

## 19. USART0

### 19.1 Features

- Full duplex operation (independent serial receive and transmit registers)
- Asynchronous or synchronous operation
- Master or slave clocked synchronous operation
- High resolution baud rate generator
- Supports serial frames with 5, 6, 7, 8, or 9 data bits and 1 or 2 stop bits
- Odd or even parity generation and parity check supported by hardware
- Data overrun detection
- Framing error detection
- Noise filtering includes false start bit detection and digital low pass filter
- Three separate interrupts on TX complete, TX data register empty and RX complete
- Multi-processor communication mode
- Double speed asynchronous communication mode

### 19.2 Overview

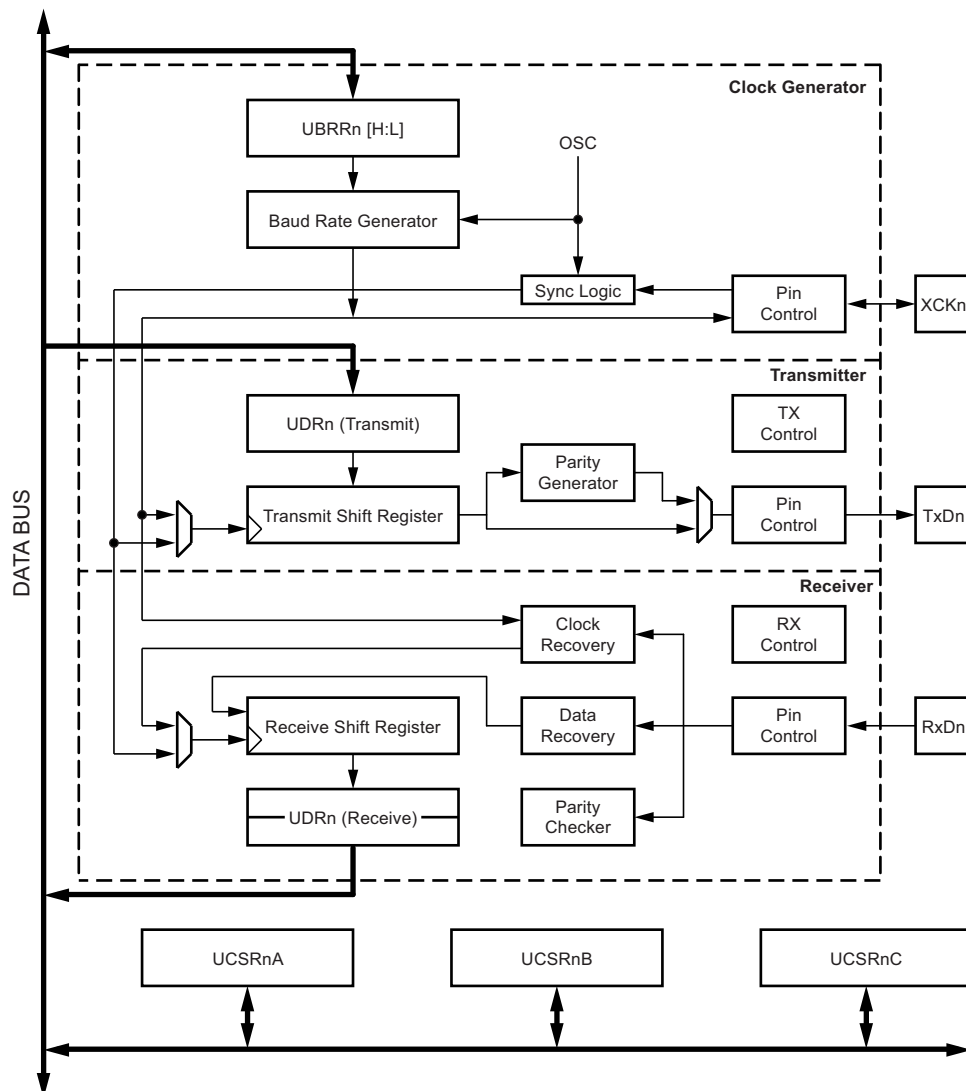
The universal synchronous and asynchronous serial receiver and transmitter (USART) is a highly flexible serial communication device.

The USART0 can also be used in master SPI mode, see [Section 20. “USART in SPI Mode” on page 166](#). The power reduction USART bit, PRUSART0, in [Section 9.10 “Minimizing Power Consumption” on page 36](#) must be disabled by writing a logical zero to it.

A simplified block diagram of the USART transmitter is shown in [Figure 19-1 on page 144](#). CPU accessible I/O registers and I/O pins are shown in bold.

The dashed boxes in the block diagram separate the three main parts of the USART (listed from the top): Clock generator, transmitter and receiver. Control registers are shared by all units. The clock generation logic consists of synchronization logic for external clock input used by synchronous slave operation, and the baud rate generator. The XCKn (transfer clock) pin is only used by synchronous transfer mode. The transmitter consists of a single write buffer, a serial shift register, parity generator and control logic for handling different serial frame formats. The write buffer allows a continuous transfer of data without any delay between frames. The receiver is the most complex part of the USART module due to its clock and data recovery units. The recovery units are used for asynchronous data reception. In addition to the recovery units, the receiver includes a parity checker, control logic, a shift register and a two level receive buffer (UDRn). The receiver supports the same frame formats as the transmitter, and can detect frame error, data overrun and parity errors.

**Figure 19-1. USART Block Diagram<sup>(1)</sup>**



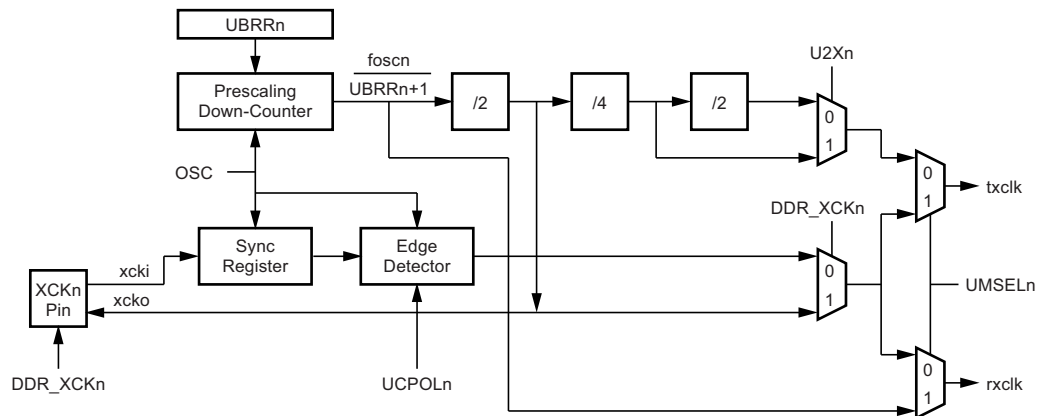
Note: 1. Refer to [Figure 1-1 on page 3](#) and [Table 13-9 on page 70](#) for USART0 pin placement.

### 19.3 Clock Generation

The clock generation logic generates the base clock for the transmitter and receiver. The USART supports four modes of clock operation: Normal asynchronous, double speed asynchronous, master synchronous and slave synchronous mode. The UMSELn bit in USART control and status register C (UCSRnC) selects between asynchronous and synchronous operation. Double speed (asynchronous mode only) is controlled by the U2Xn found in the UCSRnA register. When using synchronous mode (UMSELn = 1), the data direction register for the XCKn pin (DDR\_XCKn) controls whether the clock source is internal (master mode) or external (slave mode). The XCKn pin is only active when using synchronous mode.

Figure 19-2 shows a block diagram of the clock generation logic.

**Figure 19-2. Clock Generation Logic, Block Diagram**



Signal description:

- txclk** Transmitter clock (Internal Signal).
- rxclk** Receiver base clock (Internal Signal).
- xcki** Input from XCK pin (internal Signal). Used for synchronous slave operation.
- xcko** Clock output to XCK pin (Internal Signal). Used for synchronous master operation.
- fosc** XTAL pin frequency (System Clock).

### 19.3.1 Internal Clock Generation – The Baud Rate Generator

Internal clock generation is used for the asynchronous and the synchronous master modes of operation. The description in this section refers to Figure 19-2.

The USART baud rate register (UBRRn) and the down-counter connected to it function as a programmable prescaler or baud rate generator. The down-counter, running at system clock ( $f_{osc}$ ), is loaded with the UBRRn value each time the counter has counted down to zero or when the UBRRnL register is written. A clock is generated each time the counter reaches zero. This clock is the baud rate generator clock output ( $= f_{osc}/(UBRRn+1)$ ). The transmitter divides the baud rate generator clock output by 2, 8 or 16 depending on mode. The baud rate generator output is used directly by the receiver's clock and data recovery units. However, the recovery units use a state machine that uses 2, 8 or 16 states depending on mode set by the state of the UMSELn, U2Xn and DDR\_XCKn bits.

Table 19-1 contains equations for calculating the baud rate (in bits per second) and for calculating the UBRRn value for each mode of operation using an internally generated clock source.

**Table 19-1. Equations for Calculating Baud Rate Register Setting**

Operating Mode	Equation for Calculating Baud Rate <sup>(1)</sup>	Equation for Calculating UBRRn Value
Asynchronous normal mode (U2Xn = 0)	$\text{BAUD} = \frac{f_{\text{OSC}}}{16(\text{UBRRn} + 1)}$	$\text{UBRRn} = \frac{f_{\text{OSC}}}{16\text{BAUD}} - 1$
Asynchronous double speed mode (U2Xn = 1)	$\text{BAUD} = \frac{f_{\text{OSC}}}{8(\text{UBRRn} + 1)}$	$\text{UBRRn} = \frac{f_{\text{OSC}}}{8\text{BAUD}} - 1$
Synchronous master mode	$\text{BAUD} = \frac{f_{\text{OSC}}}{8(\text{UBRRn} + 1)}$	$\text{UBRRn} = \frac{f_{\text{OSC}}}{2\text{BAUD}} - 1$

Note: 1. The baud rate is defined to be the transfer rate in bit per second (bps)

<b>BAUD</b>	Baud rate (in bits per second, bps)
<b>f<sub>OSC</sub></b>	System oscillator clock frequency
<b>UBRRn</b>	Contents of the UBRRnH and UBRRnL registers, (0-4095)

Some examples of UBRRn values for some system clock frequencies are found in [Table 19-9 on page 163](#).

### 19.3.2 Double Speed Operation (U2Xn)

The transfer rate can be doubled by setting the U2Xn bit in UCSRnA. Setting this bit only has effect for the asynchronous operation. Set this bit to zero when using synchronous operation.

Setting this bit will reduce the divisor of the baud rate divider from 16 to 8, effectively doubling the transfer rate for asynchronous communication. Note however that the receiver will in this case only use half the number of samples (reduced from 16 to 8) for data sampling and clock recovery, and therefore a more accurate baud rate setting and system clock are required when this mode is used. For the transmitter, there are no downsides.

### 19.3.3 External Clock

External clocking is used by the synchronous slave modes of operation. The description in this section refers to [Figure 19-2 on page 145](#) for details.

External clock input from the XCKn pin is sampled by a synchronization register to minimize the chance of meta-stability. The output from the synchronization register must then pass through an edge detector before it can be used by the transmitter and receiver. This process introduces a two CPU clock period delay and therefore the maximum external XCKn clock frequency is limited by the following equation:

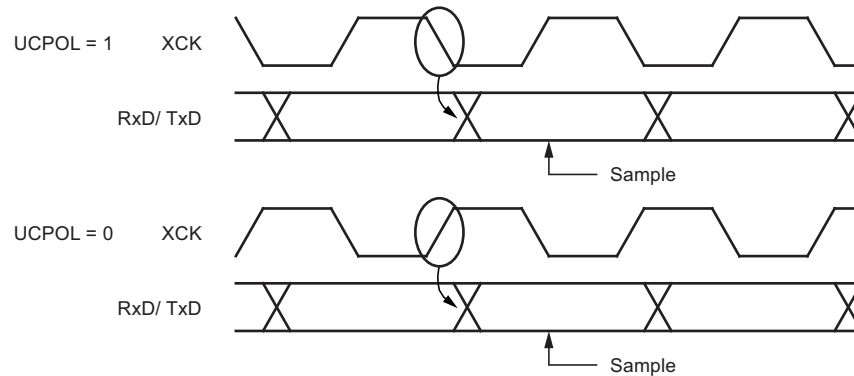
$$f_{\text{XCK}} < \frac{f_{\text{OSC}}}{4}$$

Note that  $f_{\text{OSC}}$  depends on the stability of the system clock source. It is therefore recommended to add some margin to avoid possible loss of data due to frequency variations.

### 19.3.4 Synchronous Clock Operation

When synchronous mode is used ( $UMSELn = 1$ ), the XCKn pin will be used as either clock input (Slave) or clock output (master). The dependency between the clock edges and data sampling or data change is the same. The basic principle is that data input (on Rx/Dn) is sampled at the opposite XCKn clock edge of the edge the data output (Tx/Dn) is changed.

**Figure 19-3. Synchronous Mode XCKn Timing**



The UCPOLn bit UCRSC selects which XCKn clock edge is used for data sampling and which is used for data change. As [Figure 19-3](#) shows, when UCPOLn is zero the data will be changed at rising XCKn edge and sampled at falling XCKn edge. If UCPOLn is set, the data will be changed at falling XCKn edge and sampled at rising XCKn edge.

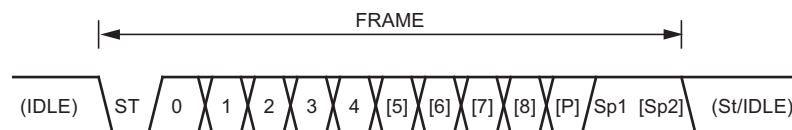
## 19.4 Frame Formats

A serial frame is defined to be one character of data bits with synchronization bits (start and stop bits), and optionally a parity bit for error checking. The USART accepts all 30 combinations of the following as valid frame formats:

- 1 start bit
- 5, 6, 7, 8, or 9 data bits
- no, even or odd parity bit
- 1 or 2 stop bits

A frame starts with the start bit followed by the least significant data bit. Then the next data bits, up to a total of nine, are succeeding, ending with the most significant bit. If enabled, the parity bit is inserted after the data bits, before the stop bits. When a complete frame is transmitted, it can be directly followed by a new frame, or the communication line can be set to an idle (high) state. [Figure 19-4](#) illustrates the possible combinations of the frame formats. Bits inside brackets are optional.

**Figure 19-4. Frame Formats**



- 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 (Rx/Dn or Tx/Dn). An IDLE line must be high.

The frame format used by the USART is set by the UCSZn2:0, UPMn1:0 and USBn bits in UCSRnB and UCSRnC. The receiver and transmitter use the same setting. Note that changing the setting of any of these bits will corrupt all ongoing communication for both the receiver and transmitter.

The USART character size (UCSZn2:0) bits select the number of data bits in the frame. The USART parity mode (UPMn1:0) bits enable and set the type of parity bit. The selection between one or two stop bits is done by the USART stop bit select (USBn) bit. The receiver ignores the second stop bit. An FE (frame error) will therefore only be detected in the cases where the first stop bit is zero.

#### 19.4.1 Parity Bit Calculation

The parity bit is calculated by doing an exclusive-or of all the data bits. If odd parity is used, the result of the exclusive or is inverted. The relation between the parity bit and data bits is as follows:

$$P_{even} = d_{n-1} \oplus \dots \oplus d_3 \oplus d_2 \oplus d_1 \oplus d_0 \oplus 0$$

$$P_{odd} = d_{n-1} \oplus \dots \oplus d_3 \oplus d_2 \oplus d_1 \oplus d_0 \oplus 1$$

<b>P<sub>even</sub></b>	Parity bit using even parity
<b>P<sub>odd</sub></b>	Parity bit using odd parity
<b>d<sub>n</sub></b>	Data bit n of the character

If used, the parity bit is located between the last data bit and first stop bit of a serial frame.

#### 19.5 USART Initialization

The USART has to be initialized before any communication can take place. The initialization process normally consists of setting the baud rate, setting frame format and enabling the transmitter or the receiver depending on the usage. For interrupt driven USART operation, the global interrupt flag should be cleared (and interrupts globally disabled) when doing the initialization.

Before doing a re-initialization with changed baud rate or frame format, be sure that there are no ongoing transmissions during the period the registers are changed. The TXCn flag can be used to check that the transmitter has completed all transfers, and the RXC flag can be used to check that there are no unread data in the receive buffer. Note that the TXCn flag must be cleared before each transmission (before UDRn is written) if it is used for this purpose.

The following simple USART initialization code examples show one assembly and one C function that are equal in functionality. The examples assume asynchronous operation using polling (no interrupts enabled) and a fixed frame format. The baud rate is given as a function parameter. For the assembly code, the baud rate parameter is assumed to be stored in the r17:r16 registers.

Assembly Code Example <sup>(1)</sup>
<pre> USART_Init:     ; Set baud rate     out    UBRRnH, r17     out    UBRRnL, r16     ; Enable receiver and transmitter     ldi    r16, (1&lt;&lt;RXENn) (1&lt;&lt;TXENn)     out    UCSRnB,r16     ; Set frame format: 8data, 2stop bit     ldi    r16, (1&lt;&lt;USBSn) (3&lt;&lt;UCSZn0)     out    UCSRnC,r16     ret </pre>
C Code Example <sup>(1)</sup>
<pre> #define FOSC 1843200 // Clock Speed #define BAUD 9600 #define MYUBRR FOSC/16/BAUD-1 void main(void) {     ...     USART_Init(MYUBRR)     ... } void USART_Init(unsigned int ubrr) {     /*Set baud rate */     UBRR0H = (unsigned char)(ubrr&gt;&gt;8);     UBRR0L = (unsigned char)ubrr;     /* Enable receiver and transmitter */     UCSR0B = (1&lt;&lt;RXEN0) (1&lt;&lt;TXEN0);     /* Set frame format: 8data, 2stop bit */     UCSR0C = (1&lt;&lt;USBS0) (3&lt;&lt;UCSZ00); } </pre>

Note: 1. See [Section 5. “About Code Examples” on page 8](#).

More advanced initialization routines can be made that include frame format as parameters, disable interrupts and so on. However, many applications use a fixed setting of the baud and control registers, and for these types of applications the initialization code can be placed directly in the main routine, or be combined with initialization code for other I/O modules.

## 19.6 Data Transmission – The USART Transmitter

The USART transmitter is enabled by setting the transmit enable (TXEN) bit in the UCSRnB register. When the transmitter is enabled, the normal port operation of the TxDn pin is overridden by the USART and given the function as the transmitter's serial output. The baud rate, mode of operation and frame format must be set up once before doing any transmissions. If synchronous operation is used, the clock on the XCKn pin will be overridden and used as transmission clock.

### 19.6.1 Sending Frames with 5 to 8 Data Bit

A data transmission is initiated by loading the transmit buffer with the data to be transmitted. The CPU can load the transmit buffer by writing to the UDRn I/O location. The buffered data in the transmit buffer will be moved to the shift register when the shift register is ready to send a new frame. The shift register is loaded with new data if it is in idle state (no ongoing transmission) or immediately after the last stop bit of the previous frame is transmitted. When the shift register is loaded with new data, it will transfer one complete frame at the rate given by the baud register, U2Xn bit or by XCKn depending on mode of operation.

The following code examples show a simple USART transmit function based on polling of the data register empty (UDREN) flag. When using frames with less than eight bits, the most significant bits written to the UDRn are ignored. The USART has to be initialized before the function can be used. For the assembly code, the data to be sent is assumed to be stored in register R16.

#### Assembly Code Example<sup>(1)</sup>

```
USART_Transmit:
    ; Wait for empty transmit buffer
    sbis    UCSRnA,UDREN
    rjmp    USART_Transmit
    ; Put data (r16) into buffer, sends the data
    out     UDRn,r16
    ret
```

#### C Code Example<sup>(1)</sup>

```
void USART_Transmit(unsigned char data)
{
    /* Wait for empty transmit buffer */
    while (!(UCSRnA & (1<<UDREN)))
    ;
    /* Put data into buffer, sends the data */
    UDRn = data;
}
```

Note: 1. See [Section 5. "About Code Examples" on page 8](#)

The function simply waits for the transmit buffer to be empty by checking the UDREN flag, before loading it with new data to be transmitted. If the data register empty interrupt is utilized, the interrupt routine writes the data into the buffer.



## 19.6.2 Sending Frames with 9 Data Bit

If 9-bit characters are used (UCSZn = 7), the ninth bit must be written to the TXB8 bit in UCSRnB before the low byte of the character is written to UDRn. The following code examples show a transmit function that handles 9-bit characters. For the assembly code, the data to be sent is assumed to be stored in registers R17:R16.

### Assembly Code Example<sup>(1)(2)</sup>

```
USART_Transmit:
    ; Wait for empty transmit buffer
    sbis    UCSRnA, UDREn
    rjmp    USART_Transmit
    ; Copy 9th bit from r17 to TXB8
    cbi     UCSRnB, TXB8
    sbrc    r17, 0
    sbi     UCSRnB, TXB8
    ; Put LSB data (r16) into buffer, sends the data
    out     UDRn, r16
    ret
```

### C Code Example<sup>(1)(2)</sup>

```
void USART_Transmit(unsigned int data)
{
    /* Wait for empty transmit buffer */
    while (!(UCSRnA & (1<<UDREn)))
    ;
    /* Copy 9th bit to TXB8 */
    UCSRnB &= ~(1<<TXB8);
    if (data & 0x0100)
        UCSRnB |= (1<<TXB8);
    /* Put data into buffer, sends the data */
    UDRn = data;
}
```

- Notes:
1. These transmit functions are written to be general functions. They can be optimized if the contents of the UCSRnB is static. For example, only the TXB8 bit of the UCSRnB Register is used after initialization.
  2. See [Section 5. "About Code Examples" on page 8](#).

The ninth bit can be used for indicating an address frame when using multi processor communication mode or for other protocol handling as for example synchronization.

## 19.6.3 Transmitter Flags and Interrupts

The USART transmitter has two flags that indicate its state: USART data register empty (UDREn) and transmit complete (TXCn). Both flags can be used for generating interrupts.

The data register empty (UDREn) flag indicates whether the transmit buffer is ready to receive new data. This bit is set when the transmit buffer is empty, and cleared when the transmit buffer contains data to be transmitted that has not yet been moved into the shift register. For compatibility with future devices, always write this bit to zero when writing the UCSRnA register.

When the data register empty interrupt enable (UDRIEn) bit in UCSRnB is written to one, the USART data register empty interrupt will be executed as long as UDREn is set (provided that global interrupts are enabled). UDREn is cleared by writing UDRn. When interrupt-driven data transmission is used, the data register empty interrupt routine must either write new data to UDRn in order to clear UDREn or disable the data register empty interrupt, otherwise a new interrupt will occur once the interrupt routine terminates.

The transmit complete (TXCn) flag bit is set one when the entire frame in the transmit shift register has been shifted out and there are no new data currently present in the transmit buffer. The TXCn flag bit is automatically cleared when a transmit complete interrupt is executed, or it can be cleared by writing a one to its bit location. The TXCn flag is useful in half-duplex communication interfaces (like the RS-485 standard), where a transmitting application must enter receive mode and free the communication bus immediately after completing the transmission.

When the transmit complete interrupt enable (TXCIEn) bit in UCSRnB is set, the USART transmit complete interrupt will be executed when the TXCn flag becomes set (provided that global interrupts are enabled). When the transmit complete interrupt is used, the interrupt handling routine does not have to clear the TXCn flag, this is done automatically when the interrupt is executed.

#### 19.6.4 Parity Generator

The parity generator calculates the parity bit for the serial frame data. When parity bit is enabled (UPMn1 = 1), the transmitter control logic inserts the parity bit between the last data bit and the first stop bit of the frame that is sent.

#### 19.6.5 Disabling the Transmitter

The disabling of the transmitter (setting the TXEN to zero) will not become effective until ongoing and pending transmissions are completed, i.e., when the transmit shift register and transmit buffer register do not contain data to be transmitted. When disabled, the transmitter will no longer override the TxDn pin.

### 19.7 Data Reception – The USART Receiver

The USART receiver is enabled by writing the receive enable (RXENn) bit in the UCSRnB register to one. When the receiver is enabled, the normal pin operation of the RxDn pin is overridden by the USART and given the function as the receiver's serial input. The baud rate, mode of operation and frame format must be set up once before any serial reception can be done. If synchronous operation is used, the clock on the XCKn pin will be used as transfer clock.

#### 19.7.1 Receiving Frames with 5 to 8 Data Bits

The receiver starts data reception when it detects a valid start bit. Each bit that follows the start bit will be sampled at the baud rate or XCKn clock, and shifted into the receive shift register until the first stop bit of a frame is received. A second stop bit will be ignored by the receiver. When the first stop bit is received, i.e., a complete serial frame is present in the receive shift register, the contents of the shift register will be moved into the receive buffer. The receive buffer can then be read by reading the UDRn I/O location.

The following code example shows a simple USART receive function based on polling of the Receive Complete (RXCn) Flag. When using frames with less than eight bits the most significant bits of the data read from the UDRn will be masked to zero. The USART has to be initialized before the function can be used.

Assembly Code Example <sup>(1)</sup>
<pre> USART_Receive:     ; Wait for data to be received     sbis  UCSRnA, RXCn     rjmp  USART_Receive     ; Get and return received data from buffer     in    r16, UDRn     ret </pre>
C Code Example <sup>(1)</sup>
<pre> unsigned char USART_Receive(void) {     /* Wait for data to be received */     while (!(UCSRnA &amp; (1&lt;RXCn)))     ;     /* Get and return received data from buffer */     return UDRn; } </pre>

Note: 1. See [Section 5. “About Code Examples” on page 8](#)  
For I/O registers located in extended I/O map, “IN”, “OUT”, “SBIS”, “SBIC”, “CBI”, and “SBI” instructions must be replaced with instructions that allow access to extended I/O. Typically “LDS” and “STS” combined with “SBRs”, “SBRc”, “SBR”, and “CBR”.

The function simply waits for data to be present in the receive buffer by checking the RXCn flag, before reading the buffer and returning the value.

## 19.7.2 Receiving Frames with 9 Data Bits

If 9-bit characters are used (UCSZn=7) the ninth bit must be read from the RXB8n bit in UCSRnB **before** reading the low bits from the UDRn. This rule applies to the FEn, DORn and UPEn status flags as well. Read status from UCSRnA, then data from UDRn. Reading the UDRn I/O location will change the state of the receive buffer FIFO and consequently the TXB8n, FEn, DORn and UPEn bits, which all are stored in the FIFO, will change.

The following code example shows a simple USART receive function that handles both nine bit characters and the status bits.

### Assembly Code Example<sup>(1)</sup>

```
USART_Receive:
    ; Wait for data to be received
    sbis UCSRnA, RXCn
    rjmp USART_Receive
    ; Get status and 9th bit, then data from buffer
    in r18, UCSRnA
    in r17, UCSRnB
    in r16, UDRn
    ; If error, return -1
    andi r18, (1<<FEn) | (1<<DORn) | (1<<UPEn)
    breq USART_ReceiveNoError
    ldi r17, HIGH(-1)
    ldi r16, LOW(-1)
USART_ReceiveNoError:
    ; Filter the 9th bit, then return
    lsr r17
    andi r17, 0x01
    ret
```

### C Code Example<sup>(1)</sup>

```
unsigned int USART_Receive( void )
{
    unsigned char status, resh, resl;
    /* Wait for data to be received */
    while (!(UCSRnA & (1<<RXCn)))
        ;

    /* Get status and 9th bit, then data */
    /* from buffer */
    status = UCSRnA;
    resh = UCSRnB;
    resl = UDRn;
    /* If error, return -1 */
    if (status & (1<<FEn) | (1<<DORn) | (1<<UPEn))
        return -1;
    /* Filter the 9th bit, then return */
    resh = (resh >> 1) & 0x01;
    return ((resh << 8) | resl);
}
```

Note: 1. See [Section 5. "About Code Examples" on page 8](#)

For I/O registers located in extended I/O map, "IN", "OUT", "SBIS", "SBIC", "CBI", and "SBI" instructions must be replaced with instructions that allow access to extended I/O. Typically "LDS" and "STS" combined with "SBR", "SBR", "SBR", and "CBR".

The receive function example reads all the I/O registers into the register file before any computation is done. This gives an optimal receive buffer utilization since the buffer location read will be free to accept new data as early as possible.

### 19.7.3 Receive Complete Flag and Interrupt

The USART receiver has one flag that indicates the receiver state.

The receive complete (RXCn) flag indicates if there are unread data present in the receive buffer. This flag is one when unread data exist in the receive buffer, and zero when the receive buffer is empty (i.e., does not contain any unread data). If the receiver is disabled (RXENn = 0), the receive buffer will be flushed and consequently the RXCn bit will become zero.

When the receive complete interrupt enable (RXCIEn) in UCSRnB is set, the USART receive complete interrupt will be executed as long as the RXCn flag is set (provided that global interrupts are enabled). When interrupt-driven data reception is used, the receive complete routine must read the received data from UDRn in order to clear the RXCn flag, otherwise a new interrupt will occur once the interrupt routine terminates.

### 19.7.4 Receiver Error Flags

The USART receiver has three error flags: Frame error (FEn), data overrun (DORn) and parity error (UPEn). All can be accessed by reading UCSRnA. Common for the error flags is that they are located in the receive buffer together with the frame for which they indicate the error status. Due to the buffering of the error flags, the UCSRnA must be read before the receive buffer (UDRn), since reading the UDRn I/O location changes the buffer read location. Another equality for the error flags is that they can not be altered by software doing a write to the flag location. However, all flags must be set to zero when the UCSRnA is written for upward compatibility of future USART implementations. None of the error flags can generate interrupts.

The frame error (FEn) flag indicates the state of the first stop bit of the next readable frame stored in the receive buffer. The FEn flag is zero when the stop bit was correctly read (as one), and the FEn flag will be one when the stop bit was incorrect (zero). This flag can be used for detecting out-of-sync conditions, detecting break conditions and protocol handling. The FEn flag is not affected by the setting of the USBSn bit in UCSRnC since the receiver ignores all, except for the first, stop bits. For compatibility with future devices, always set this bit to zero when writing to UCSRnA.

The data overrun (DORn) flag indicates data loss due to a receiver buffer full condition. A data overrun occurs when the receive buffer is full (two characters), it is a new character waiting in the receive shift register, and a new start bit is detected. If the DORn flag is set there was one or more serial frame lost between the frame last read from UDRn, and the next frame read from UDRn. For compatibility with future devices, always write this bit to zero when writing to UCSRnA. The DORn flag is cleared when the frame received was successfully moved from the shift register to the receive buffer.

The parity error (UPEn) flag indicates that the next frame in the receive buffer had a parity error when received. If parity check is not enabled the UPEn bit will always be read zero. For compatibility with future devices, always set this bit to zero when writing to UCSRnA. For more details see [Section 19.4.1 “Parity Bit Calculation” on page 148](#) and [Section 19.7.5 “Parity Checker” on page 154](#).

### 19.7.5 Parity Checker

The parity checker is active when the high USART parity mode (UPMn1) bit is set. Type of parity check to be performed (odd or even) is selected by the UPMn0 bit. When enabled, the parity checker calculates the parity of the data bits in incoming frames and compares the result with the parity bit from the serial frame. The result of the check is stored in the receive buffer together with the received data and stop bits. The parity error (UPEn) flag can then be read by software to check if the frame had a parity error.

The UPEn bit is set if the next character that can be read from the receive buffer had a parity error when received and the parity checking was enabled at that point (UPMn1 = 1). This bit is valid until the receive buffer (UDRn) is read.

### 19.7.6 Disabling the Receiver

In contrast to the transmitter, disabling of the Receiver will be immediate. Data from ongoing receptions will therefore be lost. When disabled (i.e., the RXENn is set to zero) the receiver will no longer override the normal function of the Rx/Dn port pin. The receiver buffer FIFO will be flushed when the receiver is disabled. Remaining data in the buffer will be lost.

## 19.7.7 Flushing the Receive Buffer

The receiver buffer FIFO will be flushed when the receiver is disabled, i.e., the buffer will be emptied of its contents. Unread data will be lost. If the buffer has to be flushed during normal operation, due to for instance an error condition, read the UDRn I/O location until the RXCn flag is cleared. The following code example shows how to flush the receive buffer.

Assembly Code Example <sup>(1)</sup>
<pre>USART_Flush:     sbis    UCSRnA, RXCn     ret     in      r16, UDRn     rjmp    USART_Flush</pre>
C Code Example <sup>(1)</sup>
<pre>void USART_Flush(void) {     unsigned char dummy;     while (UCSRnA &amp; (1&lt;&lt;RXCn)) dummy = UDRn; }</pre>

Note: 1. See [Section 5. “About Code Examples” on page 8](#).

For I/O registers located in extended I/O map, “IN”, “OUT”, “SBIS”, “SBIC”, “CBI”, and “SBI” instructions must be replaced with instructions that allow access to extended I/O. Typically “LDS” and “STS” combined with “SBR”, “SBRC”, “SBR”, and “CBR”.

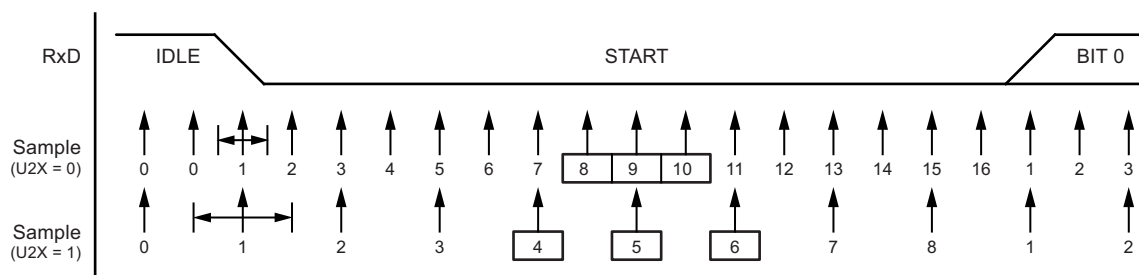
## 19.8 Asynchronous Data Reception

The USART includes a clock recovery and a data recovery unit for handling asynchronous data reception. The clock recovery logic is used for synchronizing the internally generated baud rate clock to the incoming asynchronous serial frames at the Rx/Dn pin. The data recovery logic samples and low pass filters each incoming bit, thereby improving the noise immunity of the receiver. The asynchronous reception operational range depends on the accuracy of the internal baud rate clock, the rate of the incoming frames, and the frame size in number of bits.

### 19.8.1 Asynchronous Clock Recovery

The clock recovery logic synchronizes internal clock to the incoming serial frames. [Figure 19-5](#) illustrates the sampling process of the start bit of an incoming frame. The sample rate is 16 times the baud rate for Normal mode, and eight times the baud rate for double speed mode. The horizontal arrows illustrate the synchronization variation due to the sampling process. Note the larger time variation when using the double speed mode (U2Xn = 1) of operation. Samples denoted zero are samples done when the Rx/Dn line is idle (i.e., no communication activity).

Figure 19-5. Start Bit Sampling

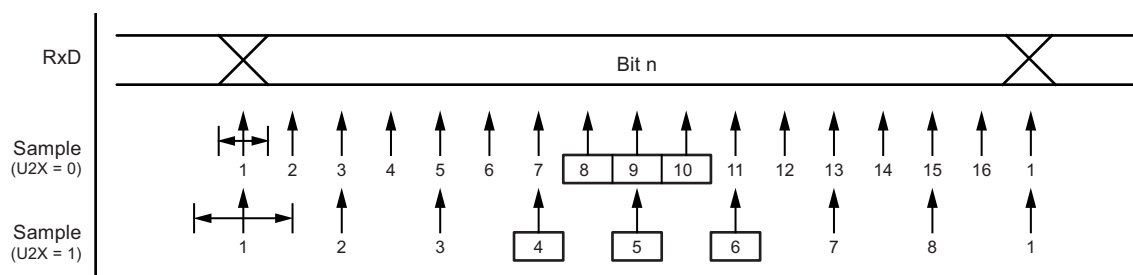


When the clock recovery logic detects a high (idle) to low (start) transition on the Rx/Dn line, the start bit detection sequence is initiated. Let sample 1 denote the first zero-sample as shown in the figure. The clock recovery logic then uses samples 8, 9, and 10 for normal mode, and samples 4, 5, and 6 for double speed mode (indicated with sample numbers inside boxes on the figure), to decide if a valid start bit is received. If two or more of these three samples have logical high levels (the majority wins), the start bit is rejected as a noise spike and the receiver starts looking for the next high to low-transition. If however, a valid start bit is detected, the clock recovery logic is synchronized and the data recovery can begin. The synchronization process is repeated for each start bit.

## 19.8.2 Asynchronous Data Recovery

When the receiver clock is synchronized to the start bit, the data recovery can begin. The data recovery unit uses a state machine that has 16 states for each bit in normal mode and eight states for each bit in double speed mode. [Figure 19-6](#) shows the sampling of the data bits and the parity bit. Each of the samples is given a number that is equal to the state of the recovery unit.

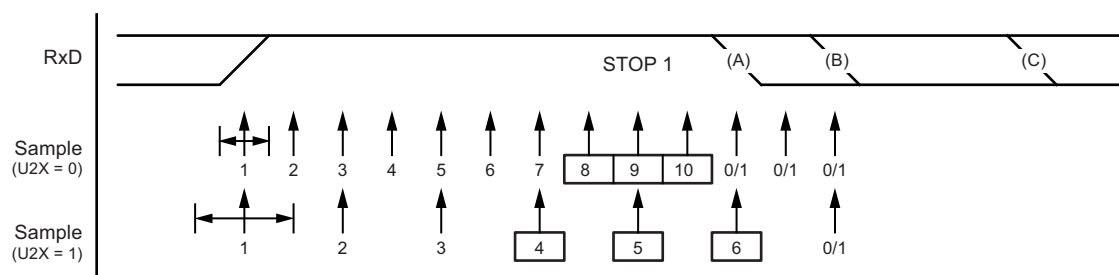
**Figure 19-6. Sampling of Data and Parity Bit**



The decision of the logic level of the received bit is taken by doing a majority voting of the logic value to the three samples in the center of the received bit. The center samples are emphasized on the figure by having the sample number inside boxes. The majority voting process is done as follows: If two or all three samples have high levels, the received bit is registered to be a logic 1. If two or all three samples have low levels, the received bit is registered to be a logic 0. This majority voting process acts as a low pass filter for the incoming signal on the RxDn pin. The recovery process is then repeated until a complete frame is received. Including the first stop bit. Note that the receiver only uses the first stop bit of a frame.

[Figure 19-7](#) shows the sampling of the stop bit and the earliest possible beginning of the start bit of the next frame.

**Figure 19-7. Stop Bit Sampling and Next Start Bit Sampling**



The same majority voting is done to the stop bit as done for the other bits in the frame. If the stop bit is registered to have a logic 0 value, the frame error (FEn) flag will be set.

A new high to low transition indicating the start bit of a new frame can come right after the last of the bits used for majority voting. For normal speed mode, the first low level sample can be at point marked (A) in [Figure 19-7](#). For double speed mode the first low level must be delayed to (B). (C) marks a stop bit of full length. The early start bit detection influences the operational range of the receiver.

### 19.8.3 Asynchronous Operational Range

The operational range of the receiver is dependent on the mismatch between the received bit rate and the internally generated baud rate. If the transmitter is sending frames at too fast or too slow bit rates, or the internally generated baud rate of the receiver does not have a similar (see [Table 19-2](#)) base frequency, the receiver will not be able to synchronize the frames to the start bit.

The following equations can be used to calculate the ratio of the incoming data rate and internal receiver baud rate.

$$R_{\text{slow}} = \frac{(D + 1)S}{S - 1 + D \times S + S_F}$$

$$R_{\text{fast}} = \frac{(D + 2)S}{(D + 1)S + S_M}$$

- D** Sum of character size and parity size (D = 5 to 10 bit)
- S** Samples per bit. S = 16 for normal speed mode and S = 8 for double speed mode.
- S<sub>F</sub>** First sample number used for majority voting. S<sub>F</sub> = 8 for normal speed and S<sub>F</sub> = 4 for double speed mode.
- S<sub>M</sub>** Middle sample number used for majority voting. S<sub>M</sub> = 9 for normal speed and S<sub>M</sub> = 5 for double speed mode.
- R<sub>slow</sub>** is the ratio of the slowest incoming data rate that can be accepted in relation to the receiver baud rate. R<sub>fast</sub> is the ratio of the fastest incoming data rate that can be accepted in relation to the receiver baud rate.

[Table 19-2](#) and [Table 19-3](#) list the maximum receiver baud rate error that can be tolerated. Note that normal speed mode has higher toleration of baud rate variations.

**Table 19-2. Recommended Maximum Receiver Baud Rate Error for Normal Speed Mode (U2Xn = 0)**

D # (Data+Parity Bit)	R <sub>slow</sub> (%)	R <sub>fast</sub> (%)	Max Total Error (%)	Recommended Max Receiver Error (%)
5	93.20	106.67	+6.67/–6.8	±3.0
6	94.12	105.79	+5.79/–5.88	±2.5
7	94.81	105.11	+5.11/–5.19	±2.0
8	95.36	104.58	+4.58/–4.54	±2.0
9	95.81	104.14	+4.14/–4.19	±1.5
10	96.17	103.78	+3.78/–3.83	±1.5

**Table 19-3. Recommended Maximum Receiver Baud Rate Error for Double Speed Mode (U2Xn = 1)**

D # (Data+Parity Bit)	R <sub>slow</sub> (%)	R <sub>fast</sub> (%)	Max Total Error (%)	Recommended Max Receiver Error (%)
5	94.12	105.66	+5.66/–5.88	±2.5
6	94.92	104.92	+4.92/–5.08	±2.0
7	95.52	104.35	+4.35/–4.48	±1.5
8	96.00	103.90	+3.90/–4.00	±1.5
9	96.39	103.53	+3.53/–3.61	±1.5
10	96.70	103.23	+3.23/–3.30	±1.0

The recommendations of the maximum receiver baud rate error was made under the assumption that the receiver and transmitter equally divides the maximum total error.

There are two possible sources for the receivers baud rate error. The receiver's system clock (XTAL) will always have some minor instability over the supply voltage range and the temperature range. When using a crystal to generate the system clock, this is rarely a problem, but for a resonator the system clock may differ more than 2% depending of the resonators tolerance. The second source for the error is more controllable. The baud rate generator can not always do an exact division of the system frequency to get the baud rate wanted. In this case an UBRRn value that gives an acceptable low error can be used if possible.

## 19.9 Multi-processor Communication Mode

Setting the multi-processor communication mode (MPCMn) bit in UCSRnA enables a filtering function of incoming frames received by the USART receiver. Frames that do not contain address information will be ignored and not put into the receive buffer. This effectively reduces the number of incoming frames that has to be handled by the CPU, in a system with multiple MCUs that communicate via the same serial bus. The transmitter is unaffected by the MPCMn setting, but has to be used differently when it is a part of a system utilizing the multi-processor communication mode.

If the receiver is set up to receive frames that contain 5 to 8 data bits, then the first stop bit indicates if the frame contains data or address information. If the receiver is set up for frames with nine data bits, then the ninth bit (RXB8n) is used for identifying address and data frames. When the frame type bit (the first stop or the ninth bit) is one, the frame contains an address. When the frame type bit is zero the frame is a data frame.

The multi-processor communication mode enables several slave MCUs to receive data from a master MCU. This is done by first decoding an address frame to find out which MCU has been addressed. If a particular slave MCU has been addressed, it will receive the following data frames as normal, while the other slave MCUs will ignore the received frames until another address frame is received.

### 19.9.1 Using MPCMn

For an MCU to act as a master MCU, it can use a 9-bit character frame format (UCSZn = 7). The ninth bit (TXB8n) must be set when an address frame (TXB8n = 1) or cleared when a data frame (TXB = 0) is being transmitted. The slave MCUs must in this case be set to use a 9-bit character frame format.

The following procedure should be used to exchange data in multi-processor communication mode:

1. All Slave MCUs are in multi-processor communication mode (MPCMn in UCSRnA is set).
2. The master MCU sends an address frame, and all slaves receive and read this frame. In the Slave MCUs, the RXCn flag in UCSRnA will be set as normal.
3. Each slave MCU reads the UDRn register and determines if it has been selected. If so, it clears the MPCMn bit in UCSRnA, otherwise it waits for the next address byte and keeps the MPCMn setting.
4. The addressed MCU will receive all data frames until a new address frame is received. The other slave MCUs, which still have the MPCMn bit set, will ignore the data frames.
5. When the last data frame is received by the addressed MCU, the addressed MCU sets the MPCMn bit and waits for a new address frame from master. The process then repeats from 2.

Using any of the 5- to 8-bit character frame formats is possible, but impractical since the receiver must change between using n and n+1 character frame formats. This makes full-duplex operation difficult since the transmitter and receiver uses the same character size setting. If 5- to 8-bit character frames are used, the transmitter must be set to use two stop bit (USBSn = 1) since the first stop bit is used for indicating the frame type.

Do not use read-modify-write instructions (SBI and CBI) to set or clear the MPCMn bit. The MPCMn bit shares the same I/O location as the TXCn flag and this might accidentally be cleared when using SBI or CBI instructions.



## 19.10 Register Description

### 19.10.1 UDRn – USART I/O Data Register n

Bit	7	6	5	4	3	2	1	0	
	RXB[7:0]								UDRn (Read)
	TXB[7:0]								UDRn (Write)
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

The USART transmit data buffer register and USART receive data buffer registers share the same I/O address referred to as USART data register or UDRn. The transmit data buffer register (TXB) will be the destination for data written to the UDRn register location. Reading the UDRn register location will return the contents of the receive data buffer register (RXB).

For 5-, 6-, or 7-bit characters the upper unused bits will be ignored by the transmitter and set to zero by the receiver.

The transmit buffer can only be written when the UDREN flag in the UCSRnA register is set. Data written to UDRn when the UDREN flag is not set, will be ignored by the USART transmitter. When data is written to the transmit buffer, and the transmitter is enabled, the transmitter will load the data into the transmit shift register when the shift register is empty. Then the data will be serially transmitted on the TxDn pin.

The receive buffer consists of a two level FIFO. The FIFO will change its state whenever the receive buffer is accessed. Due to this behavior of the receive buffer, do not use read-modify-write instructions (SBI and CBI) on this location. Be careful when using bit test instructions (SBIC and SBIS), since these also will change the state of the FIFO.

### 19.10.2 UCSRnA – USART Control and Status Register n A

Bit	7	6	5	4	3	2	1	0	
	RXCn	TXCn	UDREN	FEn	DORn	UPEn	U2Xn	MPCMn	UCSRnA
Read/Write	R	R/W	R	R	R	R	R/W	R/W	
Initial Value	0	0	1	0	0	0	0	0	

- **Bit 7 – RXCn: USART Receive Complete**

This flag bit is set when there are unread data in the receive buffer and cleared when the receive buffer is empty (i.e., does not contain any unread data). If the receiver is disabled, the receive buffer will be flushed and consequently the RXCn bit will become zero. The RXCn flag can be used to generate a receive complete interrupt (see description of the RXCIEn bit).

- **Bit 6 – TXCn: USART Transmit Complete**

This flag bit is set when the entire frame in the transmit shift register has been shifted out and there are no new data currently present in the transmit buffer (UDRn). The TXCn flag bit is automatically cleared when a transmit complete interrupt is executed, or it can be cleared by writing a one to its bit location. The TXCn flag can generate a transmit complete interrupt (see description of the TXCIEn bit).

- **Bit 5 – UDREN: USART Data Register Empty**

The UDREN flag indicates if the transmit buffer (UDRn) is ready to receive new data. If UDREN is one, the buffer is empty, and therefore ready to be written. The UDREN flag can generate a data register empty interrupt (see description of the UDRIEn bit). UDREN is set after a reset to indicate that the transmitter is ready.

- **Bit 4 – FEn: Frame Error**

This bit is set if the next character in the receive buffer had a frame error when received. I.e., when the first stop bit of the next character in the receive buffer is zero. This bit is valid until the receive buffer (UDRn) is read. The FEn bit is zero when the stop bit of received data is one. Always set this bit to zero when writing to UCSRnA.

- **Bit 3 – DORn: Data OverRun**

This bit is set if a data overrun condition is detected. A data overrun occurs when the receive buffer is full (two characters), it is a new character waiting in the receive shift register, and a new start bit is detected. This bit is valid until the receive buffer (UDRn) is read. Always set this bit to zero when writing to UCSRnA.

- **Bit 2 – UPEn: USART Parity Error**

This bit is set if the next character in the receive buffer had a parity error when received and the parity checking was enabled at that point (UPMn1 = 1). This bit is valid until the receive buffer (UDRn) is read. Always set this bit to zero when writing to UCSRnA.

- **Bit 1 – U2Xn: Double the USART Transmission Speed**

This bit only has effect for the asynchronous operation. Write this bit to zero when using synchronous operation.

Writing this bit to one will reduce the divisor of the baud rate divider from 16 to 8 effectively doubling the transfer rate for asynchronous communication.

- **Bit 0 – MPCMn: Multi-processor Communication Mode**

This bit enables the multi-processor communication mode. When the MPCMn bit is written to one, all the incoming frames received by the USART receiver that do not contain address information will be ignored. The transmitter is unaffected by the MPCMn setting. For more detailed information see [Section 19.9 “Multi-processor Communication Mode” on page 158](#).

### 19.10.3 UCSRnB – USART Control and Status Register n B

Bit	7	6	5	4	3	2	1	0	
	<b>RXCIE<sub>n</sub></b>	<b>TXCIE<sub>n</sub></b>	<b>UDRIE<sub>n</sub></b>	<b>RXEN<sub>n</sub></b>	<b>TXEN<sub>n</sub></b>	<b>UCSZ<sub>n2</sub></b>	<b>RXB8<sub>n</sub></b>	<b>TXB8<sub>n</sub></b>	<b>UCSRnB</b>
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R	R/W	
Initial Value	0	0	0	0	0	0	0	0	

- **Bit 7 – RXCIE<sub>n</sub>: RX Complete Interrupt Enable n**

Writing this bit to one enables interrupt on the RXC<sub>n</sub> flag. A USART receive complete interrupt will be generated only if the RXCIE<sub>n</sub> bit is written to one, the global interrupt flag in SREG is written to one and the RXC<sub>n</sub> bit in UCSRnA is set.

- **Bit 6 – TXCIE<sub>n</sub>: TX Complete Interrupt Enable n**

Writing this bit to one enables interrupt on the TXC<sub>n</sub> flag. A USART transmit complete interrupt will be generated only if the TXCIE<sub>n</sub> bit is written to one, the global interrupt flag in SREG is written to one and the TXC<sub>n</sub> bit in UCSRnA is set.

- **Bit 5 – UDRIE<sub>n</sub>: USART Data Register Empty Interrupt Enable n**

Writing this bit to one enables interrupt on the UDRE<sub>n</sub> flag. A data register empty interrupt will be generated only if the UDRIE<sub>n</sub> bit is written to one, the global interrupt flag in SREG is written to one and the UDRE<sub>n</sub> bit in UCSRnA is set.

- **Bit 4 – RXEN<sub>n</sub>: Receiver Enable n**

Writing this bit to one enables the USART receiver. The receiver will override normal port operation for the Rx<sub>Dn</sub> pin when enabled. Disabling the receiver will flush the receive buffer invalidating the FEN, DOR<sub>n</sub>, and UPEN flags.

- **Bit 3 – TXEN<sub>n</sub>: Transmitter Enable n**

Writing this bit to one enables the USART transmitter. The transmitter will override normal port operation for the Tx<sub>Dn</sub> pin when enabled. The disabling of the transmitter (writing TXEN<sub>n</sub> to zero) will not become effective until ongoing and pending transmissions are completed, i.e., when the transmit shift register and transmit buffer register do not contain data to be transmitted. When disabled, the transmitter will no longer override the Tx<sub>Dn</sub> port.

- **Bit 2 – UCSZ<sub>n2</sub>: Character Size n**

The UCSZ<sub>n2</sub> bits combined with the UCSZ<sub>n1:0</sub> bit in UCSRnC sets the number of data bits (character size) in a frame the receiver and transmitter use.

- **Bit 1 – RXB8<sub>n</sub>: Receive Data Bit 8 n**

RXB8<sub>n</sub> is the ninth data bit of the received character when operating with serial frames with nine data bits. Must be read before reading the low bits from UDR<sub>n</sub>.

- **Bit 0 – TXB8<sub>n</sub>: Transmit Data Bit 8 n**

TXB8<sub>n</sub> is the ninth data bit in the character to be transmitted when operating with serial frames with nine data bits. Must be written before writing the low bits to UDR<sub>n</sub>.

## 19.10.4 UCSRnC – USART Control and Status Register n C

Bit	7	6	5	4	3	2	1	0	
	<b>UMSELn1</b>	<b>UMSELn0</b>	<b>UPMn1</b>	<b>UPMn0</b>	<b>USBSn</b>	<b>UCSZn1</b>	<b>UCSZn0</b>	<b>UCPOLn</b>	<b>UCSRnC</b>
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	1	1	0	

- **Bits 7:6 – UMSELn1:0 USART Mode Select**

These bits select the mode of operation of the USARTn as shown in [Table 19-4](#).

**Table 19-4. UMSELn Bits Settings**

UMSELn1	UMSELn0	Mode
0	0	Asynchronous USART
0	1	Synchronous USART
1	0	(Reserved)
1	1	Master SPI (MSPIM) <sup>(1)</sup>

Note: 1. See [Section 20. “USART in SPI Mode” on page 166](#) for full description of the master SPI mode (MSPIM) operation

- **Bits 5:4 – UPMn1:0: Parity Mode**

These bits enable and set type of parity generation and check. If enabled, the transmitter will automatically generate and send the parity of the transmitted data bits within each frame. The receiver will generate a parity value for the incoming data and compare it to the UPMn setting. If a mismatch is detected, the UPEn flag in UCSRnA will be set.

**Table 19-5. UPMn Bits Settings**

UPMn1	UPMn0	Parity Mode
0	0	Disabled
0	1	Reserved
1	0	Enabled, even parity
1	1	Enabled, odd parity

- **Bit 3 – USBSn: Stop Bit Select**

This bit selects the number of stop bits to be inserted by the transmitter. The receiver ignores this setting.

**Table 19-6. USBS Bit Settings**

USBSn	Stop Bit(s)
0	1-bit
1	2-bit

- **Bit 2:1 – UCSZn1:0: Character Size**

The UCSZn1:0 bits combined with the UCSZn2 bit in UCSRnB sets the number of data bits (character size) in a frame the receiver and transmitter use.

**Table 19-7. UCSZn Bits Settings**

UCSZn2	UCSZn1	UCSZn0	Character Size
0	0	0	5-bit
0	0	1	6-bit
0	1	0	7-bit
0	1	1	8-bit
1	0	0	Reserved
1	0	1	Reserved
1	1	0	Reserved
1	1	1	9-bit

- **Bit 0 – UCPOLn: Clock Polarity**

This bit is used for synchronous mode only. Write this bit to zero when asynchronous mode is used. The UCPOLn bit sets the relationship between data output change and data input sample, and the synchronous clock (XCKn).

**Table 19-8. UCPOLn Bit Settings**

UCPOLn	Transmitted Data Changed (Output of TxDn Pin)	Received Data Sampled (Input on RxDn Pin)
0	Rising XCKn edge	Falling XCKn edge
1	Falling XCKn edge	Rising XCKn edge

### 19.10.5 UBRRnL and UBRRnH – USART Baud Rate Registers

Bit	15	14	13	12	11	10	9	8	
	–	–	–	–	UBRRn[11:8]				UBRRnH
	UBRRn[7:0]								UBRRnL
	7	6	5	4	3	2	1	0	
Read/Write	R	R	R	R	R/W	R/W	R/W	R/W	
	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	
	0	0	0	0	0	0	0	0	

- **Bit 15:12 – Reserved Bits**

These bits are reserved for future use. For compatibility with future devices, these bit must be written to zero when UBRRnH is written.

- **Bit 11:0 – UBRR11:0: USART Baud Rate Register**

This is a 12-bit register which contains the USART baud rate. The UBRRnH contains the four most significant bits, and the UBRRnL contains the eight least significant bits of the USART baud rate. Ongoing transmissions by the transmitter and receiver will be corrupted if the baud rate is changed. Writing UBRRnL will trigger an immediate update of the baud rate prescaler.

## 19.11 Examples of Baud Rate Setting

For standard crystal and resonator frequencies, the most commonly used baud rates for asynchronous operation can be generated by using the UBRRn settings in [Table 19-9](#). UBRRn values which yield an actual baud rate differing less than 0.5% from the target baud rate, are bold in the table. Higher error ratings are acceptable, but the receiver will have less noise resistance when the error ratings are high, especially for large serial frames (see [Section 19.8.3 “Asynchronous Operational Range” on page 157](#)). The error values are calculated using the following equation:

$$\text{Error}[\%] = \left( \frac{\text{BaudRate}_{\text{Closest Match}}}{\text{BaudRate}} - 1 \right) \times 100\%$$

**Table 19-9. Examples of UBRRn Settings for Commonly Used Oscillator Frequencies**

Baud Rate (bps)	$f_{\text{osc}} = 1.0000\text{MHz}$				$f_{\text{osc}} = 1.8432\text{MHz}$				$f_{\text{osc}} = 2.0000\text{MHz}$			
	U2Xn = 0		U2Xn = 1		U2Xn = 0		U2Xn = 1		U2Xn = 0		U2Xn = 1	
	UBRRn	Error	UBRRn	Error	UBRRn	Error	UBRRn	Error	UBRRn	Error	UBRRn	Error
2400	25	0.2%	51	0.2%	47	0.0%	95	0.0%	51	0.2%	103	0.2%
4800	12	0.2%	25	0.2%	23	0.0%	47	0.0%	25	0.2%	51	0.2%
9600	6	-7.0%	12	0.2%	11	0.0%	23	0.0%	12	0.2%	25	0.2%
14.4k	3	8.5%	8	-3.5%	7	0.0%	15	0.0%	8	-3.5%	16	2.1%
19.2k	2	8.5%	6	-7.0%	5	0.0%	11	0.0%	6	-7.0%	12	0.2%
28.8k	1	8.5%	3	8.5%	3	0.0%	7	0.0%	3	8.5%	8	-3.5%
38.4k	1	-18.6%	2	8.5%	2	0.0%	5	0.0%	2	8.5%	6	-7.0%
57.6k	0	8.5%	1	8.5%	1	0.0%	3	0.0%	1	8.5%	3	8.5%
76.8k	—	—	1	-18.6%	1	-25.0%	2	0.0%	1	-18.6%	2	8.5%
115.2k	—	—	0	8.5%	0	0.0%	1	0.0%	0	8.5%	1	8.5%
230.4k	—	—	—	—	—	—	0	0.0%	—	—	—	—
250k	—	—	—	—	—	—	—	—	—	—	0	0.0%
Max. <sup>(1)</sup>	62.5kbps		125kbps		115.2kbps		230.4kbps		125kbps		250kbps	

Note: 1. UBRRn = 0, error = 0.0%

**Table 19-10. Examples of UBRRn Settings for Commonly Used Oscillator Frequencies**

Baud Rate (bps)	$f_{osc} = 3.6864\text{MHz}$				$f_{osc} = 4.0000\text{MHz}$				$f_{osc} = 7.3728\text{MHz}$			
	U2Xn = 0		U2Xn = 1		U2Xn = 0		U2Xn = 1		U2Xn = 0		U2Xn = 1	
	UBRRn	Error	UBRRn	Error	UBRRn	Error	UBRRn	Error	UBRRn	Error	UBRRn	Error
2400	95	0.0%	191	0.0%	103	0.2%	207	0.2%	191	0.0%	383	0.0%
4800	47	0.0%	95	0.0%	51	0.2%	103	0.2%	95	0.0%	191	0.0%
9600	23	0.0%	47	0.0%	25	0.2%	51	0.2%	47	0.0%	95	0.0%
14.4k	15	0.0%	31	0.0%	16	2.1%	34	-0.8%	31	0.0%	63	0.0%
19.2k	11	0.0%	23	0.0%	12	0.2%	25	0.2%	23	0.0%	47	0.0%
28.8k	7	0.0%	15	0.0%	8	-3.5%	16	2.1%	15	0.0%	31	0.0%
38.4k	5	0.0%	11	0.0%	6	-7.0%	12	0.2%	11	0.0%	23	0.0%
57.6k	3	0.0%	7	0.0%	3	8.5%	8	-3.5%	7	0.0%	15	0.0%
76.8k	2	0.0%	5	0.0%	2	8.5%	6	-7.0%	5	0.0%	11	0.0%
115.2k	1	0.0%	3	0.0%	1	8.5%	3	8.5%	3	0.0%	7	0.0%
230.4k	0	0.0%	1	0.0%	0	8.5%	1	8.5%	1	0.0%	3	0.0%
250k	0	-7.8%	1	-7.8%	0	0.0%	1	0.0%	1	-7.8%	3	-7.8%
0.5M	—	—	0	-7.8%	—	—	0	0.0%	0	-7.8%	1	-7.8%
1M	—	—	—	—	—	—	—	—	—	—	0	-7.8%
Max. <sup>(1)</sup>	230.4kbps		460.8kbps		250kbps		0.5Mbps		460.8kbps		921.6kbps	

Note: 1. UBRRn = 0, error = 0.0%

**Table 19-11. Examples of UBRRn Settings for Commonly Used Oscillator Frequencies**

Baud Rate (bps)	$f_{osc} = 8.0000\text{MHz}$				$f_{osc} = 11.0592\text{MHz}$				$f_{osc} = 14.7456\text{MHz}$			
	U2Xn = 0		U2Xn = 1		U2Xn = 0		U2Xn = 1		U2Xn = 0		U2Xn = 1	
	UBRRn	Error	UBRRn	Error	UBRRn	Error	UBRRn	Error	UBRRn	Error	UBRRn	Error
2400	207	0.2%	416	-0.1%	287	0.0%	575	0.0%	383	0.0%	767	0.0%
4800	103	0.2%	207	0.2%	143	0.0%	287	0.0%	191	0.0%	383	0.0%
9600	51	0.2%	103	0.2%	71	0.0%	143	0.0%	95	0.0%	191	0.0%
14.4k	34	-0.8%	68	0.6%	47	0.0%	95	0.0%	63	0.0%	127	0.0%
19.2k	25	0.2%	51	0.2%	35	0.0%	71	0.0%	47	0.0%	95	0.0%
28.8k	16	2.1%	34	-0.8%	23	0.0%	47	0.0%	31	0.0%	63	0.0%
38.4k	12	0.2%	25	0.2%	17	0.0%	35	0.0%	23	0.0%	47	0.0%
57.6k	8	-3.5%	16	2.1%	11	0.0%	23	0.0%	15	0.0%	31	0.0%
76.8k	6	-7.0%	12	0.2%	8	0.0%	17	0.0%	11	0.0%	23	0.0%
115.2k	3	8.5%	8	-3.5%	5	0.0%	11	0.0%	7	0.0%	15	0.0%
230.4k	1	8.5%	3	8.5%	2	0.0%	5	0.0%	3	0.0%	7	0.0%
250k	1	0.0%	3	0.0%	2	-7.8%	5	-7.8%	3	-7.8%	6	5.3%
0.5M	0	0.0%	1	0.0%	—	—	2	-7.8%	1	-7.8%	3	-7.8%
1M	—	—	0	0.0%	—	—	—	—	0	-7.8%	1	-7.8%
Max. <sup>(1)</sup>	0.5Mbps		1Mbps		691.2kbps		1.3824Mbps		921.6kbps		1.8432Mbps	

Note: 1. UBRRn = 0, error = 0.0%

**Table 19-12. Examples of UBRRn Settings for Commonly Used Oscillator Frequencies**

Baud Rate (bps)	$f_{osc} = 16.0000\text{MHz}$			
	U2Xn = 0		U2Xn = 1	
	UBRRn	Error	UBRRn	Error
2400	416	−0.1%	832	0.0%
4800	207	0.2%	416	−0.1%
9600	103	0.2%	207	0.2%
14.4k	68	0.6%	138	−0.1%
19.2k	51	0.2%	103	0.2%
28.8k	34	−0.8%	68	0.6%
38.4k	25	0.2%	51	0.2%
57.6k	16	2.1%	34	−0.8%
76.8k	12	0.2%	25	0.2%
115.2k	8	−3.5%	16	2.1%
230.4k	3	8.5%	8	−3.5%
250k	3	0.0%	7	0.0%
0.5M	1	0.0%	3	0.0%
1M	0	0.0%	1	0.0%
Max. <sup>(1)</sup>	1Mbps		2Mbps	

Note: 1. UBRRn = 0, error = 0.0%