

Software UART for Stellaris® Microcontrollers

Chris Lande

ABSTRACT

The universal asynchronous receiver transmitter (UART) is a widely used serial communications peripheral used in many applications for connection to legacy devices. Many systems use multiple instances of legacy devices and modern microcontrollers generally support this. However, in some cases additional instances beyond the hardware limit may be required. This application report looks at an implementation of a software-based UART that, using general-purpose input/outputs (GPIO), allows you to overcome the hardware limitations or lack of dedicated peripherals.

Contents

1	Software UART Initialization.....	1
2	Software UART Performance Limitations.....	2
3	Software UART Receiver	3
4	Software UART Transmitter	3
5	API Functional Description	3
6	Conclusion	7
7	References	7

1 Software UART Initialization

This implementation uses two GPIOs, one for transmit (TX), and one for receive (RX) and two timers, a single 32-bit timer configured as two individual 16-bit timers. One 16-bit timer is used to generate the transmit tick and the other is used for the receive tick. Each timer interrupt function is loaded into the nested vectored interrupt controller (NVIC) table in the `startup.c` file. The GPIOs used in this example both belong to the same GPIO bank, for example, BANK 'C' IO 0, 1.

1.1 Inputs and Outputs

The GPIO bank and individual GPIOs used for TX, RX are configured in the `sw_uart_basic.c` file by way of definitions. TX and RX GPIOs are configured by the `SWU_GPIO_TX` and `SWU_GPIO_RX` definitions, respectively. Note that in this implementation, both RX and TX GPIOs use the same GPIO bank via the `SWU_GPIO_PORT_BASE` definition.

1.2 Software UART Port Configuration

The baud rate, number of data-bits, parity, and stop-bits are also configured by the `SW_UARTConfigSetExpClk` function. It has been tested with the following configurations. ⁽¹⁾

⁽¹⁾ For running clock frequency limitations, see [Section 2](#).

Baud Rate:	9600, 19200, 38400, 57600, 115200
Data Bits:	8
Parity:	NONE
Stop Bits:	1

There are two functions used to configure and initialize the software UART:

- `SW_UARTConfigSetExpClk`
Sets up baud-rate, number of data-bits, and number of stop-bits.
- `SW_UARTEnable`
Enables the timers and interrupts used by software UART.

Each of the above functions is detailed in [Section 5](#).

2 Software UART Performance Limitations

The software UART has been tested through a range of system clock frequencies for both data transmission and reception. Both the receive and transmit functions are independently interrupt-driven. The receive functionality has a higher priority than transmit. Therefore, there will be some cases, typically seen at lower system frequencies, where transmission can be interrupted by a received event resulting in the transmission failing.

[Table 1](#) shows the tested system frequencies and attainable baud rates for character transmission.

Table 1. Transmit Performance Versus System Clock Frequency

System Clock Frequency (MHz)	Baud Rate				
	9600	19200	38400	57600	115200
50	√	√	√	√	√
40	√	√	√	√	√
33	√	√	√	√	√
25	√	√	√	√	√
20	√	√	√	√	√
12.5	√	√	√	√	√
8	√	√	√	√	√

[Table 2](#) shows the tested system frequencies and attainable baud rates for character reception.

Table 2. Receive Performance Versus System Clock Frequency

System Clock Frequency (MHz)	Baud Rate				
	9600	19200	38400	57600	115200
50	√	√	√	√	√
40	√	√	√	√	√
33	√	√	√	√	√
25	√	√	√	√	√
20	√	√	√	√	√
12.5	√	√	√	√	-
8	√	√	√	-	-

3 Software UART Receiver

The RX GPIO is configured as an input that interrupts on a falling edge. The interrupt is used to detect a valid start condition.

There are three functions available to handle character reception:

- `SW_UARTCharsAvail`
Returns the number of characters in the receive buffer.
- `SW_UARTCharGet`
Returns a character if there is one available in the receive buffer. If there is no character available, it blocks until there is.
- `SW_UARTCharGetNonBlocking`
Returns a character if there is one available in the receive buffer. If there is no character available, it returns an error code.

Each of the above functions is described in detail in [Section 5](#).

3.1 Receive Buffer Configuration

A circular buffer is implemented for received characters. The default size of this buffer is 16 characters. The size is configured by a definition in the `sw_uart.c` file in the section labeled "Receive buffer/Variables." The `#define` is labeled as below. This value must be 1 or greater to ensure correct operation.

```
#define RX_BUFFER_SIZE
    16
```

4 Software UART Transmitter

The TX GPIO is configured as an output. There are three functions available to handle character transmission:

- `SW_UARTSpaceAvail`
Checks whether there is space available in the transmit buffer.
- `SW_UARTCharPut`
Puts a character in the transmit buffer if there is space available. If there is no space available, it blocks until there is.
- `SW_UARTCharPutNonBlocking`
Puts a character in the transmit buffer if there is space available. If there is no space available, it returns an error code.

Each of the above functions is described in detail in [Section 5](#).

4.1 Transmit Buffer Configuration

A circular buffer is implemented for characters to be transmitted. The default size of this buffer is 16 characters. The size is configured by a definition in the `sw_uart.c` file in the section labeled "Transmit buffer/Variables." The `#define` is labeled as below. This value must be 1 or greater to ensure correct operation.

```
#define TX_BUFFER_SIZE 16
```

5 API Functional Description

5.1 Existing Compatibility

To maintain compatibility with the existing StellarisWare® UART API functionality, all of the functions used in the software UART have the `ulBase` parameter. In the software UART implementation, this parameter is currently unused.

5.2 Functions

```
long SW_UARTCharGet (unsigned long ulBase);
long SW_UARTCharGetNonBlocking (unsigned long ulBase);
void SW_UARTCharPut (unsigned long ulBase, unsigned char ucData);
tBoolean SW_UARTCharPutNonBlocking (unsigned long ulBase, unsigned char ucData);
tBoolean SW_UARTCharsAvail (unsigned long ulBase);
void SW_UARTConfigSetExpClk (unsigned long ulBase, unsigned long ulUARTClk, unsigned long
ulBaud, unsigned long ulConfig, unsigned long ulPortBase, unsigned long ulTxPin, unsigned
long ulRxPin);
void SW_UARTDisable (unsigned long ulBase);
void SW_UARTEnable (unsigned long ulBase);
tBoolean SW_UARTSpaceAvail (unsigned long ulBase);
```

5.3 API Function Documentation

Table 3. API Functions

Title	Page
SW_UARTCharGet — Gets a character from the software UART receiver.	4
SW_UARTCharGetNonBlocking — Receives a character from the software UART.	4
SW_UARTCharPut — Sends a character via the software UART, blocking if necessary.	5
SW_UARTCharPutNonBlocking — Sends a character via the software UART if space exists in the transmit buffer.	5
SW_UARTCharsAvail — Determines if there are any characters in the receive buffer.	5
SW_UARTConfigSetExpClk — Sets the configuration of a UART.	6
SW_UARTDisable — Disables transmission and reception.	6
SW_UARTEnable — Enables transmission and reception.	6
SW_UARTSpaceAvail — Determines if there is any space in the transmit buffer.	7

SW_UARTCharGet *Gets a character from the software UART receiver.*

Prototype	long SW_UARTCharGet(unsigned long ulBase)
Parameters	ulBase is not used and is for compatibility with HW UART StellarisWare API calls.
Description	Gets a character from the receive buffer for the software UART receiver. If there are no characters available, this function blocks until a character is received before returning.
Returns	Returns the character read from the software UART, cast as a long.

SW_UARTCharGetNonBlocking *Receives a character from the software UART.*

Prototype	long SW_UARTCharGetNonBlocking(unsigned long ulBase)
Parameters	ulBase is not used and is for compatibility with HW UART StellarisWare API calls.
Description	Gets a character from the receive buffer for the software UART.
Returns	Returns the character read from the software UART, cast as a long. -1 is returned if there are no characters present in the receive buffer.

SW_UARTCharPut *Sends a character via the software UART, blocking if necessary.*

Prototype	<pre>void SW_UARTCharPut(unsigned long ulBase, unsigned char ucData)</pre>
Parameters	<ulbase and="" api="" calls.<br="" compatibility="" for="" hw="" is="" not="" stellarisware="" uart="" used="" with=""></ulbase> ucData is the character to be transmitted.
Description	Sends the ucData character to the transmit buffer for the software UART. If there is no space available in the transmit buffer, this function blocks until there is space available before returning.
Returns	None.

SW_UARTCharPutNonBlocking *Sends a character via the software UART if space exists in the transmit buffer.*

Prototype	<pre>tBoolean SW_UARTCharPutNonBlocking(unsigned long ulBase, unsigned char ucData)</pre>
Parameters	<ulbase and="" api="" calls.<br="" compatibility="" for="" hw="" is="" not="" stellarisware="" uart="" used="" with=""></ulbase> ucData is the character to be transmitted.
Description	Writes the ucData character to the transmit buffer for the software UART. This function does not block, so if there is no space available, then false is returned and the application must retry the function later.
Returns	Returns true if the character is successfully placed in the transmit buffer, or false if there is no space available in the transmit buffer.

SW_UARTCharsAvail *Determines if there are any characters in the receive buffer.*

Prototype	<pre>tBoolean SW_UARTCharsAvail(unsigned long ulBase)</pre>
Parameters	ulBase is not used and is for compatibility with HW UART StellarisWare API calls.
Description	This function returns a flag indicating whether there is data available in the receive buffer.
Returns	Returns true if there is data in the receive buffer, and false if there is no data in the receive buffer.

SW_UARTConfigSetExpClk *Sets the configuration of a UART.*

Prototype	<pre>void SW_UARTConfigSetExpClk(unsigned long ulBase, unsigned long ulUARTClk, unsigned long ulBaud, unsigned long ulConfig, unsigned long ulPortBase)</pre>
Parameters	<p>ulBase is not used and is for compatibility with HW UART StellarisWare API calls. ulUARTClk is the rate of the clock supplied to the UART module. ulBaud is the desired baud rate. ulConfig is the data format for the port (number of data bits, number of stop bits, and parity).</p>
Description	<p>This function configures the UART for operation in the specified data format. The baud rate is provided in the ulBaud parameter and the data format in the ulConfig parameter. The ulConfig parameter is the logical OR of three values: the number of data bits, the number of stop bits, and the parity. UART_CONFIG_WLEN_8, UART_CONFIG_WLEN_7, UART_CONFIG_WLEN_6, and UART_CONFIG_WLEN_5 select from eight to five data bits per byte. UART_CONFIG_STOP_ONE and UART_CONFIG_STOP_TWO select one or two stop bits, respectively. UART_CONFIG_PAR_NONE, UART_CONFIG_PAR_EVEN, UART_CONFIG_PAR_ODD, UART_CONFIG_PAR_ONE, and UART_CONFIG_PAR_ZERO select the parity mode (no parity bit, even parity bit, odd parity bit, parity bit always one, and parity bit always zero, respectively). The peripheral clock is the same as the processor clock. This is the value returned by SysCtlClockGet(), or it can be explicitly hard-coded if it is constant and known (to save the code/execution overhead of a call to SysCtlClockGet()).</p>
Returns	None.

SW_UARTDisable *Disables transmission and reception.*

Prototype	<pre>void SW_UARTDisable(unsigned long ulBase)</pre>
Parameters	ulBase is not used and is for compatibility with HW UART StellarisWare API calls.
Description	Clears the UARTEN, TXE, and RXE bits, then waits for the end of transmission of the current character, and flushes the transmit buffer.
Returns	None.

SW_UARTEnable *Enables transmission and reception.*

Prototype	<pre>void SW_UARTEnable(unsigned long ulBase)</pre>
Parameters	ulBase is not used and is for compatibility with HW UART StellarisWare API calls.
Description	Sets the UARTEN, TXE, and RXE bits, and enables the transmit and receive buffers.
Returns:	None.

SW_UARTSpaceAvail *Determines if there is any space in the transmit buffer.*

Prototype	tBoolean SW_UARTSpaceAvail(unsigned long ulBase)
Parameters	ulBase is not used and is for compatibility with HW UART StellarisWare API calls.
Description	This function returns a flag indicating whether there is space available in the transmit buffer.
Returns	Returns true if there is space available in the transmit buffer, or false if there is no space available in the transmit buffer.

6 Conclusion

The software-based UART can be used on any Stellaris product to extend the number of available UARTs available to an application. When the number of hardware-based UARTs is not sufficient, the software-based UART gives the application access to additional UARTs. Special care should be taken when using the software-based UART to ensure that enough processing time is given to the software UART in order to allow it to function at all baud rates. As the required baud rates get higher, the processing time required to handle the baud rate will increase.

7 Refernces

- *Tiva™ C Series Data Sheet* (individual device-specific documents available through the [product folders](#))
- *Tiva™ C Series Errata* (individual device-specific documents available through the [product folders](#))
- *Tiva™ C Series ROM User's Guide* (individual device-specific documents available through the [product folders](#))
- [TivaWare™ Peripheral Driver Library for C Series](#)

IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, enhancements, improvements and other changes to its semiconductor products and services per JESD46, latest issue, and to discontinue any product or service per JESD48, latest issue. Buyers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All semiconductor products (also referred to herein as "components") are sold subject to TI's terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its components to the specifications applicable at the time of sale, in accordance with the warranty in TI's terms and conditions of sale of semiconductor products. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by applicable law, testing of all parameters of each component is not necessarily performed.

TI assumes no liability for applications assistance or the design of Buyers' products. Buyers are responsible for their products and applications using TI components. To minimize the risks associated with Buyers' products and applications, Buyers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI components or services are used. Information published by TI regarding third-party products or services does not constitute a license to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of significant portions of TI information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

Resale of TI components or services with statements different from or beyond the parameters stated by TI for that component or service voids all express and any implied warranties for the associated TI component or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

Buyer acknowledges and agrees that it is solely responsible for compliance with all legal, regulatory and safety-related requirements concerning its products, and any use of TI components in its applications, notwithstanding any applications-related information or support that may be provided by TI. Buyer represents and agrees that it has all the necessary expertise to create and implement safeguards which anticipate dangerous consequences of failures, monitor failures and their consequences, lessen the likelihood of failures that might cause harm and take appropriate remedial actions. Buyer will fully indemnify TI and its representatives against any damages arising out of the use of any TI components in safety-critical applications.

In some cases, TI components may be promoted specifically to facilitate safety-related applications. With such components, TI's goal is to help enable customers to design and create their own end-product solutions that meet applicable functional safety standards and requirements. Nonetheless, such components are subject to these terms.

No TI components are authorized for use in FDA Class III (or similar life-critical medical equipment) unless authorized officers of the parties have executed a special agreement specifically governing such use.

Only those TI components which TI has specifically designated as military grade or "enhanced plastic" are designed and intended for use in military/aerospace applications or environments. Buyer acknowledges and agrees that any military or aerospace use of TI components which have **not** been so designated is solely at the Buyer's risk, and that Buyer is solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI has specifically designated certain components as meeting ISO/TS16949 requirements, mainly for automotive use. In any case of use of non-designated products, TI will not be responsible for any failure to meet ISO/TS16949.

Products

Audio	www.ti.com/audio
Amplifiers	amplifier.ti.com
Data Converters	dataconverter.ti.com
DLP® Products	www.dlp.com
DSP	dsp.ti.com
Clocks and Timers	www.ti.com/clocks
Interface	interface.ti.com
Logic	logic.ti.com
Power Mgmt	power.ti.com
Microcontrollers	microcontroller.ti.com
RFID	www.ti-rfid.com
OMAP Applications Processors	www.ti.com/omap
Wireless Connectivity	www.ti.com/wirelessconnectivity

Applications

Automotive and Transportation	www.ti.com/automotive
Communications and Telecom	www.ti.com/communications
Computers and Peripherals	www.ti.com/computers
Consumer Electronics	www.ti.com/consumer-apps
Energy and Lighting	www.ti.com/energy
Industrial	www.ti.com/industrial
Medical	www.ti.com/medical
Security	www.ti.com/security
Space, Avionics and Defense	www.ti.com/space-avionics-defense
Video and Imaging	www.ti.com/video

TI E2E Community

e2e.ti.com

IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, enhancements, improvements and other changes to its semiconductor products and services per JESD46, latest issue, and to discontinue any product or service per JESD48, latest issue. Buyers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All semiconductor products (also referred to herein as "components") are sold subject to TI's terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its components to the specifications applicable at the time of sale, in accordance with the warranty in TI's terms and conditions of sale of semiconductor products. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by applicable law, testing of all parameters of each component is not necessarily performed.

TI assumes no liability for applications assistance or the design of Buyers' products. Buyers are responsible for their products and applications using TI components. To minimize the risks associated with Buyers' products and applications, Buyers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI components or services are used. Information published by TI regarding third-party products or services does not constitute a license to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of significant portions of TI information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

Resale of TI components or services with statements different from or beyond the parameters stated by TI for that component or service voids all express and any implied warranties for the associated TI component or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

Buyer acknowledges and agrees that it is solely responsible for compliance with all legal, regulatory and safety-related requirements concerning its products, and any use of TI components in its applications, notwithstanding any applications-related information or support that may be provided by TI. Buyer represents and agrees that it has all the necessary expertise to create and implement safeguards which anticipate dangerous consequences of failures, monitor failures and their consequences, lessen the likelihood of failures that might cause harm and take appropriate remedial actions. Buyer will fully indemnify TI and its representatives against any damages arising out of the use of any TI components in safety-critical applications.

In some cases, TI components may be promoted specifically to facilitate safety-related applications. With such components, TI's goal is to help enable customers to design and create their own end-product solutions that meet applicable functional safety standards and requirements. Nonetheless, such components are subject to these terms.

No TI components are authorized for use in FDA Class III (or similar life-critical medical equipment) unless authorized officers of the parties have executed a special agreement specifically governing such use.

Only those TI components which TI has specifically designated as military grade or "enhanced plastic" are designed and intended for use in military/aerospace applications or environments. Buyer acknowledges and agrees that any military or aerospace use of TI components which have **not** been so designated is solely at the Buyer's risk, and that Buyer is solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI has specifically designated certain components as meeting ISO/TS16949 requirements, mainly for automotive use. In any case of use of non-designated products, TI will not be responsible for any failure to meet ISO/TS16949.

Products

Audio	www.ti.com/audio
Amplifiers	amplifier.ti.com
Data Converters	dataconverter.ti.com
DLP® Products	www.dlp.com
DSP	dsp.ti.com
Clocks and Timers	www.ti.com/clocks
Interface	interface.ti.com
Logic	logic.ti.com
Power Mgmt	power.ti.com
Microcontrollers	microcontroller.ti.com
RFID	www.ti-rfid.com
OMAP Applications Processors	www.ti.com/omap
Wireless Connectivity	www.ti.com/wirelessconnectivity

Applications

Automotive and Transportation	www.ti.com/automotive
Communications and Telecom	www.ti.com/communications
Computers and Peripherals	www.ti.com/computers
Consumer Electronics	www.ti.com/consumer-apps
Energy and Lighting	www.ti.com/energy
Industrial	www.ti.com/industrial
Medical	www.ti.com/medical
Security	www.ti.com/security
Space, Avionics and Defense	www.ti.com/space-avionics-defense
Video and Imaging	www.ti.com/video

TI E2E Community

e2e.ti.com