then do a read operation of three bytes to get the contents of the three registers.

I^{2}C Software

- We provide software on our class web site that will communicate with I^{2}C devices.

```
i2c_io(uint8_t dev_addr, uint8_t *wbuf, uint16_t wn,
       uint8_t *rbuf, uint16_t rn);
```

`dev_addr`	I^{2}C **8-bit** device address
`wbuf`	pointer to buffer containing data to write
`wn`	number of bytes to write
`rbuf`	pointer to buffer to hold data being read
`rn`	number of bytes to read

- You are welcome to use it, or find or develop your own.
- See the document on “Using the I^{2}C interface” in the Reference Library section of the web site for information on using our I^{2}C software.

I^2C Example

Example of using i2c_io to configure a DS1631 temperature sensor and read sensor data from it.

```
wdata[0] = 0xac;            // Set config for active high = 1
wdata[1] = 0x00;            // and continuous acquisitions
status = i2c_io(I2C_ADDR, wdata, 2, NULL, 0);

wdata[0] = 0x51;            // Start conversions
status = i2c_io(I2C_ADDR, wdata, 1, NULL, 0);

while (1) {                 // Loop forever
    // Send a read command temperature command in wdata[0] and
    // read 2 bytes back in rdata[0] and rdata[1]
    wdata[0] = 0xaa;
    status = i2c_io(I2C_ADDR, wdata, 1, rdata, 2);
        c2 = rdata[0] * 2;
        if (rdata[1] != 0)
            c2++;
        f = (c2 * 9) / 10 + 32;
        sprintf(ostr, "Temp=0x%02x%02x=%3d ", rdata[0], rdata[1], f);
        lcd_stringout(ostr);
        _delay_ms(1000);
    }
}
```

I^2C Debugging

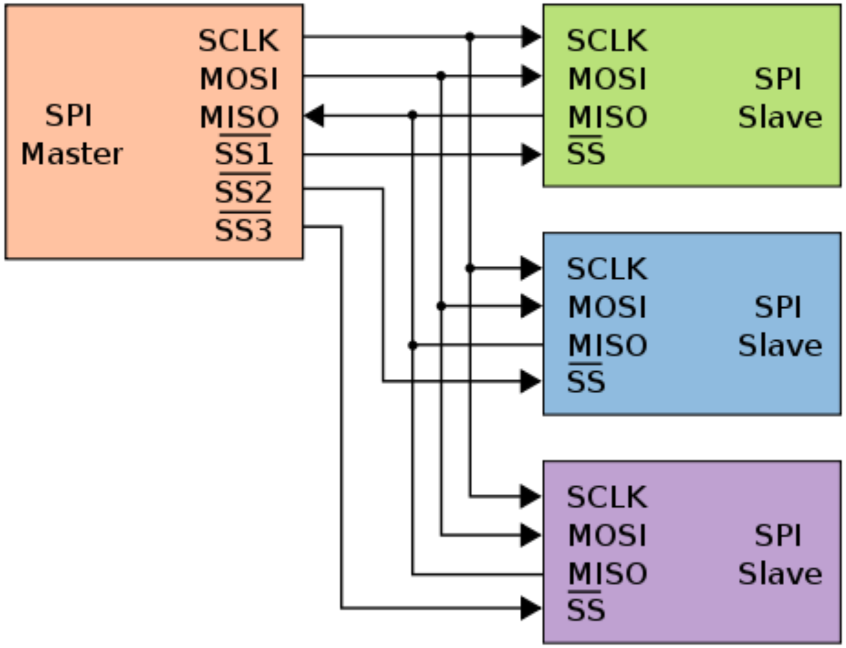
- I^2C devices can be challenging to get working.
- Do not try to debug I^2C from the software side alone.
- The Tektronix oscilloscopes in OHE 240 have special trigging capabilities that will capture and display I^2C transfers (or attempted transfers).
- **Use of these scopes in I^2C triggering mode is essential for working with I^2C devices.**
- The document on “Using the I^2C interface” in the Reference Library section of the web site has detailed instructions on how to use the scopes to debug I^2C.

I^2C Debugging

- The Tek scopes will display the clock (yellow) and data (blue), and will also decipher what is being transferred.
- In this example, device at 0x90 was sent 0xAA, and then two bytes, 0X1A and 0x00, were read back

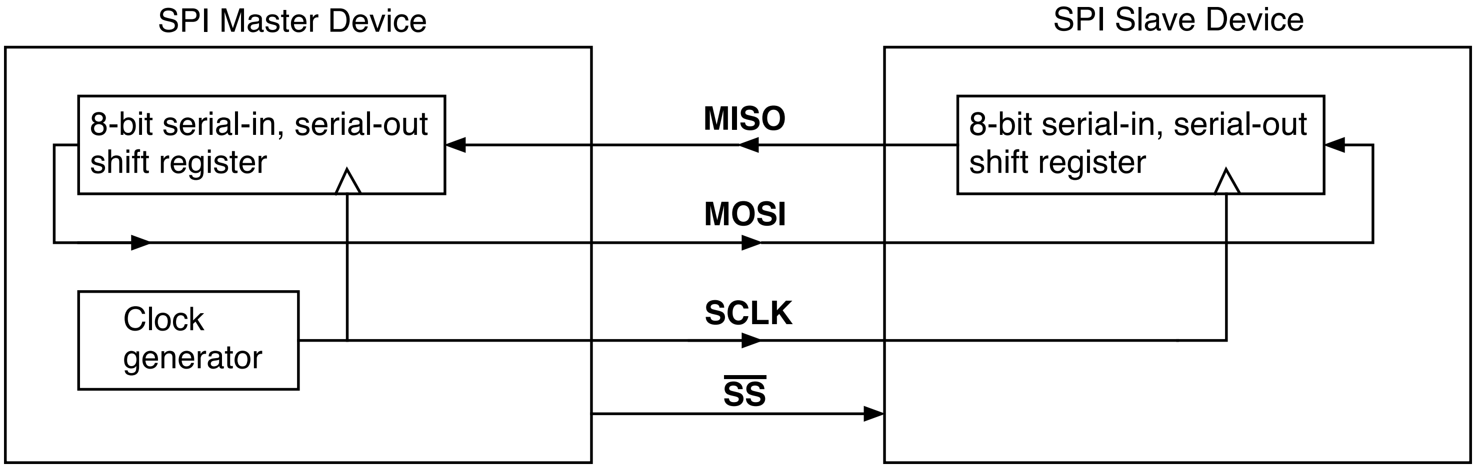
SPI Interface

- Serial Peripheral Interface Bus
- Uses four wires (three in many cases)
- Full Duplex
  - Data is transferred in both directions at the same time
- Bus topology
  - One master can talk with multiple slave devices using three wires
  - SCLK (clock signal to slaves)
  - MOSI (master out, slave in)
  - MISO (master in, slave out)
  - SS (slave select), one for each slave device



SPI Interface

- Both devices have an 8-bit shift register
- There are no separate write and read operations
- A data transfer moves a byte from master to slave, and from slave to master at the same time.
- To read data, the master must transfer dummy data to the slave.



SPI Registers

SPCR - SPI Control Register

SPIE	**SPE**	**DORD**	**MSTR**	**CPOL**	**CPHA**	**SPR1**	**SPR0**

SPIE - SPI Interupt Enable
SPE - SPI Enable
DORD - Data Order
MSTR - Master/Slave Select

CPOL - Clock Polarity
CPHA - Clock Phase
SPR1 - SPI Clock Rate Select 1
SPR0 - SPI Clock Rate Select 0

SPSR - SPI Status Register

SPIF	**WCOL**						**SPR2X**

SPIF - SPI Interupt Flag
WCOL - Write Collision Flag
SPI2X - Double SPI Speed Bit

SPDR - SPI Data Register

MSB							**LSB**

SPI Registers

- SPCR – SPI Control Register
  - SPE – Set to 1 to enable SPI operation
  - MSTR – Set to 1 to make device SPI master
  - SPR1, SPR0 – Determines clock frequency
- SPSR – SPI Status Register
  - SPIF – A 1 after transfer complete
  - SPR2X – Determines clock frequency
- SPDR – SPI Data Register
  - Write data to SPDR to send
  - Read received data from SPDR

SPI2X	SPR1	SPI0	SCLK
0	0	0	$f_{osc}/4$
0	0	1	$f_{osc}/16$
0	1	0	$f_{osc}/64$
0	1	1	$f_{osc}/128$
1	0	0	$f_{osc}/2$
1	0	1	$f_{osc}/8$
1	1	0	$f_{osc}/32$
1	1	1	$f_{osc}/64$

SPI Example

```
#include <avr/io.h>
#include <util/delay.h>

int main(void) {

    DDRB |= (1 << PB3);         // set MOSI for output
    DDRB |= (1 << PB5);         // set SCLK for output
    DDRB |= (1 << PB2);         // set SS for output

    // Enable SPI, set for master mode, divide clock by 16
    SPCR |= (1 << SPE) | (1 << MSTR) | (1 << SPR0);

    while (1) {
        PORTB &= ~(1 << PB2);   // Select line to zero
        SPDR = 'a';             // Send an 'a'

        while (!(SPSR & (1 << SPIF))) ;  // Wait for transmit complete

        PORTB |= (1 << PB2);    // Select line to one
        _delay_ms(10);
    }
}
```