Chapter 22
Serial Communication

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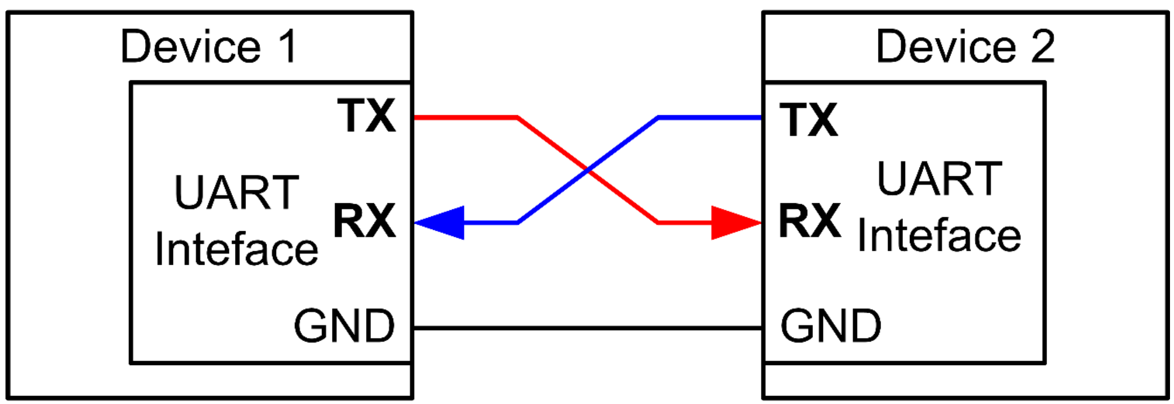
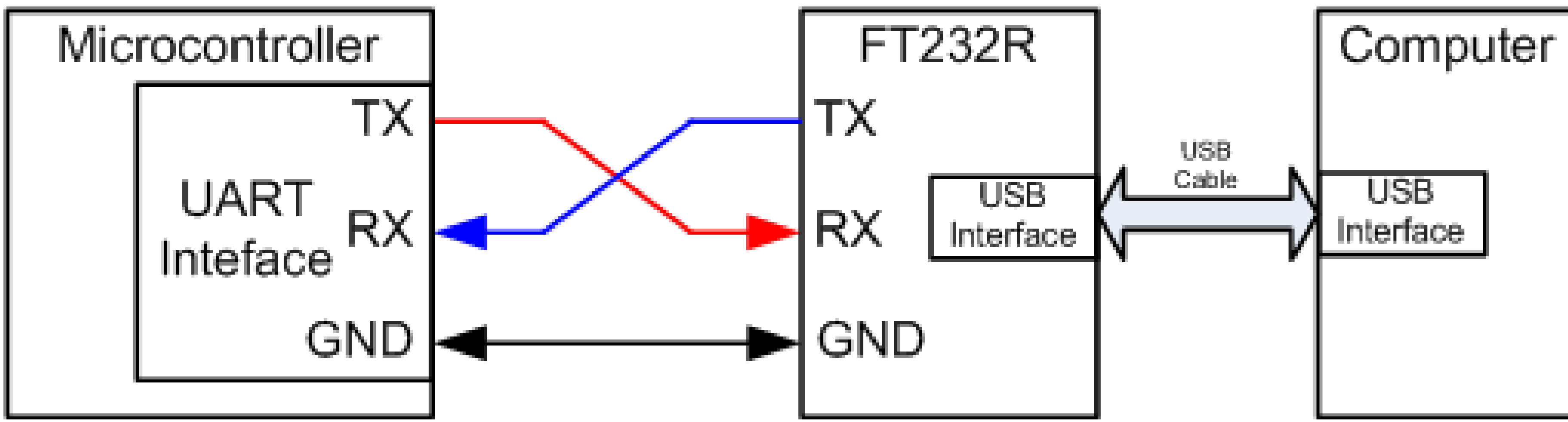
Universal Asynchronous Receiver and Transmitter (UART)

- Universal
  - UART is programmable.
- Asynchronous
  - Sender provides no clock signal to receivers



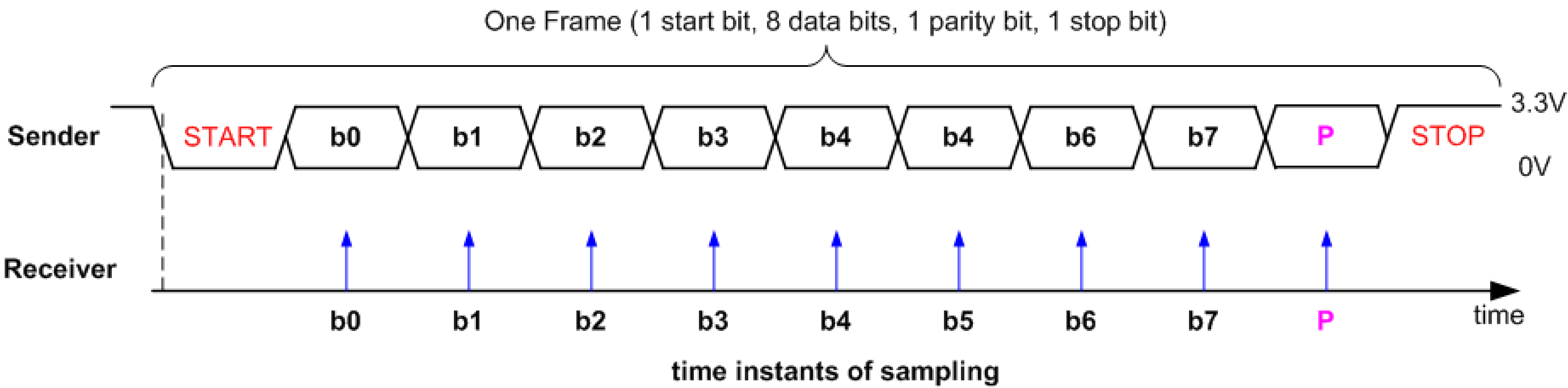
Connecting to PC

- FT232R converts the UART port to a standard USB interface



USB to serial UART

Data Frame



Tolerate 10% clock shift during transmission

- Sender and receiver uses the same transmission speed
- Data frame
  - One start bit
  - Data (LSB first or MSB, and size of 7, 8, 9 bits)
  - Optional parity bit
  - One or two stop bit

Baud Rate

- Historically used in telecommunication to represent the number of pulses physically transferred per second
- In digital communication, baud rate is the number of bits physically transferred per second
- Example:
  - Baud rate is 9600
  - each frame: a start bit, 8 data bits, a stop bit, and no parity bit.
  - Transmission rate of actual data

    ~~9600/8 = 1200 bytes/second~~

    9600/(1 + 8 + 1) = 960 bytes/second
  - The start and stop bits are the protocol overhead

Baud Rate

$$Baud\ Rate = \frac{f_{PCLK}}{8 \times (2 - OVER8) \times USARTDIV}$$

- If *OVER8* is 0, then the signal is oversampled by 16, and 4 bits are used for the fractional part.
- If *OVER8* is 1, then the signal is oversampled by 8, and 3 bits are used.
- If BRR is **`0x1BC`** and *OVER8* is 0, then **`0x1B`** is the integer part and **`0xC`** is the fractional part.
- $USARTDV = 0x1B + \frac{0xC}{0x10} = 27 + \frac{12}{16} = 27.75$

Baud Rate

- Suppose the processor clock f_{PCLK} is 16MHz, and the system is oversampled by 16 ($OVER8 = 0$),
- $USARTDIV = \frac{f_{PCLK}}{8 \times (2 - OVER8) \times Baud\ Rate}$

$$= \frac{16 \times 10^6}{8 \times (2 - 0) \times 9600} = 104.1667$$

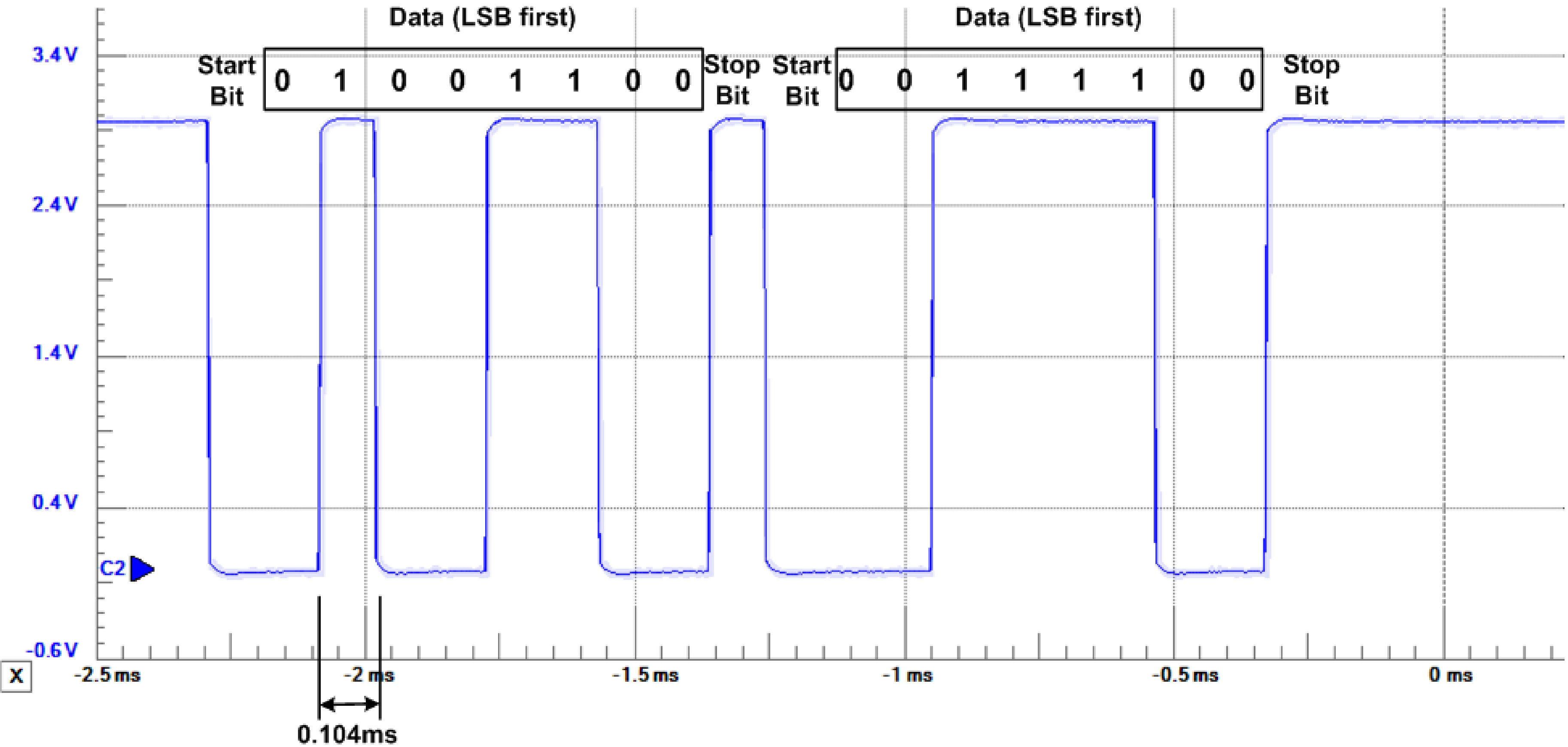
- Thus *USARTDIV* is 104.1875, which is encoded as 0x683.
- desired baud rate 9600

$$Baud\ Rate = \frac{16 \times 10^6}{8 \times (2 - 0) \times 104.1875} = 9598$$

Error Detection

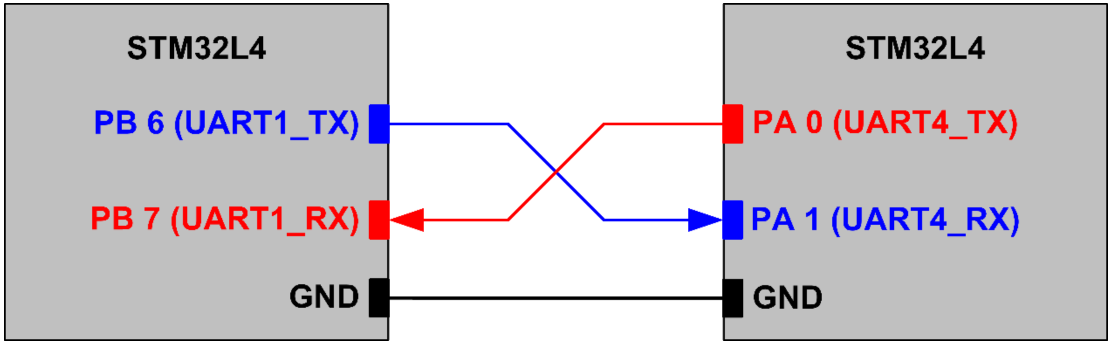
- Even Parity: total number of "1" bits in data and parity is even
- Odd Parity: total number of "1" bits in data and parity is odd
- Example: Data = 10101011 (five "1" bits)
  - The parity bit should be 0 for odd parity and 1 for even parity
- This can detect single-bit data corruption

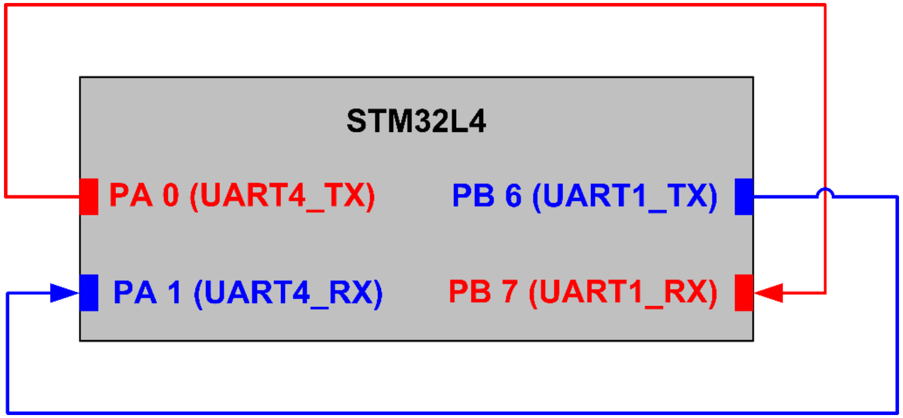
Transmitting 0x32 and 0x3C



1 start bit, 1 stop bit, 8 data bits, no parity, baud rate = 9600

UART Connection





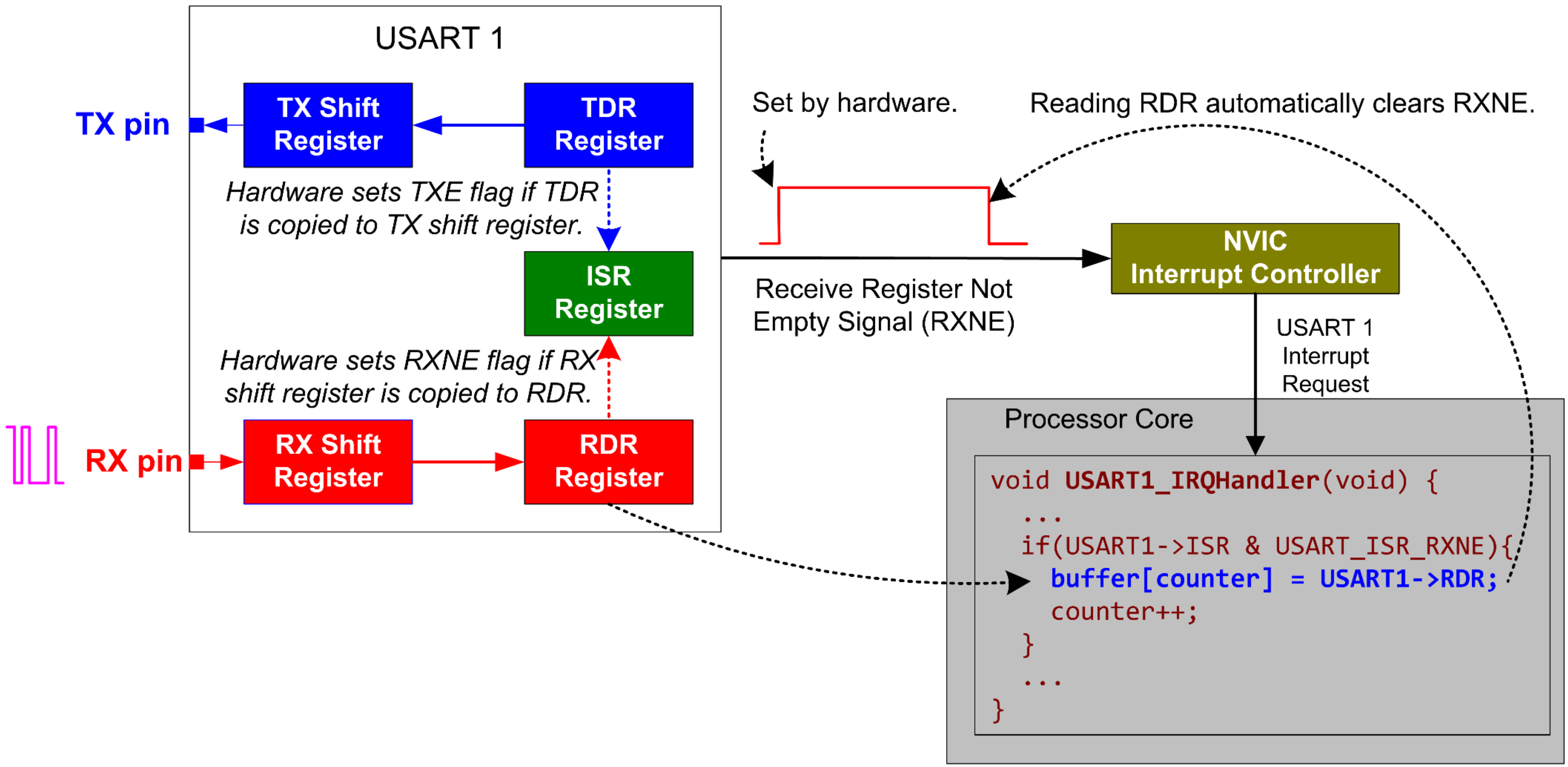
Sending Data

```
void USART_Write(USART_TypeDef * USARTx, uint8_t * buffer, int nBytes) {
   int i;

   // TXE is cleared by a write to the USART_DR register.
   // TXE is set by hardware when the content of the TDR
   // register has been transferred into the shift register.

   for (i = 0; i < nBytes; i++) {
    // wait until TXE (TX empty) is set
    // Writing USART_DR automatically clears the TXE flag
     while (!(USARTx->SR & USART_SR_TXE));
     USARTx->DR = (buffer[i] & 0x1FF);
   }

   while (!(USARTx->SR & USART_SR_TC));     // wait until TC bit is set
   USARTx->SR &= ~USART_SR_TC;
}
```

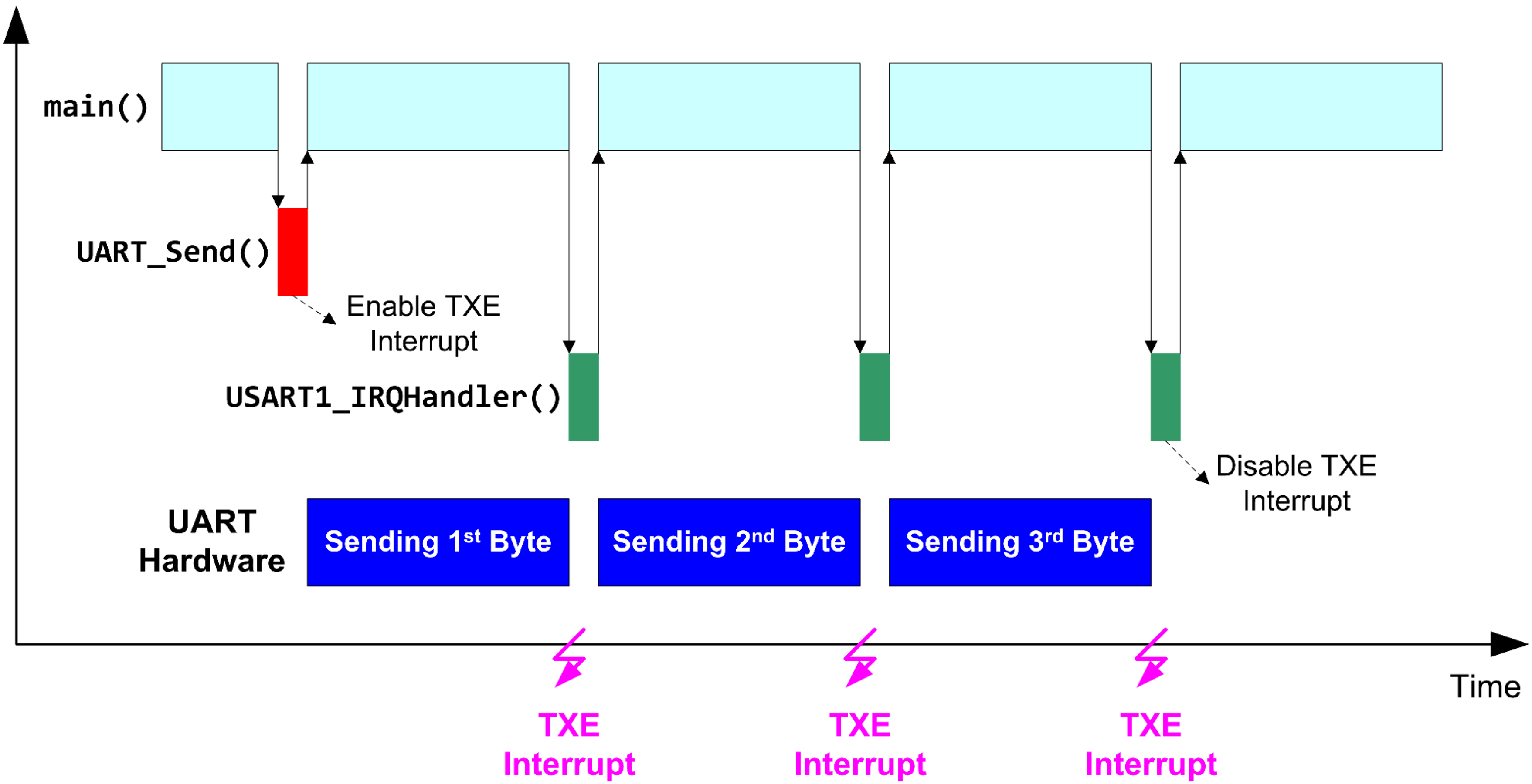
Receiving Data

```
void USART_IRQHandler(USART_TypeDef * USARTx, uint8_t * buffer,  uint8_t * pRx_counter){
   if(USARTx->SR & USART_SR_RXNE) { // Received data
     buffer[*pRx_counter] = USARTx->DR;
     // Reading USART_DR automatically clears the RXNE flag
     (*pRx_counter)++;
     if((*pRx_counter) >= BufferSize )
       (*pRx_counter) = 0;
  }
}

void USART1_IRQHandler(void) {
   USART_IRQHandler(USART1, USART1_Buffer_Rx, &Rx1_Counter);
}

void USART2_IRQHandler(void) {
   USART_IRQHandler(USART2, USART2_Buffer_Rx, &Rx2_Counter);
}
```

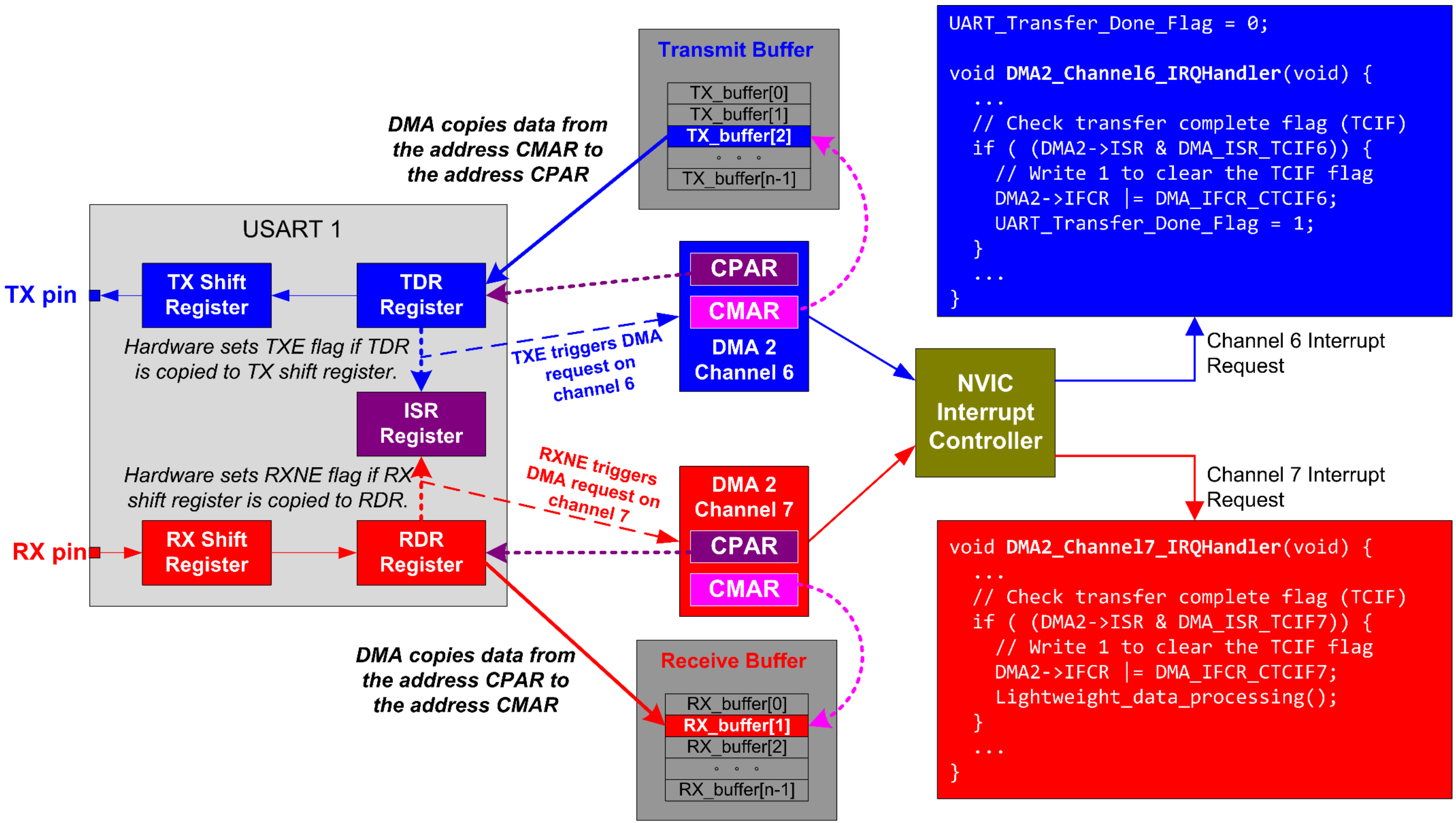
UART Interrupt: Receiving Data



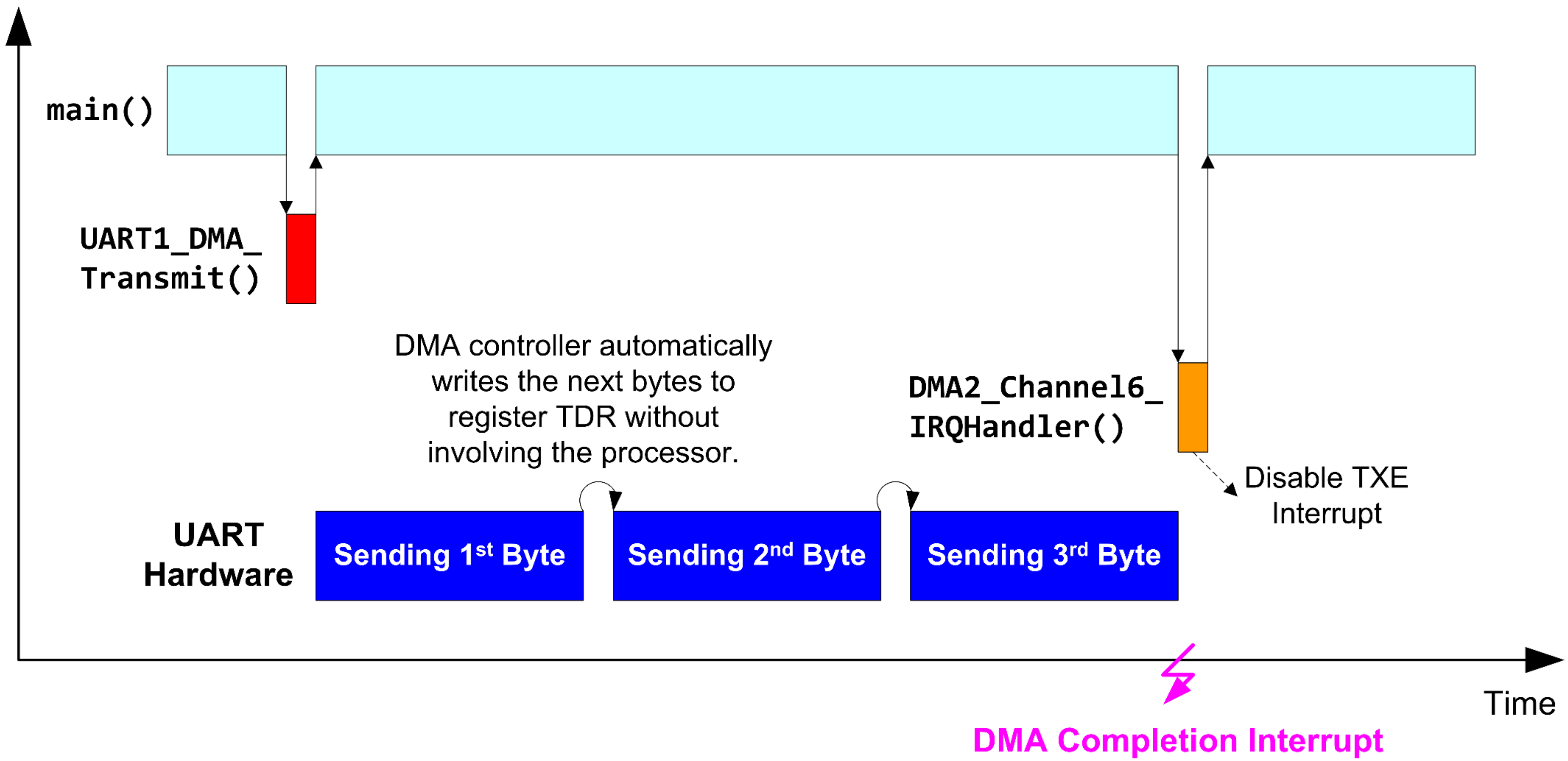
UART Interrupt: Receiving Data



UART DMA: Receiving & Sending



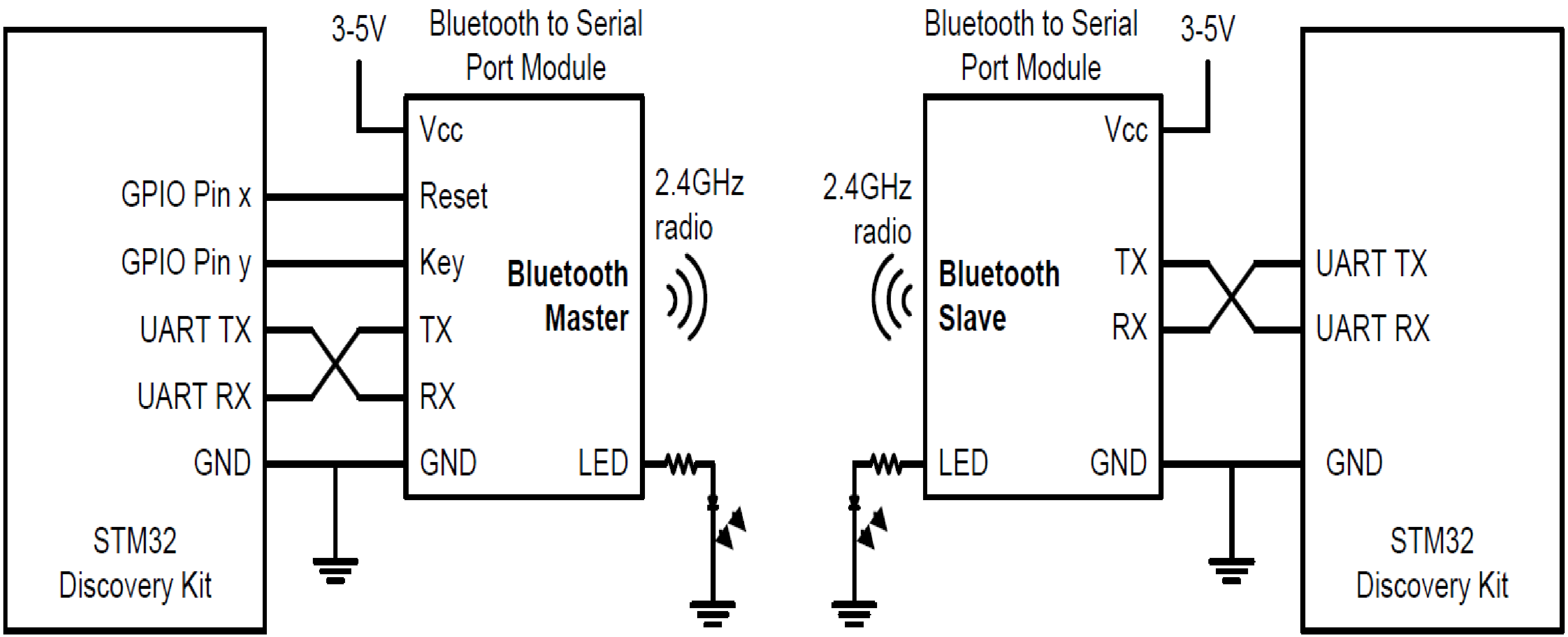
UART DMA: Receiving & Sending



Voltage Levels

Standard	Voltage signal	Max distance	Max speed	Number of devices supported per port
RS-232	Single end (logic 1: +5 to +15V, logic 0: -5 to -15 V)	100 feet	115Kbit/s	1 master, 1 receiver
RS-422	Differential (-6V to +6V)	4000 feet	10Mbit/s	1 master, 10 receivers
RS-485	Differential (-7V to +12V)	4000 feet	10Mbit/s	32 masters, 32 receivers

Bluetooth



3-5V
Bluetooth to Serial
Port Module
Vcc
GPIO Pin x
Reset
GPIO Pin y
Key
Bluetooth
Master
UART TX
TX
UART RX
RX
GND
GND
LED
2.4GHz
radio
STM32
Discovery Kit
Bluetooth to Serial
Port Module
3-5V
Vcc
2.4GHz
radio
Bluetooth
Slave
TX
UART TX
RX
UART RX
LED
GND
GND
STM32
Discovery Kit