AN4908
Application note

STM32 USART automatic baud rate detection

Introduction

Correct USART communication requires the transmission and reception baud rates to be matched reasonably closely, otherwise communication errors may occur.

Automatic baud rate detection is useful when establishing a communication link between two devices, where the slave device is able to detect the baud rate of the master controller and self-adjust accordingly. This requires an automatic mechanism to determine the baud rate.

The USART peripheral embedded in some STM32 devices offers many features, including automatic baud rate detection hardware.

The purpose of this application note is to present the automatic baud rate detection feature of STM32 microcontrollers and to give an alternative software approach for STM32 devices that do not implement this feature in hardware.

This application note applies to the products listed in *Table 1*.

Table 1. Applicable products

Type	Product series
Microcontrollers	STM32F0 Series, STM32F1 Series, STM32F3 Series, STM32F2 Series, STM32F4 Series, STM32F7 Series, STM32H7 Series, STM32L0 Series, STM32L1 Series, STM32L4 Series.

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1 General information

STM32 Series microcontrollers are Arm®[(a)]-based devices.

arm

2 Hardware automatic baud rate detection

2.1 Feature overview

Automatic baud rate detection (ABR) allows the receiving device to accept data from a variety of transmitting devices operating at different speeds without needing to establish data rates in advance.

In some STM32 products, the USART is able to automatically determine the baud rate using dedicated hardware.

Table 2 gives an overview of the STM32 series devices that support automatic baud rate detection.

Table 2. USART hardware automatic baud rate detection on STM32 Series devices

Product	ABR support
Mainstream	
STM32F0	Yes
STM32F1	No
STM32F3	Yes
High-performance	
STM32F2	No
STM32F4	No
STM32F7	Yes
STM32H7	Yes
Ultra-low power	
STM32L0	Yes
STM32L1	No
STM32L4	Yes

For STM32 Series devices that embed ABR, not all of the instantiated USART interfaces support the automatic baud rate feature. This constraint is detailed in *Table 3: Hardware automatic baud rate detection on STM32 USART interfaces*.

a. Arm is a registered trademark of Arm Limited (or its subsidiaries) in the US and/or elsewhere.

Table 3. Hardware automatic baud rate detection on STM32 USART interfaces(1)(2)(3)

Port	STM32 F0										STM32 F3							STM32 F7		STM32 H7		STM32 L0			STM32 L4
	STM32F030x4 STM32F030x6	STM32F030x8	STM32F070x6	STM32F070xB	STM32F030xC	STM32F03x	STM32F05x	STM32F04x	STM32F04x STM32F07x	STM32F09x	STM32F37xx	STM32F302xB/C STM32F302xD/E	STM32F302x6/8	STM32F303xB/C STM32F358xC STM32F303xD/E STM32F398xE	STM32F303x6/8 STM32F328x8	STM32F334xx	STM32F301x6/8 STM32F318x8	STM32F745xx	STM32F756xx	STM32H743/5/7 STM32H753/5/7	STM32H7A3/B3/B0	STM32L0x1	STM32L0x2	STM32L0x3	STM32L4x1 STM32L4x2 STM32L4x3 STM32L4x5 STM32L4x6
USART 1	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
USART 2	0	-	-	X	X	0	-	-	X	X	X	X	-	X	-	-	X	X	X	X	X	X	X	X	X
USART 3	0	0	0	-	-	0	0	0	-	X	X	X	-	X	-	-	X	X	X	X	X	0	0	0	X
USART 4	0	0	0	-	-	0	0	0	-	-	-	-	0	-	0	0	0	X	X	0	0	-	-	-	X
USART 5	0	0	0	0	0	0	0	0	0	-	-	-	0	-	0	0	0	X	X	0	0	-	-	-	X
USART 6	0	0	0	0	0	0	0	0	0	-	-	0	0	0	0	0	0	X	X	X	X	0	0	0	0
USART 7	0	0	0	0	0	0	0	0	0	-	-	0	0	0	0	0	0	X	X	0	0	0	0	0	0
USART 8	0	0	0	0	0	0	0	0	0	-	-	0	0	0	0	0	0	X	X	0	0	0	0	0	0
UART 9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	-	-	-	-
USART 10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-

1. X: supported
2. -: not supported
3. 0: USART instance not available

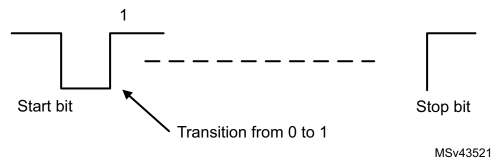
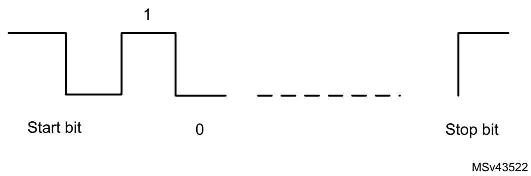
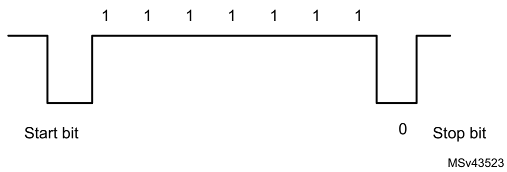
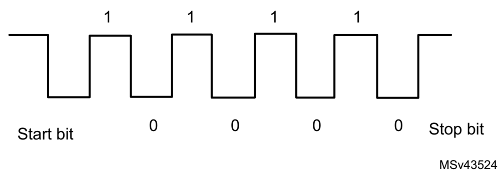
2.2 Automatic baud rate detection modes

ABR refers to the process by which a receiving device determines the speed of incoming data by examining the first character, usually a preselected sign-on character.

The automatic baud rate feature on STM32 products embed various modes based on different character patterns:

- any character starting with a bit at ‘1’: **Mode 0**
- any character starting with a 10xx pattern: **Mode 1**
- 0x7F: **Mode 2**
- 0x55**: Mode 3**.

Table 4. Automatic baud rate detection modes

ABR mode	Description	Waveform
0	The received character can be a character starting with a bit at 1. In this case, the USART measures the duration of the start bit (falling edge to rising edge).	
1	Any character starting with a 10xx pattern. In this case, the USART measures the duration of the start and of the 1st data bit. The duration is measured from falling edge to falling edge, **ensuring better accuracy in the case of slow signal slopes.**	
2	0x7F character frame. In this case, the baud rate is updated first at the end of the start bit then at the end of the bit 6.	
3	A 0x55 character frame. In this case, the baud rate is updated first at the end of the start bit, then at the end of bit and finally at the end of bit 6. In parallel, another check is performed for each intermediate transition of RX line.	

Before activating the automatic baud rate detection, one of the ABR modes must be selected through the ABRMOD[1:0] field in the USARTx_CR2 register. In all ABR modes, the baud rate is measured several times during the synchronization data reception, and is compared each time to the previous measurement.

Note: In 7-bit data length mode, 0x7F and 0x55 frames detection ABR modes are not supported.

2.3 Error calculation for ABR

The communication speed range (specifically the maximum communication speed) is determined by the USART clock source (fCK). The receiver implements different user-configurable oversampling techniques for data recovery by discriminating between valid incoming data and noise. This allows a trade-off between the maximum communication speed and immunity to noise / clock inaccuracy.

The oversampling method is selected by programming the **OVER8** bit in the **USARTx_CR1** register, and can be either 16 or 8 times the baud-rate clock.

The USART clock source frequency must be compatible with the expected communication speed:

- **When oversampling by 16**, the baud rate is between fCK/65535 and fCK/16
- **When oversampling by 8**, the baud rate is between fCK/65535 and fCK/8.

The baud-rate error is dependent on the USART clock source, the oversampling method and the ABR mode.

$$\text{Error}(\%) = \left|\frac{\text{desired baud rate} - \text{actual baud rate}}{\text{desired baud rate}}\right| \cdot 100$$

Where:

- *desired baud rate* is fixed by the transmitter device
- *actual baud rate* is the baud rate determined by the USART receiver using the automatic baud rate detection operation.

3 Software automatic baud rate detection

When hardware auto baud rate detection is not supported, the software approach described in this section can be adopted.

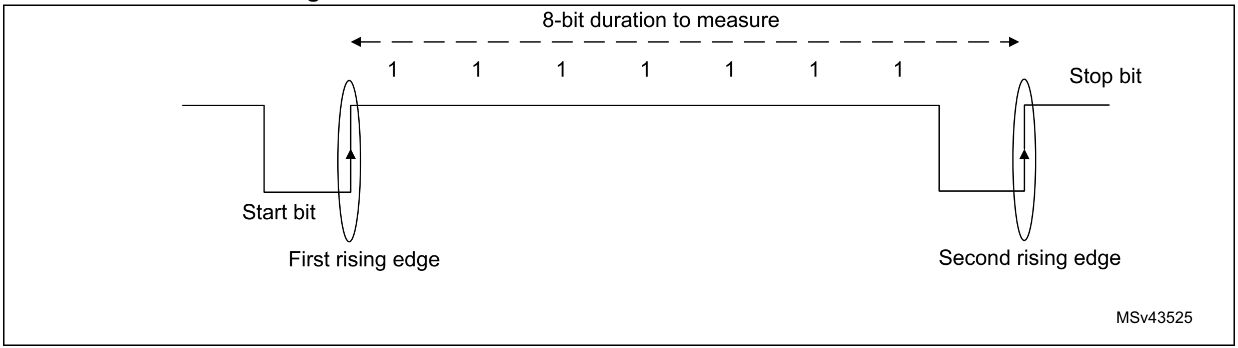
The idea of the software approach is to send a **0x7F** data frame to the **USARTx_RX** pin. This is connected to the EXTI line, which is configured to generate an interrupt on each rising edge.

The duration of the interval between the two rising edges is measured using the Systick timer. This duration corresponds to the duration of 8 bits, so

- bit time = calculated duration / 8
- baud rate = 1/bit time

The USARTx_BRR register is then programmed, based on the calculated baud rate value.

Figure 1. Software automatic baud rate detection overview



4 Setups for software and hardware approaches

The STM32F303xD/E embedding the hardware automatic baud rate feature, is used for this set-up example.

The HyperTerminal PC application is used to send and receive data frames to and from the STM32F303. Consequently, standard baud rates in the range 600 bits/s to 115200 bits/s are tested.The highest baud-rate value that can be reached (9 Mbits/s) is tested using another STM32F3 device as a transmitter.

4.1 USART1 configuration example

In both examples, the STM32 USART1 is configured as follows:

```
/*##-1- Configure the UART peripheral
#######################################*/
  /* Put the USART peripheral in the Asynchronous mode (UART Mode) */
  /* UART configured as follows:
   - Word Length = 8 Bits
   - Stop Bit    = One Stop bit
   - Parity      = NONE  parity
   - BaudRate    = 115200 baud  It can be any other value as the USARTx_BRR
register will be reprogrammed
   - Hardware flow control disabled (RTS and CTS signals)
   - The oversampling mode is 8 or 16 (Both are tested)
*/
  UartHandle.Instance           = USARTx;
  UartHandle.Init.BaudRate      = 115200;
  UartHandle.Init.WordLength    = UART_WORDLENGTH_8B;
  UartHandle.Init.StopBits      = UART_STOPBITS_1;
  UartHandle.Init.Parity        = UART_PARITY_NONE;
  UartHandle.Init.HwFlowCtl     = UART_HWCONTROL_NONE;
  UartHandle.Init.Mode          = UART_MODE_TX_RX;
  UartHandle.Init.OverSampling = UART_OVERSAMPLING_16;
```

Note: The USART1 clock source is a system clock at 72 MHz, using the HSE PLL clock source. (Some tests are made using the HSI clock as USART1 clock source. This is to check the impact of the HSI inaccuracy on the results.)

4.2 Hardware auto baud rate detection

The USART1 is configured to detect baud rate automatically. The user has to select the ABR mode in the USART1 initialization function as follows:

```
/*##-2- Configure the AutoBaudRate method */
UartHandle.AdvancedInit.AdvFeatureInit =UART_ADVFEATURE_AUTOBAUDRATE_INIT;
UartHandle.AdvancedInit.AutoBaudRateEnable =
UART_ADVFEATURE_AUTOBAUDRATE_ENABLE;

/*Uncomment your appropriate mode */

//UartHandle.AdvancedInit.AutoBaudRateMode =
UART_ADVFEATURE_AUTOBAUDRATE_ONSTARTBIT;
//UartHandle.AdvancedInit.AutoBaudRateMode =
UART_ADVFEATURE_AUTOBAUDRATE_ONFALLINGEDGE;
//UartHandle.AdvancedInit.AutoBaudRateMode =
UART_ADVFEATURE_AUTOBAUDRATE_ON0X7FFRAME;
//UartHandle.AdvancedInit.AutoBaudRateMode =
UART_ADVFEATURE_AUTOBAUDRATE_ON0X55FRAME;

if (HAL_UART_Init(&UartHandle) != HAL_OK)
{
/* Initialization Error */
 Error_Handler();
}

/* Wait until Receive enable acknowledge flag is set */
while(__HAL_UART_GET_FLAG(&UartHandle,UART_FLAG_REACK) == RESET)
{}

/* Wait until Transmit enable acknowledge flag is set */
while(__HAL_UART_GET_FLAG(&UartHandle,UART_FLAG_TEACK) == RESET)
{}

/* Loop until the end of Autobaudrate phase */
while(__HAL_UART_GET_FLAG(&UartHandle,UART_FLAG_ABRF) == RESET)
{}
```

Once the whole initialization is complete, the USART waits until data is received from the HyperTerminal before launching the automatic baud rate detection phase. The end of this phase is monitored by the ABRF flag.

- If the auto baud rate operation is unsuccessful, the ABRE flag is set
- If the auto baud rate operation is completed successfully, an acknowledgment data is transmitted to the HyperTerminal.

```
/* If AutoBaudBate error occurred */

if (__HAL_UART_GET_FLAG(&UartHandle, UART_FLAG_ABRE)!= RESET)
{
  Error_Handler();
}
else
{
   /* Wait until RXNE flag is set */
 while(__HAL_UART_GET_FLAG(&UartHandle,UART_FLAG_RXNE) == RESET)
 {}
   /* Send acknowledgement message*/
 if (HAL_UART_Transmit_DMA(&UartHandle, (uint8_t *)aTxBuffer, TXBUFFERSIZE)
!= HAL_OK)
 {
   /* Transfer error in transmission process */
   Error_Handler();
 }
 while (HAL_UART_GetState(&UartHandle) != HAL_UART_STATE_READY)
 {
 }
}
```

4.3 Software automatic baud rate detection

Table 5 details the software approach.

Table 5. Software automatic baud rate detection details

Action	Code
HAL library initialization. Suspend Tick increment to prevent wakeup by Systick interrupt.	`HAL_Init();` `HAL_SuspendTick();`

Configure the system clock to 72 MHz.
The SystemCoreClockUpdate function can eventually be executed in the main to verify the CPU operating frequency.
	`System Clock source     = PLL (HSE)`
	`PLLMUL                  = RCC_PLL_MUL9 (9)`
	`Flash Latency(WS)       = 2`

Configure the UART peripheral.	See *Section 4.1: USART1 configuration example*.

Configure the USARTx RX pin to generate an interrupt on each rising edge.	`static void EXTILine1_Config(void)`
	`{`
	`  GPIO_InitTypeDef   GPIO_InitStructure;`
	` /* Enable GPIOE clock */`
	`  __GPIOE_CLK_ENABLE();`
	` /* Configure PE1 pin as input floating */`
	`  GPIO_InitStructure.Mode = GPIO_MODE_IT_RISING;`
	`  GPIO_InitStructure.Pull = GPIO_NOPULL;`
	`  GPIO_InitStructure.Pin = GPIO_PIN_1;`
	`  HAL_GPIO_Init(GPIOE, &GPIO_InitStructure);`
	` /* Enable and set EXTI Line0 Interrupt to the lowest priority */`
	`  HAL_NVIC_SetPriority(EXTI1_IRQn, 2, 2);`
	`  HAL_NVIC_EnableIRQ(EXTI1_IRQn);`
	`}`

Table 5. Software automatic baud rate detection details (continued)

Action	Code

0x7F received on Rx pin, wait until the end of the interrupt.
Launch the automatic baud rate sequence described in *Section 3: Software automatic baud rate detection*.
	/*Wait until the end of interrupt */
	while (**end_interrupt_flag** != 1) {
	  BSP_LED_On(LED2);
	}
	/* Autobaudrate sequence : Update BRR register */
	Autobaudrate();
	/* Send acknowledgement */
	 if (HAL_UART_Transmit_DMA(&UartHandle, (uint8_t *)aTxBuffer, TXBUFFERSIZE) != HAL_OK)
	{
	  /* Transfer error in transmission process */
	  Error_Handler();
	}
	while (HAL_UART_GetState(&UartHandle) != HAL_UART_STATE_READY)
	{}
	  /* Infinite loop */
	while (1)
	{}

Automatic baud rate function	static void Autobaudrate(void)
	{
	 float tmp=0, elapsed;
	 uint32_t USART1_clk=0;
	 uint32_t start_time_val=0;
	 uint32_t BRR=0;
	 tmp += 0xFFFFFF - stop_time_val;
	 tmp -= start_time_val;
	 elapsed =(tmp/(SystemCoreClock/1000000))/8;
	 USART1_clk=SystemCoreClock;
	 if((USART1->CR1 & 0x8000)== 0x8000)
	 {
	  /*In case of oversampling by 8*/
	  BRR =(elapsed*((2*USART1_clk)/1000000))+1;
	  USART1->BRR= BRR;
	 }
	 else
	 {
	  /*In case of oversampling by 16*/
	  BRR =(elapsed* ((USART1_clk)/1000000))+1;
	  USART1->BRR=BRR;
	 }
	}

Table 5. Software automatic baud rate detection details (continued)

Action	Code

External line 1 interrupt request:
First rising: temp=0 start the systick timer
Second rising:
– disable the systick counter
– get the encoding time
– clear the SysTick counter
	`void EXTI1_IRQHandler()`
	`{`
	`  HAL_GPIO_EXTI_IRQHandler(GPIO_PIN_1);`
	`  if(temp==0)`
	`  {`
	`    HAL_SYSTICK_Config(0xFFFFFF);`
	`    temp++;`
	`  }`
	`  else`
	`  {`
	`    SysTick->CTRL &= SysTick_Counter_Disable;`
	`     /* Stop the Timer and get the encoding time  */`
	`    GETMYTIME(&stop_time_val);`
	`     /* Clear the SysTick Counter */`
	`    SysTick->VAL = SysTick_Counter_Clear;`
	`     /* Clear the temp flag*/`
	`    temp=0;`
	`    /*end of interrupt*/`
	`  interrupt_flag=1;`
	` }`
	`}`

Required project defines	`#define SysTick_Counter_Disable        ((uint32_t)0xFFFFFFFE)`
	`#define SysTick_Counter_Enable         ((uint32_t)0x00000001)`
	`#define SysTick_Counter_Clear          ((uint32_t)0x00000000)`
	`#define GETMYTIME(_t) (*_t=SysTick->VAL)`

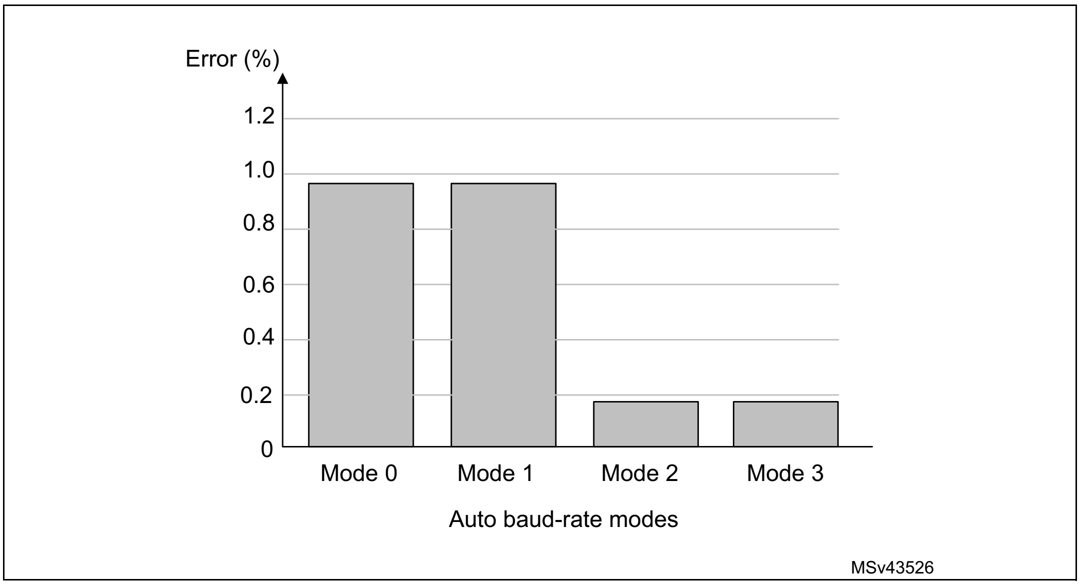
4.4 Analysis of results

4.4.1 Error calculation

Figure 2 shows that ABR modes 2 and 3 are more precise than modes 0 and 1; they provide a lower baud-rate error figure.

Nevertheless, all modes exhibit good results, as the error between the desired and actual baud rates is less than 1%.

Figure 2. Error calculation for ABR at fCK = 72 MHz, 115200 bits/s desired baud rate



4.4.2 Comparison of software and hardware approaches

Figure 3 shows that in general, when the USART is clocked by the system clock at 72 MHz (with the HSE as the PLL clock source), the results are better than when the USART clock source is used as the HSI clock. This is due to the relative inaccuracy of the HSI.

Figure 3. ABR error comparison (fCK = HSI clock, Mode 2 for HW detection)

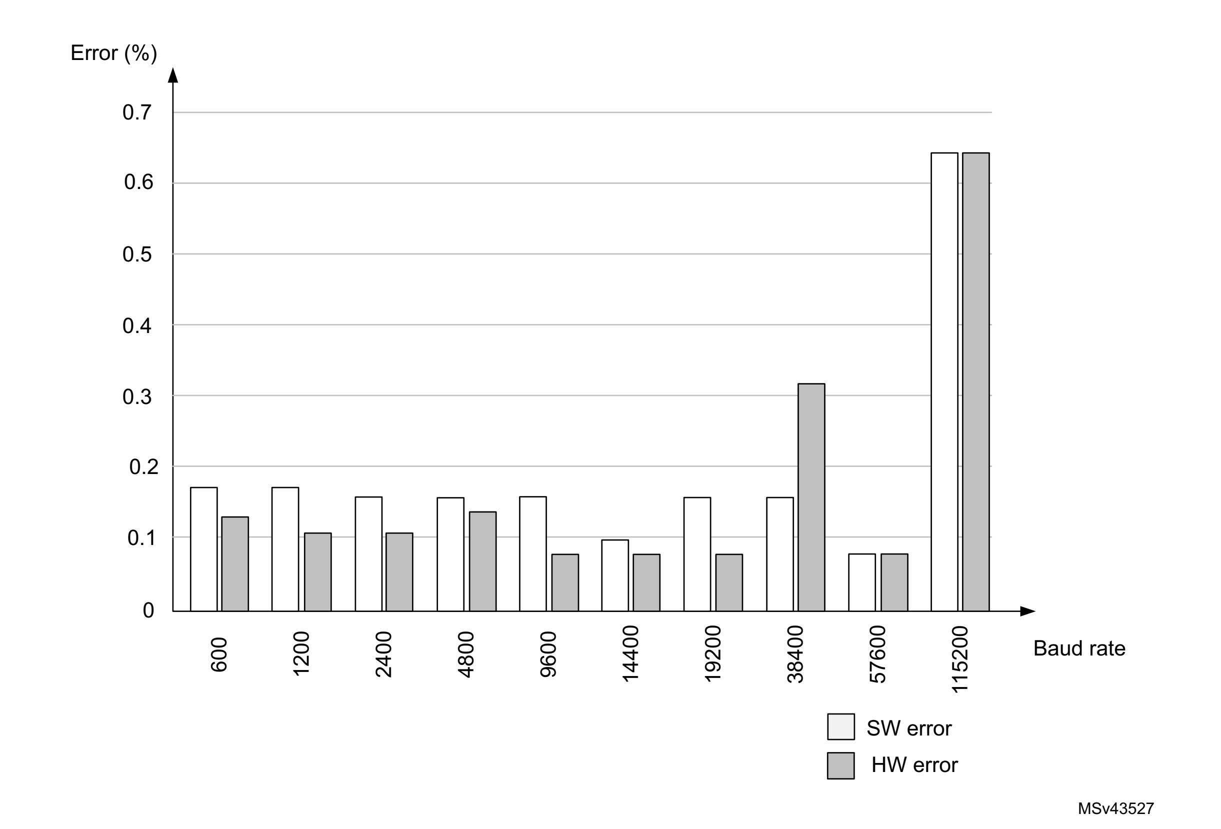


Figure 4 shows that in most cases the hardware approach provides better results than the software approach. The software approach nevertheless provides good results that are in some cases comparable to those obtained using the hardware approach.

Figure 4. ABR error comparison (fCK = 72 MHz, Mode 2 for HW detection)

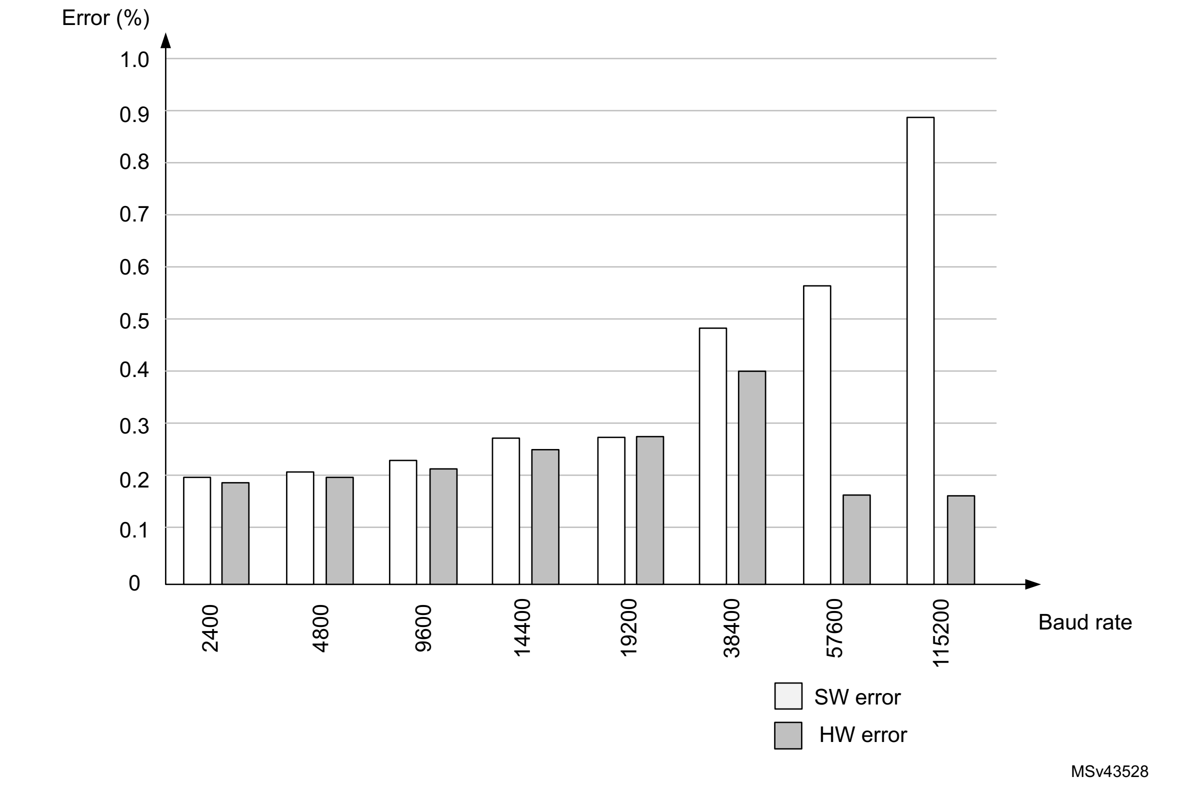
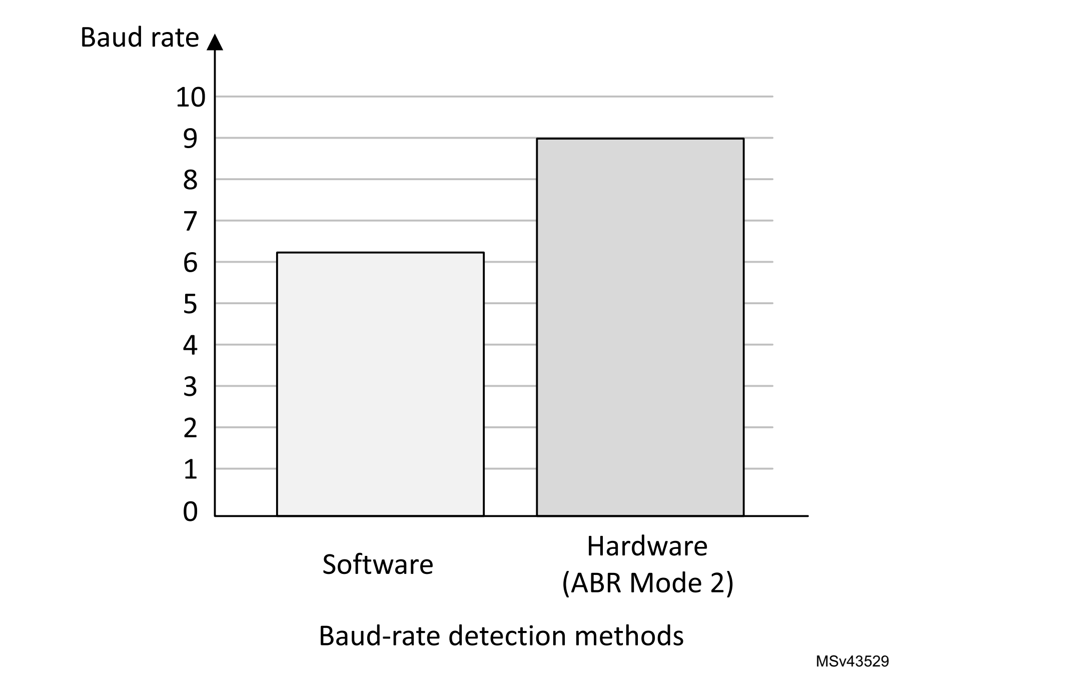


Figure 5 shows that:

- With the hardware approach we reach the maximum baud rate of 9 Mbits/s with 0% error.
- With the software approach the error at maximum baud rate is about 30%, which is explained by the CPU cycles spent executing the interrupt handler.

Figure 5. Baud rate comparison (fCK = 72 MHz, desired baud rate = 9 Mbits/s, Mode 2 for hardware detection



5 Conclusion

This application note describes the hardware automatic baud rate detection feature embedded in some STM32 devices. It also provides a technique for implementing this feature in software, as a solution for STM32 devices not implementing this feature in hardware.

Although the automatic baud rate detection is applied at the beginning of the examples, it could be extended and used whenever the transmitter and receiver devices detect communication errors. This allows a robust application where the host varies its baud rate between communications.

6 Revision history

Table 6. Document revision history

Date	Revision	Changes
15-Nov-2016	1	Initial release
01-Oct-2020	2	The following tables now scope STM32H7 Series products: – *Table 1: Applicable products* – *Table 2: USART hardware automatic baud rate detection on STM32 Series devices* – *Table 3: Hardware automatic baud rate detection on STM32 USART interfaces*.