
Section 21. UART

HIGHLIGHTS

This section of the manual contains the following major topics:

21.1	Introduction	21-2
21.2	Control Registers.....	21-3
21.3	UART Baud Rate Generator (BRG).....	21-9
21.4	UART Configuration	21-13
21.5	UART Transmitter.....	21-14
21.6	UART Receiver	21-18
21.7	Using the UART for 9-Bit Communication.....	21-21
21.8	Receiving Break Characters.....	21-23
21.9	Initialization	21-23
21.10	Other Features of the UART	21-25
21.11	UART Operation During CPU Sleep and Idle Modes.....	21-27
21.12	Operation of UxCTS and UxRTS Control Pins.....	21-29
21.13	Infrared Support	21-31
21.14	Registers Associated with the UART Module.....	21-34
21.15	Electrical Specifications.....	21-35
21.16	Design Tips	21-36
21.17	Related Application Notes.....	21-37
21.18	Revision History	21-38

21.1 INTRODUCTION

The Universal Asynchronous Receiver Transmitter (UART) module is one of the serial I/O modules available in the PIC24F device family. The UART is a full-duplex, asynchronous communication channel that communicates with peripheral devices and personal computers, using protocols such as RS-232, RS-485, LIN 1.2 and IrDA®. The module also supports the hardware flow control option with UxCTS and UxRTS pins and also includes the IrDA encoder and decoder.

The primary features of the UART module are:

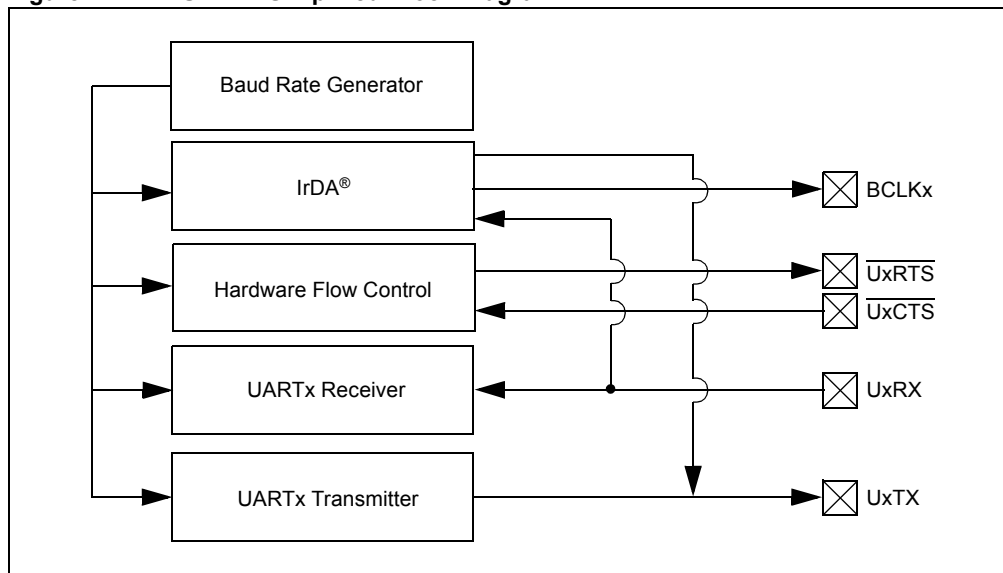
- Full-Duplex, 8 or 9-Bit Data Transmission through the UxTX and UxRX pins
- Even, Odd or No Parity options (for 8-bit data)
- One or Two Stop bits
- Hardware Auto-Baud Feature
- Hardware Flow Control Option with \overline{UxCTS} and \overline{UxRTS} pins
- Fully Integrated Baud Rate Generator with 16-Bit Prescaler
- Baud Rates Ranging from 1 Mbps to 15 bps at 16 MIPS
- 4-Deep First-In-First-Out (FIFO) Transmit Data Buffer
- 4-Deep FIFO Receive Data Buffer
- Parity, Framing and Buffer Overrun Error Detection
- Support for 9-Bit Data mode with Address Detect (9th bit = 1)
- Transmit and Receive Interrupts
- Loopback mode for Diagnostic Support
- IrDA Encoder and Decoder Logic
- LIN 1.2 Protocol Support
- 16x Baud Clock Output for External IrDA Encoder/Decoder Support

Note: Each PIC24F device variant may have one or more UART modules. An 'x' used in the names of pins, control/status bits and registers denotes the particular module. Refer to the specific device data sheets for more details.

A simplified block diagram of the UARTx is shown in Figure 21-1. The UARTx module consists of the following key important hardware elements:

- Baud Rate Generator
- Asynchronous Transmitter
- Asynchronous Receiver

Figure 21-1: UARTx Simplified Block Diagram



21.2 CONTROL REGISTERS

Register 21-1: UxMODE: UARTx Mode Register

R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0
UARTEN	UFRZ	USIDL	IREN ⁽¹⁾	RTSMD	ALTIO ⁽²⁾	UEN1	UEN0
bit 15						bit 8	

R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0
WAKE	LPBACK	ABAUD	RXINV	BRGH	PDSEL1	PDSEL0	STSEL
bit 7						bit 0	

Legend:

R = Readable bit

W = Writable bit

U = Unimplemented bit, read as '0'

-n = Value at POR

'1' = Bit is set

'0' = Bit is cleared

x = Bit is unknown

- bit 15 **UARTEN:** UARTx Enable bit
 1 = UARTx is enabled; UARTx pins are controlled by UARTx as defined by UEN<1:0> and UTXEN control bits
 0 = UARTx is disabled; UARTx pins are controlled by corresponding PORT, LAT and TRIS bits
- bit 14 **UFRZ:** Freeze in Debug Mode bit
 1 = When emulator is in Debug mode, module freezes operation
 0 = When emulator is in Debug mode, module continues operation
- bit 13 **USIDL:** Stop in Idle Mode bit
 1 = Discontinue operation when device enters Idle mode
 0 = Continue operation in Idle mode
- bit 12 **IREN:** IrDA Encoder and Decoder Enable bit⁽¹⁾
 1 = IrDA encoder and decoder enabled
 0 = IrDA encoder and decoder disabled
- bit 11 **RTSMD:** Mode Selection for $\overline{\text{UxRTS}}$ Pin bit
 1 = $\overline{\text{UxRTS}}$ in Simplex mode
 0 = $\overline{\text{UxRTS}}$ in Flow Control mode
- bit 10 **ALTIO:** UARTx Alternate I/O Selection bit⁽²⁾
 1 = UARTx communicates using UxATX and UxARX I/O pins
 0 = UARTx communicates using UxTX and UxRX I/O pins
- bit 9-8 **UEN<1:0>:** UARTx Enable bits
 11 = UxTX, UxRX and $\overline{\text{BCLKx}}$ pins are enabled and used; $\overline{\text{UxCTS}}$ pin is controlled by port latches
 10 = UxTX, UxRX, $\overline{\text{UxCTS}}$ and $\overline{\text{UxRTS}}$ pins are enabled and used
 01 = UxTX, UxRX and $\overline{\text{UxRTS}}$ pins are enabled and used; $\overline{\text{UxCTS}}$ pin is controlled by port latches
 00 = UxTX and UxRX pins are enabled and used; $\overline{\text{UxCTS}}$, $\overline{\text{UxRTS}}$ and $\overline{\text{BCLKx}}$ pins are controlled by port latches
- bit 7 **WAKE:** Enable Wake-up on Start bit Detect During Sleep Mode bit
 1 = Wake-up enabled
 0 = Wake-up disabled
- bit 6 **LPBACK:** UARTx Loopback Mode Select bit
 1 = Enable Loopback mode
 0 = Loopback mode is disabled

Note 1: This feature is available only for the 16x BRG mode (BRGH = '0').

2: The alternate UART I/O pins are not available on all devices. See specific device data sheets for details.

PIC24F Family Reference Manual

Register 21-1: UxMODE: UARTx Mode Register (Continued)

- bit 5 **ABAUD**: Auto-Baud Enable bit
1 = Enable baud rate measurement on the next character. Requires reception of a Sync field (55h); cleared in hardware upon completion.
0 = Baud rate measurement disabled or completed
- bit 4 **RXINV**: Receive Polarity Inversion bit
1 = UxRX Idle state is '0'
0 = UxRX Idle state is '1'
- bit 3 **BRGH**: High Baud Rate Select bit
1 = High speed
0 = Low speed
- bit 2-1 **PDSEL<1:0>**: Parity and Data Selection bits
11 = 9-bit data, no parity
10 = 8-bit data, odd parity
01 = 8-bit data, even parity
00 = 8-bit data, no parity
- bit 0 **STSEL**: Stop Selection bit
1 = 2 Stop bits
0 = 1 Stop bit

Note 1: This feature is available only for the 16x BRG mode (BRGH = '0').

2: The alternate UART I/O pins are not available on all devices. See specific device data sheets for details.

Register 21-2: UxSTA: UARTx Status and Control Register

R/W-0	R/W-0	R/W-0	U-0	R/W-0	R/W-0	R-0	R-1
UTXISEL1	UTXINV	UTXISEL0	—	UTXBRK	UTXEN	UTXBF	TRMT
bit 15						bit 8	

R/W-0	R/W-0	R/W-0	R-1	R-0	R-0	R/C-0	R-0
URXISEL1	URXISEL0	ADDEN	RIDLE	PERR	FERR	OERR	URXDA
bit 7						bit 0	

Legend:	C = Clearable bit
R = Readable bit	W = Writable bit
-n = Value at POR	'1' = Bit is set
	U = Unimplemented bit, read as '0'
	'0' = Bit is cleared
	x = Bit is unknown

- bit 15,13 **UTXISEL<1:0>** Transmission Interrupt Mode Selection bits
 11 = Reserved
 10 = Interrupt generated when a character is transferred to the Transmit Shift Register and the transmit buffer becomes empty
 01 = Interrupt generated when the last transmission is over (last character shifted out of the Transmit Shift Register) and all the transmit operations are completed
 00 = Interrupt generated when any character is transferred to the Transmit Shift Register (this implies at least one location is empty in the transmit buffer)
- bit 14 **UTXINV:** Transmit Polarity Inversion bit
IREN = 0:
 1 = UxTX Idle state is '0'
 0 = UxTX Idle state is '1'
IREN = 1:
 1 = IrDA encoded UxTX Idle state is '1'
 0 = IrDA encoded UxTX Idle state is '0'
- bit 12 **Unimplemented:** Read as '0'
- bit 11 **UTXBRK:** Transmit Break bit
 1 = UxTX pin is driven low regardless of transmitter state (Sync Break transmission – Start bit followed by twelve '0's and followed by a Stop bit)
 0 = Sync Break transmission is disabled or completed
- bit 10 **UTXEN:** Transmit Enable bit
 1 = UARTx transmitter enabled, UxTX pin controlled by UARTx (if UARTEN = 1)
 0 = UARTx transmitter disabled, any pending transmission is aborted and buffer is reset. UxTX pin controlled by PORT.
- bit 9 **UTXBF:** Transmit Buffer Full Status bit (read-only)
 1 = Transmit buffer is full
 0 = Transmit buffer is not full, at least one more data word can be written
- bit 8 **TRMT:** Transmit Shift Register is Empty bit (read-only)
 1 = Transmit Shift Register is empty and transmit buffer is empty (the last transmission has completed)
 0 = Transmit Shift Register is not empty, a transmission is in progress or queued in the transmit buffer
- bit 7-6 **URXISEL<1:0>:** Receive Interrupt Mode Selection bits
 11 = Interrupt flag bit is set when receive buffer is full (i.e., has 4 data characters)
 10 = Interrupt flag bit is set when receive buffer is 3/4 full (i.e., has 3 data characters)
 0x = Interrupt flag bit is set when a character is received
- bit 5 **ADDEN:** Address Character Detect bit (bit 8 of received data = 1)
 1 = Address Detect mode enabled. If 9-bit mode is not selected, this control bit has no effect.
 0 = Address Detect mode disabled

PIC24F Family Reference Manual

Register 21-2: UxSTA: UARTx Status and Control Register (Continued)

- bit 4 **RIDLE:** Receiver Idle bit (read-only)
1 = Receiver is Idle
0 = Data is being received
- bit 3 **PERR:** Parity Error Status bit (read-only)
1 = Parity error has been detected for the current character
0 = Parity error has not been detected
- bit 2 **FERR:** Framing Error Status bit (read-only)
1 = Framing error has been detected for the current character
0 = Framing error has not been detected
- bit 1 **OERR:** Receive Buffer Overrun Error Status bit (clear/read-only)
1 = Receive buffer has overflowed
0 = Receive buffer has not overflowed (clearing a previously set OERR bit will reset the receiver buffer and RSR to empty state)
- bit 0 **URXDA:** Receive Buffer Data Available bit (read-only)
1 = Receive buffer has data, at least one more character can be read
0 = Receive buffer is empty

Register 21-3: UxRXREG: UARTx Receive Register

U-0	U-0	U-0	U-0	U-0	U-0	U-0	R-0
—	—	—	—	—	—	—	URX8
bit 15							bit 8
R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0
URX<7:0>							
bit 7							bit 0

Legend:

R = Readable bit W = Writable bit U = Unimplemented bit, read as '0'
 -n = Value at POR '1' = Bit is set '0' = Bit is cleared x = Bit is unknown

bit 15-9 **Unimplemented:** Read as '0'
 bit 8 **URX8:** Data bit 8 of the Received Character (in 9-bit mode)
 bit 7-0 **URX<7:0>:** Data bits 7-0 of the Received Character

Register 21-4: UxTXREG: UARTx Transmit Register (Write-Only)

U-0	U-0	U-0	U-0	U-0	U-0	U-0	W-x
—	—	—	—	—	—	—	UTX8
bit 15							bit 8
W-x	W-x	W-x	W-x	W-x	W-x	W-x	W-x
UTX<7:0>							
bit 7							bit 0

Legend:

R = Readable bit W = Writable bit U = Unimplemented bit, read as '0'
 -n = Value at POR '1' = Bit is set '0' = Bit is cleared x = Bit is unknown

bit 15-9 **Unimplemented:** Read as '0'
 bit 8 **UTX8:** Data bit 8 of the Transmitted Character (in 9-bit mode)
 bit 7-0 **URX<7:0>:** Data bits 7-0 of the Transmitted Character

PIC24F Family Reference Manual

Register 21-5: UxBRG: UARTx Baud Rate Generator Register

R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	W-x
BRG<15:8>							
bit 15							bit 8

R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0
BRG<7:0>							
bit 7							bit 0

Legend:

R = Readable bit	W = Writable bit	U = Unimplemented bit, read as '0'
-n = Value at POR	'1' = Bit is set	'0' = Bit is cleared x = Bit is unknown

bit 15-0 **BRG<15:0>**: Baud Rate Generator Divisor bits

21.3 UART BAUD RATE GENERATOR (BRG)

The UART module includes a dedicated 16-bit Baud Rate Generator. The UxBRG register controls the period of a free-running, 16-bit timer. Equation 21-1 shows the formula for computation of the baud rate with BRGH = 0.

Equation 21-1: UART Baud Rate with BRGH = 0

$$\text{Baud Rate} = \frac{\text{FCY}}{16 \cdot (\text{UxBRG} + 1)}$$

$$\text{UxBRG} = \frac{\text{FCY}}{16 \cdot \text{Baud Rate}} - 1$$

Note: FCY denotes the instruction cycle clock frequency (FOSC/2).

Example 21-1 shows the calculation of the baud rate error for the following conditions:

- FCY = 4 MHz
- Desired Baud Rate = 9600

Example 21-1: Baud Rate Error Calculation (BRGH = 0)

Desired Baud Rate	=	FCY/(16 (UxBRG + 1))
Solving for UxBRG value:		
UxBRG	=	((FCY/Desired Baud Rate)/16) - 1
UxBRG	=	((4000000/9600)/16) - 1
UxBRG	=	25
Calculated Baud Rate	=	4000000/(16 (25 + 1))
	=	9615
Error	=	$\frac{(\text{Calculated Baud Rate} - \text{Desired Baud Rate})}{\text{Desired Baud Rate}}$
	=	(9615 - 9600)/9600
	=	0.16%

The maximum baud rate (BRGH = 0) possible is FCY/16 (for UxBRG = 0), and the minimum baud rate possible is FCY/16 * 65536.

Equation 21-2 shows the formula for computation of the baud rate with BRGH = 1.

Equation 21-2: UART Baud Rate with BRGH = 1

$$\text{Baud Rate} = \frac{\text{FCY}}{4 \cdot (\text{UxBRG} + 1)}$$

$$\text{UxBRG} = \frac{\text{FCY}}{4 \cdot \text{Baud Rate}} - 1$$

Note: FCY denotes the instruction cycle clock frequency.

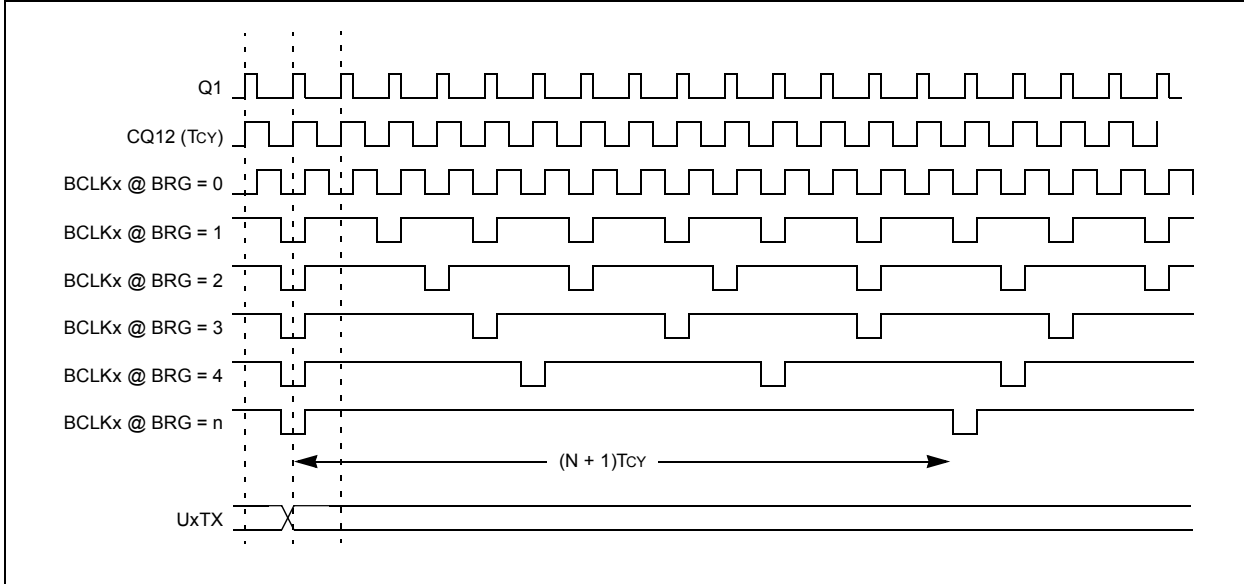
The maximum baud rate (BRGH = 1) possible is FCY/4 (for UxBRG = 0), and the minimum baud rate possible is FCY/(4 * 65536).

Writing a new value to the UxBRG register causes the BRG timer to be reset (cleared). This ensures the BRG does not wait for a timer overflow before generating the new baud rate.

21.3.1 BCLKx Output

The BCLKx pin will output the 16x baud clock if the UARTx and BCLKx output are enabled ($UEN<1:0> = 11$). This feature is used for external IrDA encoder/decoder support (refer to Figure 21-2). BCLKx output stays low during Sleep mode. BCLKx is forced as an output as long as UARTx is kept in this mode ($UEN<1:0> = 11$), irrespective of PORTx and TRISx latch bits.

Figure 21-2: BCLKx Output vs. UxBRG Programming



21.3.2 Baud Rate Tables

UART baud rates are provided in Table 21-1 and Table 21-2 for common device instruction cycle frequencies (FCY). The minimum and maximum baud rates for each frequency are also shown.

Table 21-1: UART Baud Rates (BRGH = 0)

BAUD RATE	FCY = 16 MHz			FCY = 12 MHz		
	Actual Baud Rate	% Error	BRG Value (Decimal)	Actual Baud Rate	% Error	BRG Value (Decimal)
110	110.0	0.00	9090	110.0	0.00	6817
300	300.0	0.01	3332	300.0	0.00	2499
1200	1200.5	0.04	832	1200.0	0.00	624
2400	2398.1	-0.08	416	2403.8	0.16	311
9600	9615.4	0.16	103	9615.3	0.16	77
19.2K	19230.8	0.16	51	19230.7	0.15	38
38.4K	38461.5	0.16	25	37500.0	-2.34	19
56K	55555.6	-0.79	17	57692.3	-3.02	12
115K	111111.1	-3.38	8			
250K	250000.0	0.00	3			
300K						
500K	500000.0	0.00	1			
Min.	15.0	0.00	65535	11.0	0.00	65535
Max.	1000000.0	0.00	0	480000.0	0.00	0

BAUD RATE	FCY = 8 MHz			FCY = 4 MHz			FCY = 1 MHz		
	Actual Baud Rate	% Error	BRG Value (Decimal)	Actual Baud Rate	% Error	BRG Value (Decimal)	Actual Baud Rate	% Error	BRG Value (Decimal)
110	917.4	0.00	4544	110.0	0.00	2272	110.0	0.00	567
300	299.9	0.00	1666	300.1	0.00	832	300.4	0.10	207
1200	1199.0	0.00	416	1201.9	0.16	207	1201.9	0.16	51
2400	2403.8	0.16	207	2403.8	0.15	103	2403.8	0.15	25
9600	9615.4	0.16	51	9615.4	0.20	25			
19.2K	19230.8	0.16	25	19230.8	0.20	12			
38.4K	38461.5	0.16	12						
56K	55555.6	-0.79	8						
115K									
250K									
300K									
500K									
Min.	8.0	0.00	65535	4.0	0.00	65535	0.95	0.00	65535
Max.	500000.0	0.00	0	250000.0	0.00	0	62500.0	0.00	0

PIC24F Family Reference Manual

Table 21-2: UART Baud Rates (BRGH = 1)

BAUD RATE	Fcy = 16 MHz			Fcy = 12 MHz		
	Actual Baud Rate	% Error	BRG Value (Decimal)	Actual Baud Rate	% Error	BRG Value (Decimal)
110	110.0	0.00	36363	110.0	0.00	27272
300	300.0	0.01	13332	300.0	0.00	9999
1200	1200.1	0.01	3332	1200.0	0.00	2499
2400	2399.5	-0.01	1666	2403.8	0.00	1249
9600	9592.3	-0.07	416	9584.6	-0.15	312
19.2K	19230.7	0.16	207	19230.7	0.15	155
38.4K	38461.5	0.16	103	38461.5	0.16	77
56K	56338.0	0.60	70	55555.5	-0.79	53
115K	114285.7	-0.62	34	115384.0	0.33	25
250K	250000.0	0.00	15			
300K	307692.3	2.50	12			
500K	500000.0	0.00	7			
Min.	61.0	0.00	65535	46.0	0.00	65535
Max.	4000000.0	0.00	0	3000000.0	0.00	0

BAUD RATE	Fcy = 8 MHz			Fcy = 4MHz			Fcy = 1 MHz		
	Actual Baud Rate	% Error	BRG Value (Decimal)	Actual Baud Rate	% Error	BRG Value (Decimal)	Actual Baud Rate	% Error	BRG Value (Decimal)
110	110.0	0.00	18181	110.0	0.00	9090	110.0	0.00	2272
300	300.0	0.00	6666	300.0	0.00	3332	300.1	0.10	832
1200	1199.7	-0.01	1666	1200.5	0.00	832	1201.9	0.15	207
2400	2400.9	0.04	832	2398.1	-0.07	416	2403.8	0.15	103
9600	9615.4	0.16	207	9615.3	0.16	103	9615.3	0.16	25
19.2K	19230.8	0.16	103	19230.7	0.16	51	19230.7	0.16	12
38.4K	38461.5	0.16	51	38461.5	0.16	25			
56K	55555.6	-0.79	35	55555.5	-0.79	17			
115K	117647.0	2.30	16						
250K									
300K									
500K									
Min.	31.0	0.00	65535	16.0	0.00	65535	3.81	0.00	65535
Max.	200000.0	0.00	0	1000000.0	0.00	0	250000.0	0.00	0

21.4 UART CONFIGURATION

The UART uses standard Non-Return-to-Zero (NRZ) format (one Start bit, eight or nine data bits and one or two Stop bits). Parity is supported by the hardware and may be configured by the user as even, odd or no parity. The most common data format is 8 bits, no parity and one Stop bit (denoted as 8, N, 1), which is the default (POR) setting. The number of data bits and Stop bits and the parity, are specified in the PDSEL<1:0> (UxMODE<2:1>) and STSEL (UxMODE<0>) bits. An on-chip, dedicated, 16-bit Baud Rate Generator can be used to derive standard baud rate frequencies from the oscillator. The UART transmits and receives the LSb first. The UART module's transmitter and receiver are functionally independent but use the same data format and baud rate.

21.4.1 Enabling the UART

The UART module is enabled by setting the UARTEN (UxMODE<15>) bit and UTXEN (UxSTA<10>) bit. Once enabled, the UxTX and UxRX pins are configured as an output and an input, respectively, overriding the TRIS and PORT register bit settings for the corresponding I/O port pins. The UxTX pin is at logic '1' when no transmission is taking place.

Note: The UTXEN bit should not be set until the UARTEN bit has been set; otherwise, UART transmissions will not be enabled.

21.4.2 Disabling the UART

The UART module is disabled by clearing the UARTEN (UxMODE<15>) bit. This is the default state after any Reset. If the UART is disabled, all UART pins operate as port pins under the control of their corresponding PORT and TRIS bits.

Disabling the UART module resets the buffers to empty states. Any data characters in the buffers are lost and the baud rate counter is reset.

All error and status flags associated with the UART module are reset when the module is disabled. The URXDA, OERR, FERR, PERR, UTXEN, UTXBRK and UTXBF bits are cleared, whereas RIDLE and TRMT are set. Other control bits, including ADDEN, URXISEL<1:0>, UTXISEL<1:0>, as well as the UxMODE and UxBRG registers, are not affected.

Clearing the UARTEN bit while the UART is active will abort all pending transmissions and receptions and reset the module as defined above. Re-enabling the UART will restart the UART in the same configuration.

21.4.3 Alternate UART I/O Pins

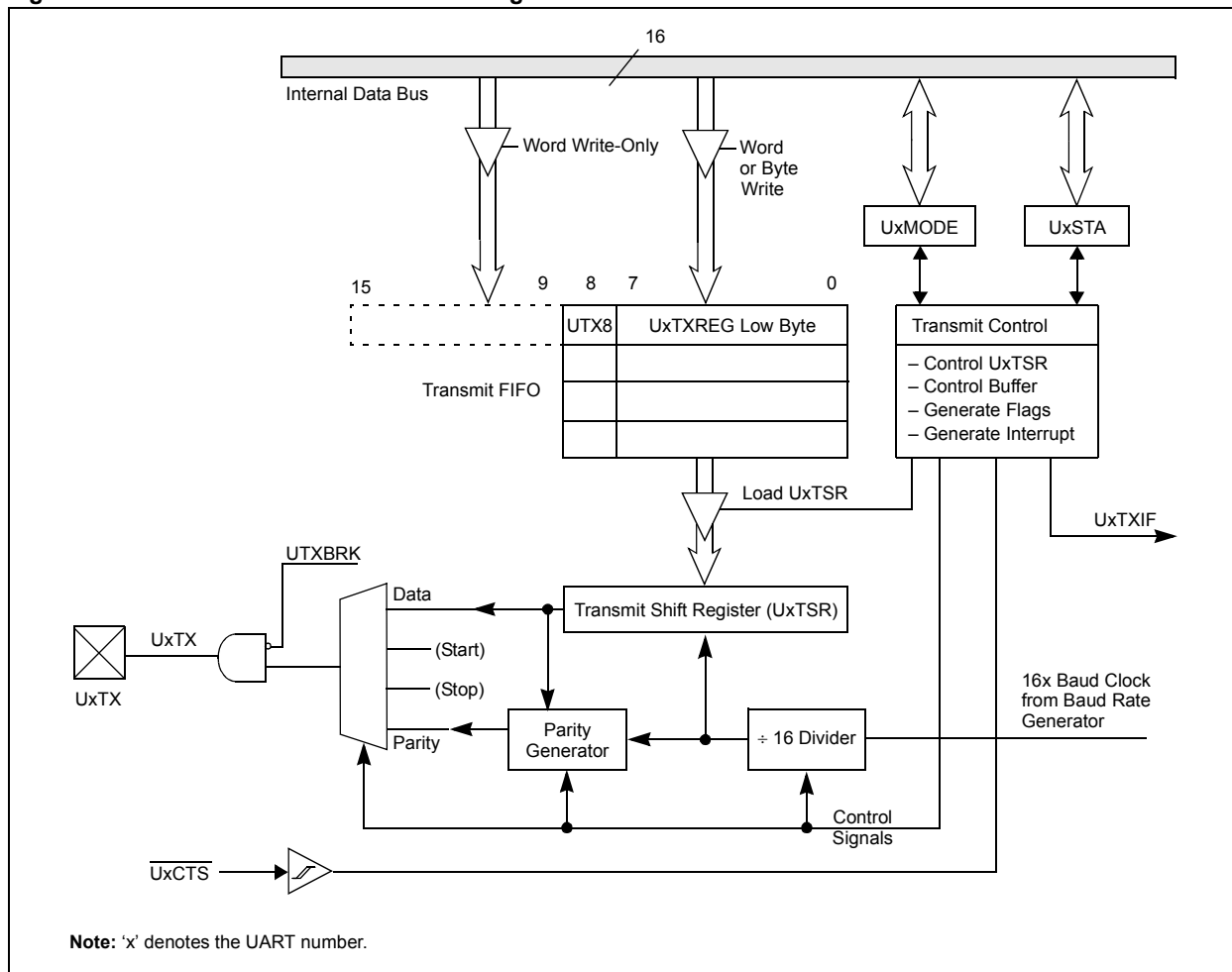
Some PIC24F devices have an alternate set of UART transmit and receive pins that can be used for communications. The alternate UART pins are useful when the primary UART pins are shared by other peripherals. The alternate I/O pins are enabled by setting the ALTIO bit (UxMODE<10>). If ALTIO = 1, the UxATX and UxARX pins (alternate transmit and alternate receive pins, respectively) are used by the UART module instead of the UxTX and UxRX pins. If ALTIO = 0, the UxTX and UxRX pins are used by the UART module.

21.5 UART TRANSMITTER

The UART transmitter block diagram is shown in Figure 21-3. The heart of the transmitter is the Transmit Shift Register (UxTSR). The Shift register obtains its data from the transmit FIFO buffer, UxTXREG. The UxTXREG register is loaded with data in software. The UxTSR register is not loaded until the Stop bit has been transmitted from the previous load. As soon as the Stop bit is transmitted, the UxTSR is loaded with new data from the UxTXREG register (if available).

Note: The UxTSR register is not mapped in data memory, so it is not available to the user.

Figure 21-3: UARTx Transmitter Block Diagram



Transmission is enabled by setting the UTXEN enable bit (UxSTA<10>). The actual transmission will not occur until the UxTXREG register has been loaded with data and the Baud Rate Generator (UxBRG) has produced a shift clock (Figure 21-3). The transmission can also be started by first loading the UxTXREG register and then setting the UTXEN enable bit. Normally, when transmission is first started, the UxTSR register is empty, so a transfer to the UxTXREG register will result in an immediate transfer to UxTSR. Clearing the UTXEN bit during a transmission will cause the transmission to be aborted and will reset the transmitter. As a result, the UxTX pin will revert to a high-impedance state.

Note: There should be a minimum 1 clock cycle delay between setting the UTXEN bit and writing data to UxTXREG. This ensures that the transmit line is held idle for an appropriate amount of time before the transmission begins.

In order to select 9-bit transmission, the PDSEL<1:0> bits (UxMODE<2:1>) should be set to '11' and the ninth bit should be written to the UTX8 bit (UxTXREG<8>). A word write should be performed to UxTXREG so that all nine bits are written at the same time.

Note: There is no parity in the case of 9-bit data transmission.

21.5.1 Transmit Buffer (UxTXREG)

The transmit buffer is 9 bits wide and 4 levels deep. Together with the Transmit Shift Registers (UxTSR), the user effectively has a 5-level deep buffer. It is organized as First-In-First-Out (FIFO). Once the UxTXREG contents are transferred to the UxTSR register, the current buffer location becomes available for new data to be written and the next buffer location is sourced to the UxTSR register. The UTXBF (UxSTA<9>) status bit is set whenever the buffer is full. If a user attempts to write to a full buffer, the new data will not be accepted into the FIFO.

The FIFO is reset during any device Reset, but is not affected when the device enters a Power-Saving mode or wakes up from a Power-Saving mode.

21.5.2 Transmit Interrupt

The Transmit Interrupt Flag (UxTXIF) is located in the corresponding Interrupt Flag Status (IFSx) register. The UTXISEL<1:0> control bits (UxSTA<15,13>) determine when the UART will generate a transmit interrupt.

1. UTXISEL<1:0> = 00, the UxTXIF is set when a character is transferred from the transmit buffer to the Transmit Shift Register (UxTSR). This implies at least one location is empty in the transmit buffer.
2. UTXISEL<1:0> = 01, the UxTXIF is set when the last character is shifted out of the Transmit Shift Register (UxTSR). This implies that all the transmit operations are completed.
3. UTXISEL<1:0> = 10, the UxTXIF is set when the character is transferred to the Transmit Shift Register (UxTSR) and the transmit buffer is empty.

The UxTXIF bit will be set when the module is first enabled. The user should clear the UxTXIF bit in the ISR.

Switching between the two Interrupt modes during operation is possible.

Note: When the UTXEN bit is set, the UxTXIF flag bit will also be set, after two cycles, if UTXISEL<1:0> = 00, since the transmit buffer is not yet full (can move transmit data to the UxTXREG register).

While the UxTXIF flag bit indicates the status of the UxTXREG register, the TRMT bit (UxSTA<8>) shows the status of the UxTSR. The TRMT status bit is a read-only bit, which is set when the UxTSR is empty. No interrupt logic is tied to this bit, so the user has to poll this bit in order to determine if the UxTSR is empty.

21.5.3 Setup for UART Transmit

Steps to follow when setting up a transmission:

1. Initialize the UxBRG register for the appropriate baud rate (see **Section 21.3 “UART Baud Rate Generator (BRG)”**).
2. Set the number of data bits, number of Stop bits and parity selection by writing to the PDSEL<1:0> (UxMODE<2:1>) and STSEL (UxMODE<0>) bits.
3. If transmit interrupts are desired, set the UxTXIE control bit in the corresponding Interrupt Enable Control register (IECx). Specify the interrupt priority for the transmit interrupt using the UxTXIP<2:0> control bits in the corresponding Interrupt Priority Control register (IPCx). Also, select the Transmit Interrupt mode by writing the UTXISEL<1:0> (UxSTA<15, 13>) bits.
4. Enable the UART module by setting the UARTEN (UxMODE<15>) bit.
5. Enable the transmission by setting the UTXEN (UxSTA<10>) bit, which will also set the UxTXIF bit. The UxTXIF bit should be cleared in the software routine that services the UART transmit interrupt. The operation of the UxTXIF bit is controlled by the UTXISEL<1:0> control bits.
6. Load data to the UxTXREG register (starts transmission). If 9-bit transmission has been selected, load a word. If 8-bit transmission is used, load a byte. Data can be loaded into the buffer until the UTXBF status bit (UxSTA<9>) is set.

Note: The UTXEN bit should not be set until the UARTEN bit has been set; otherwise, UART transmissions will not be enabled.

Figure 21-4: Transmission (8-Bit or 9-Bit Data)

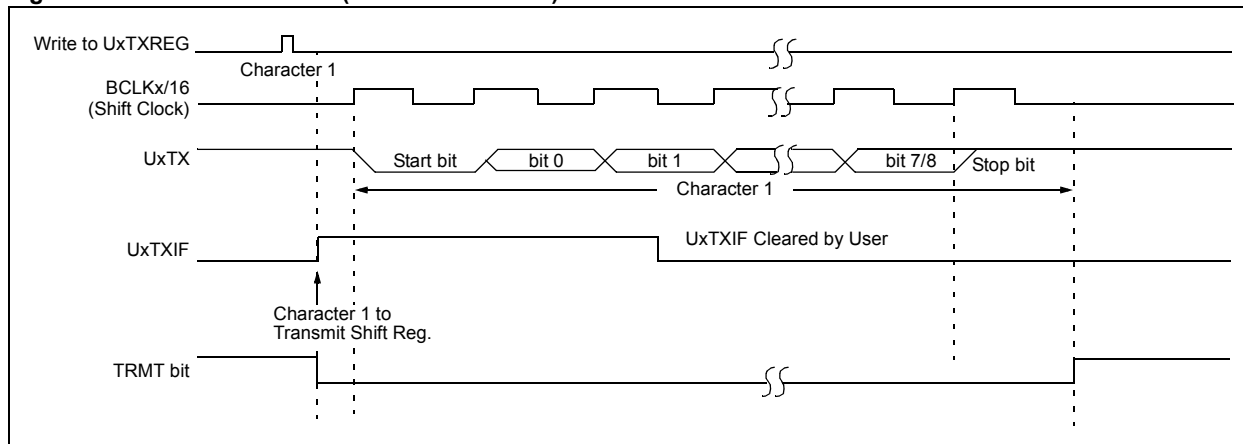
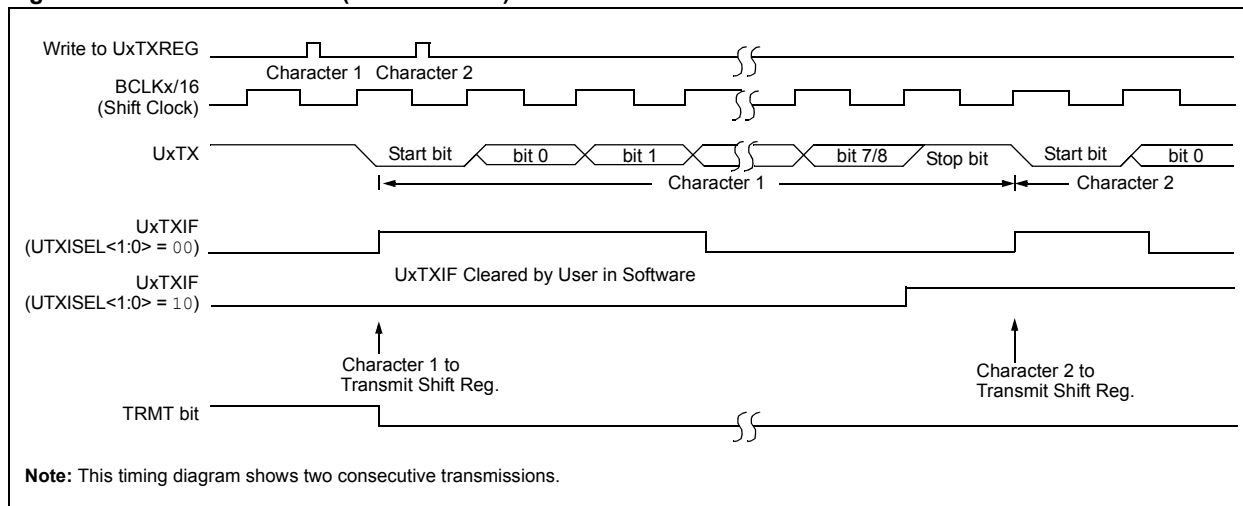


Figure 21-5: Transmission (Back-to-Back)



Note: This timing diagram shows two consecutive transmissions.

21.5.4 Transmission of Break Characters

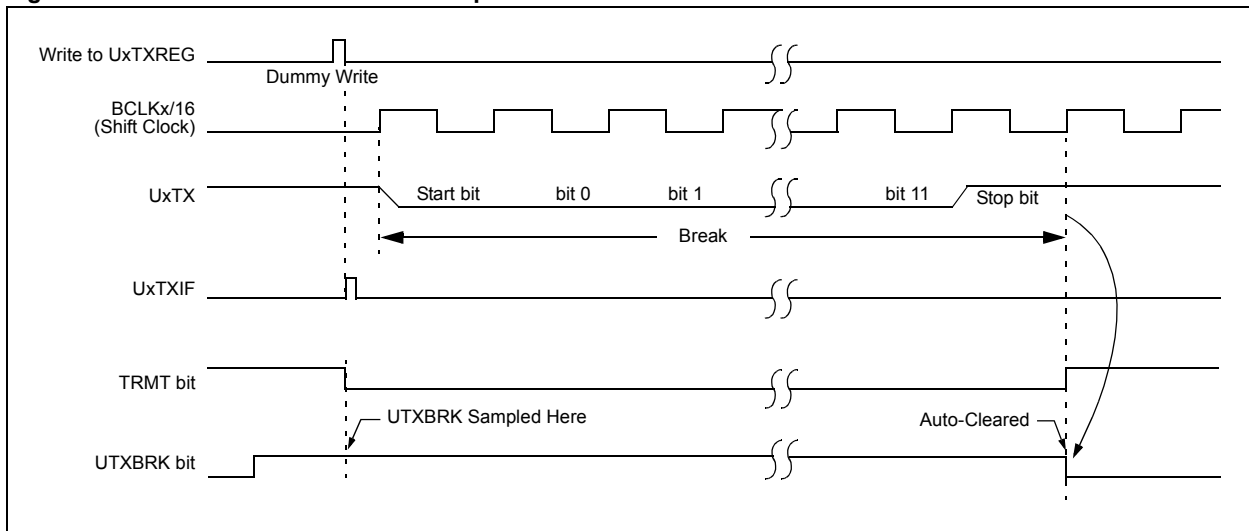
A Break character transmit consists of a Start bit, followed by twelve bits of '0' and a Stop bit. A Frame Break character is sent whenever the UTXBRK and UTXEN bits are set while the Transmit Shift Register is loaded with data. A dummy write to the UxTXREG register is necessary to initiate the Break character transmission. Note that the data value written to the UxTXREG for the Break character is ignored. The write simply serves the purpose of initiating the proper sequence – all '0's will be transmitted.

The UTXBRK bit is automatically reset by hardware after the corresponding Stop bit is sent. This allows the user to preload the transmit FIFO with the next transmit byte following the Break character (typically, the Sync character in the LIN specification).

Note: The user should wait for the transmitter to be Idle ($TRMT = 1$) before setting the UTXBRK. The UTXBRK overrides any other transmitter activity. If the user clears the UTXBRK bit prior to sequence completion, unexpected module behavior can result. Sending a Break character does not generate a transmit interrupt.

The TRMT bit indicates when the Transmit Shift Register is empty or full, just as it does during normal transmission. See Figure 21-6 for the timing of the Break character sequence.

Figure 21-6: Send Break Character Sequence



21.5.4.1 BREAK AND SYNC TRANSMIT SEQUENCE

The following sequence will send a message frame header made up of a Break, followed by an auto-baud Sync byte. This sequence is typical of a LIN bus master.

1. Configure the UART for the desired mode.
2. Set UTXEN and UTXBRK – sets up the Break character.
3. Load the UxTXREG with a dummy character to initiate transmission (value is ignored).
4. Write '55h' to UxTXREG – loads Sync character into the transmit FIFO.

After the Break has been sent, the UTXBRK bit is reset by hardware. The Sync character now transmits.

21.6 UART RECEIVER

The receiver block diagram is shown in Figure 21-7. The heart of the receiver is the Receive (Serial) Shift Register (UxRSR). The data is received on the UxRX pin and is sent to the data recovery block. The data recovery block operates at 16 times the baud rate, whereas the main receive serial shifter operates at the baud rate. After sampling the UxRX pin for the Stop bit, the received data in UxRSR is transferred to the receive FIFO (if it is empty).

Note: The UxRSR register is not mapped in data memory, so it is not available to the user.

The data on the UxRX pin is sampled three times by a majority detect circuit to determine if a high or a low level is present at the UxRX pin.

21.6.1 Receive Buffer (UxRXREG)

The UART receiver has a 4-deep, 9-bit wide FIFO receive data buffer. UxRXREG is a memory mapped register that provides access to the output of the FIFO. It is possible for 4 words of data to be received and transferred to the FIFO and a fifth word to begin shifting to the UxRSR register before a buffer overrun occurs.

21.6.2 Receiver Error Handling

If the FIFO is full (four characters) and a fifth character is fully received into the UxRSR register, the Overrun Error bit, OERR (UxSTA<1>), will be set. The word in UxRSR will be kept, but further transfers to the receive FIFO are inhibited as long as the OERR bit is set. The user must clear the OERR bit in software to allow further data to be received.

If it is desired to keep the data received prior to the overrun, the user should first read all five characters, then clear the OERR bit. If the five characters can be discarded, the user can simply clear the OERR bit. This effectively resets the receive FIFO and all prior received data is lost.

Note: The data in the receive FIFO should be read prior to clearing the OERR bit. The FIFO is reset when OERR is cleared which causes all data in the buffer to be lost.

The Framing Error bit, FERR (UxSTA<2>), is set if a Stop bit is detected at a logic low level.

The Parity Error bit, PERR (UxSTA<3>), is set if a parity error has been detected in the data word at the top of the buffer (i.e., the current word). For example, a parity error would occur if the parity is set to be even, but the total number of ones in the data has been detected to be odd. The PERR bit is irrelevant in the 9-bit mode. The FERR and PERR bits are buffered along with the corresponding word and should be read before reading the data word.

An interrupt is generated if any of these (OERR, FERR and PERR) errors occur. This generated interrupt will be valid for only one cycle. The user will have to enable the corresponding Interrupt Enable Control bit (IEC4<UxERIE>) to go to the corresponding interrupt vector location.

21.6.3 Receive Interrupt

The UARTx Receive Interrupt Flag (UxRXIF) is located in the corresponding Interrupt Flag Status (IFSx) register. The URXISEL<1:0> (UxSTA<7:6>) control bits determine when the UART receiver generates an interrupt.

- If URXISEL<1:0> = 00 or 01, an interrupt is generated each time a data word is transferred from the Receive Shift Register (UxRSR) to the receive buffer. There may be one or more characters in the receive buffer.
- If URXISEL<1:0> = 10, an interrupt is generated when a word is transferred from the Receive Shift Register (UxRSR) to the receive buffer, and as a result, the receive buffer contains 3 or 4 characters.
- If URXISEL<1:0> = 11, an interrupt is generated when a word is transferred from the Receive Shift Register (UxRSR) to the receive buffer, and as a result, the receive buffer contains 4 characters (i.e., becomes full).

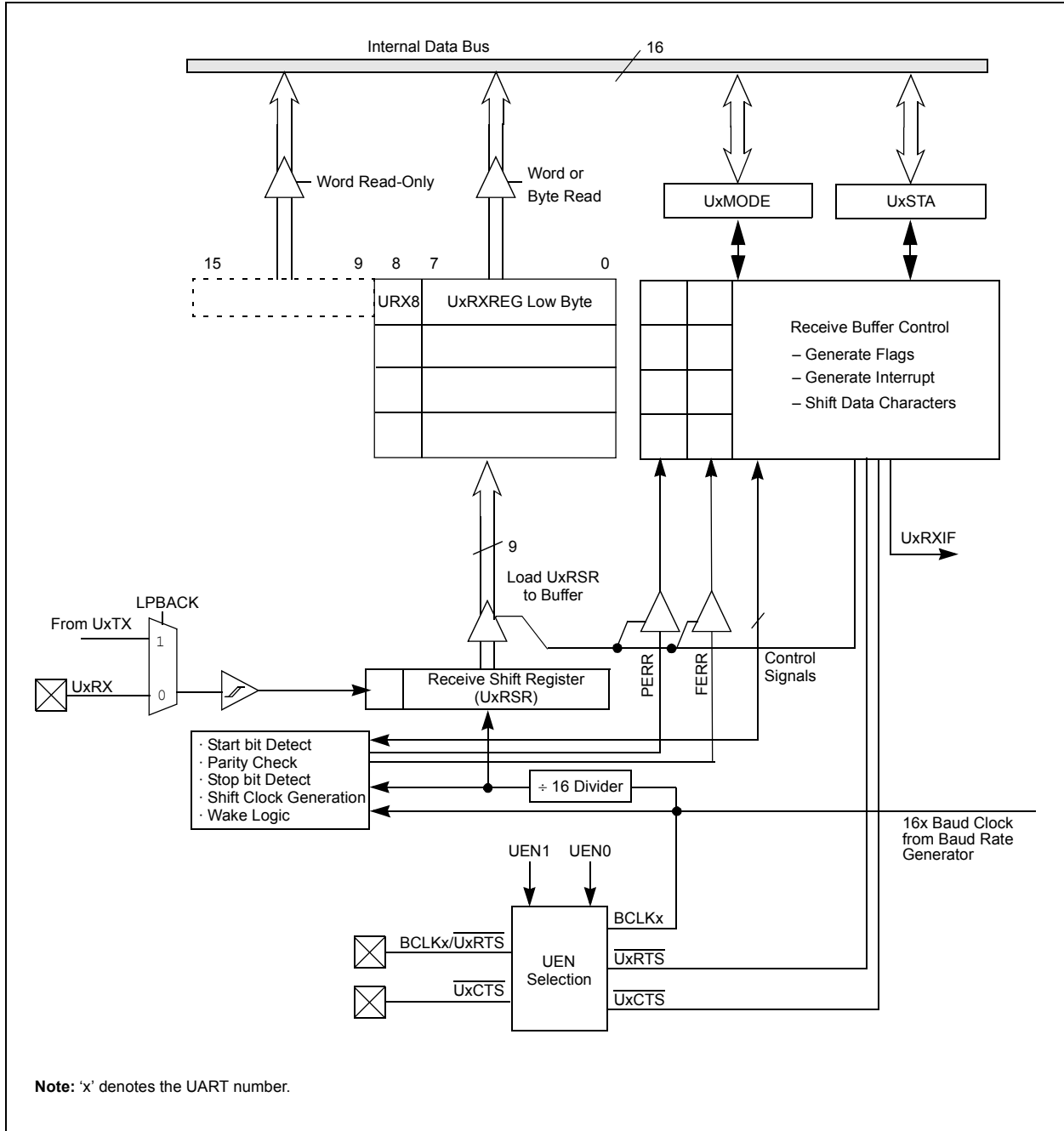
Switching between the three Interrupt modes during operation is possible.

While the URXDA and UxRXIF flag bits indicate the status of the UxRXREG register, the RIDLE bit (UxSTA<4>) shows the status of the UxRSR register. The RIDLE status bit is a read-only bit which is set when the receiver is Idle (i.e., the UxRSR register is empty). No interrupt logic is tied to this bit, so the user has to poll this bit in order to determine if the UxRSR is Idle.

The URXDA bit (UxSTA<0>) indicates whether the receive buffer has data or whether the buffer is empty. This bit is set as long as there is at least one character to be read from the receive buffer. URXDA is a read-only bit.

Figure 21-7 shows a block diagram of the UARTx receiver.

Figure 21-7: UARTx Receiver Block Diagram



21.6.4 Setup for UART Reception

Steps to follow when setting up a reception:

1. Initialize the UxBRG register for the appropriate baud rate (see **Section 21.3 “UART Baud Rate Generator (BRG)”**).
2. Set the number of data bits, number of Stop bits and parity selection by writing to the PDSEL<1:0> (UxMODE<2:1>) and STSEL (UxMODE<0>) bits.
3. If interrupts are desired, then set the UxRXIE bit in the corresponding Interrupt Enable Control (IECx) register. Specify the interrupt priority for the interrupt using the UxRXIP<2:0> control bits in the corresponding Interrupt Priority Control register (IPCx). Also, select the Receive Interrupt mode by writing to the URXISEL<1:0> (UxSTA<7:6>) bits.
4. Enable the UART module by setting the UARTEN (UxMODE<15>) bit.
5. Receive interrupts will depend on the URXISEL<1:0> control bit settings. If receive interrupts are not enabled, the user can poll the URXDA bit. The UxRXIF bit should be cleared in the software routine that services the UART receive interrupt.
6. Read data from the receive buffer. If 9-bit transmission has been selected, read a word; otherwise, read a byte. The URXDA status bit (UxSTA<0>) will be set whenever data is available in the buffer.

Figure 21-8: UARTx Reception

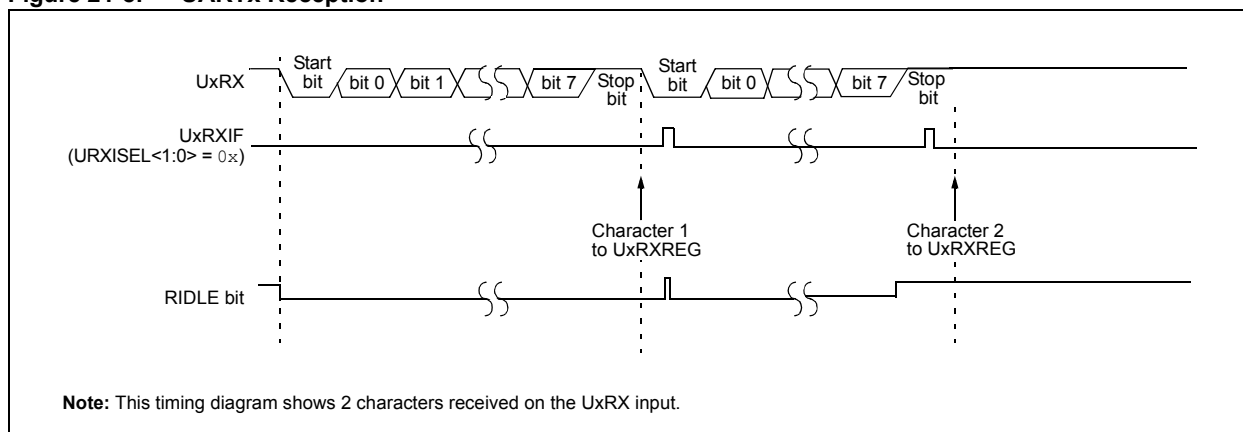
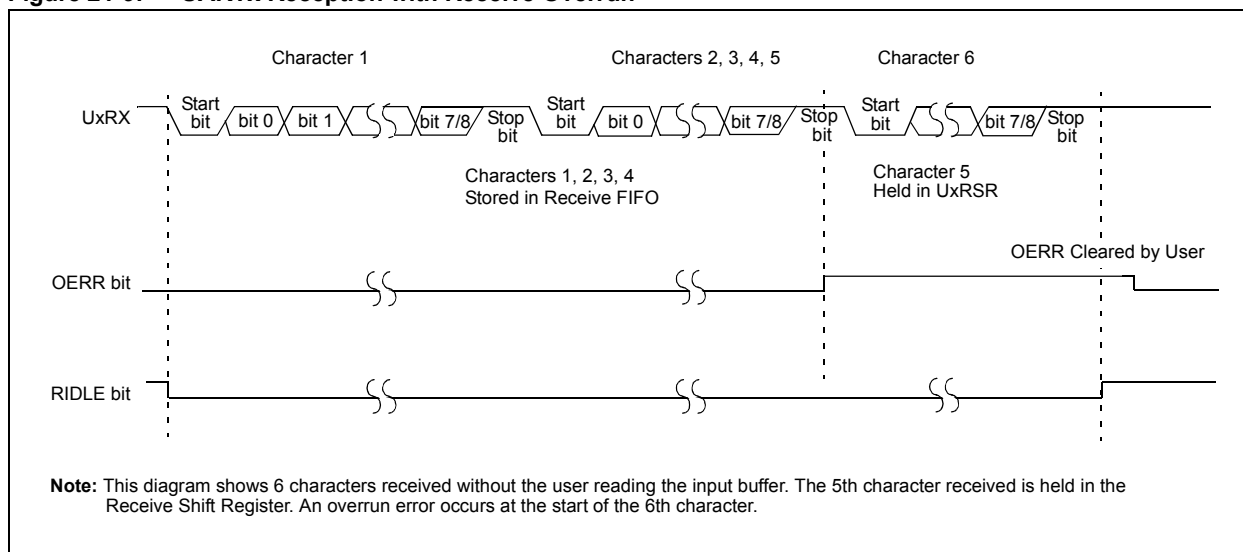


Figure 21-9: UARTx Reception with Receive Overrun



21.7 USING THE UART FOR 9-BIT COMMUNICATION

The UART receiver in 9-Bit Data mode can be used for multiprocessor communication. With the ADDEN bit set in 9-Bit Data mode, the receiver can ignore the data when the 9th bit of the data is '0'. This feature can be used in a multiprocessor environment.

21.7.1 Multiprocessor Communications

A typical multiprocessor communication protocol will differentiate between data bytes and address/control bytes. A common scheme is to use a 9th data bit to identify whether a data byte is address or data information. If the 9th bit is set, the data is processed as address or control information. If the 9th bit is cleared, the received data word is processed as data associated with the previous address/control byte.

The protocol operates as follows:

- The master device transmits a data word with the 9th bit set. The data word contains the address of a slave device.
- All slave devices in the communication chain receive the address word and check the slave address value.
- The slave device that was addressed will receive and process subsequent data bytes sent by the master device. All other slave devices will discard subsequent data bytes until a new address word (9th bit set) is received.

21.7.2 ADDEN Control Bit

The UART receiver has an Address Detect mode which allows it to ignore data words with the 9th bit cleared. This reduces the interrupt overhead, since data words with the 9th bit cleared are not buffered. This feature is enabled by setting the ADDEN bit (UxSTA<5>).

The UART must be configured for 9-Bit Data mode to use the Address Detect mode. The ADDEN bit has no effect when the receiver is configured in 8-Bit Data mode.

21.7.3 Setup for 9-Bit Transmit

The setup procedure for 9-bit transmission is identical to the 8-Bit Transmit modes, except that PDSEL<1:0> bits (UxMODE<2:1>) should be set to '11' (see **Section 21.5.3 "Setup for UART Transmit"**).

Word writes should be performed to the UxTXREG register (starts transmission).

21.7.4 Setup for 9-Bit Reception Using Address Detect Mode

The setup procedure for 9-bit reception is similar to the 8-Bit Receive modes, except that the PDSEL<1:0> bits (UxMODE<2:1>) should be set to '11' (see **Section 21.6.4 "Setup for UART Reception"**).

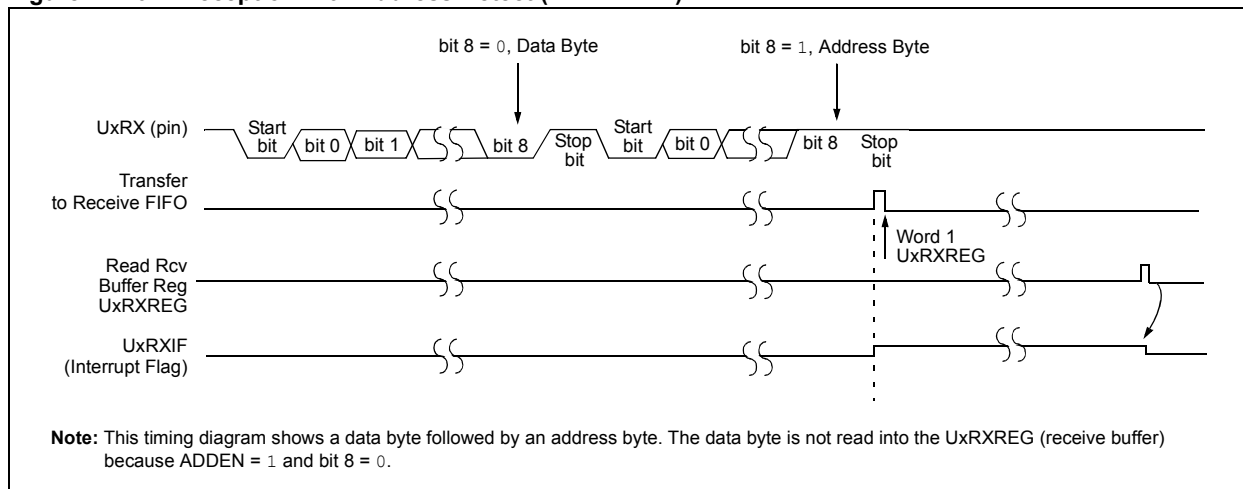
The Receive Interrupt mode should be configured by writing to the URXISEL<1:0> (UxSTA<7:6>) bits.

Note: If the Address Detect mode is enabled (ADDEN = 1), the URXISEL<1:0> control bits should be configured so that an interrupt will be generated after every received word. Each received data word must be checked in software for an address match immediately after reception.

The procedure for using the Address Detect mode is as follows:

1. Set the ADDEN (UxSTA<5>) bit to enable address detect. Ensure that the URXISEL control bits are configured to generate an interrupt after each received word.
2. Check each 8-bit address by reading the UxRXREG register to determine if the device is being addressed.
3. If this device has not been addressed, then discard the received word.
4. If this device has been addressed, clear the ADDEN bit to allow subsequent data bytes to be read into the receive buffer and interrupt the CPU. If a long data packet is expected, then the Receive Interrupt mode could be changed to buffer more than one data byte between interrupts.
5. When the last data byte has been received, set the ADDEN bit so that only address bytes will be received. Also, ensure that the URXISEL control bits are configured to generate an interrupt after each received word.

Figure 21-10: Reception with Address Detect (ADDEN = 1)



21.8 RECEIVING BREAK CHARACTERS

The wake-up feature is enabled by setting the WAKE bit (UxMODE <7>) = 1. In this mode, the module will receive the Start bit, data and the invalid Stop bit (which sets FERR), but the receiver will wait for a valid Stop bit before looking for the next Start bit. It will not assume that the Break condition on the line is the next Start bit. Break is regarded as a character containing all '0's with the FERR bit set. The Break character is loaded into the buffer. No further reception can occur until a Stop bit is received. The WAKE bit will get cleared automatically once the Stop bit is received after the 13-bit Break character. Note that the RIDLE bit goes high when the Stop bit has been received.

The receiver will count and expect a certain number of bit times based on the values programmed in the PDSEL<1:0> (UxMODE<2:1>) and STSEL (UxMODE<0>) bits.

If the Break is longer than 13 bit times, the reception is considered complete after the number of bit times specified by the PDSEL and STSEL bits. The URXDA bit is set, FERR is set, zeros are loaded into the receive FIFO and interrupts are generated.

If the wake-up feature is not set, WAKE (UxMODE <7>) = 0, Break reception is not special. The Break will be counted as one character loaded into the buffer (all '0' bits) with FERR set.

21.9 INITIALIZATION

Example 21-2 is an initialization routine for the transmitter/receiver in 8-bit mode. Example 21-3 shows an initialization of the Addressable UART in 9-Bit Address Detect mode. In both examples, the value to load into the UxBRG register is dependent on the desired baud rate and the device frequency.

Note: The UTXEN bit should not be set until the URTEN bit has been set; otherwise, UART transmissions will not be enabled.

Example 21-2: 8-Bit Transmit/Receive (UART1)

```

U1BRG=#BaudRate;                //Set Baudrate

IPC3bits.U1TXIP2 = 1;            //Set Uart TX Interrupt Priority
IPC3bits.U1TXIP1 = 0;
IPC3bits.U1TXIP0 = 0;
IPC2bits.U1RXIP2 = 1;            //Set Uart RX Interrupt Priority
IPC2bits.U1RXIP1 = 0;
IPC2bits.U1RXIP0 = 0;

U1STA                            = 0;
U1MODE                            = 0x8000;    //Enable Uart for 8-bit data
                                        //no parity, 1 STOP bit
U1STAbits.UTXEN = 1;            //Enable Transmit
IEC0bits.U1TXIE = 1;            //Enable Transmit Interrupt
IEC0bits.U1RXIE = 1;            //Enable Receive Interrupt

```

Example 21-3: 8-Bit Transmit/Receive (UART1), Address Detect Enabled

```
U1BRG=#BaudRate;           //Set Baudrate

IPC3bits.U1TXIP2 = 1;       //Set Uart TX Interrupt Priority
IPC3bits.U1TXIP1 = 0;
IPC3bits.U1TXIP0 = 0;
IPC2bits.U1RXIP2 = 1;       //Set Uart RX Interrupt Priority
IPC2bits.U1RXIP1 = 0;
IPC2bits.U1RXIP0 = 0;

U1STA                       = 0;
U1STAbits.ADDEN = 1;        //Address detect enabled
U1MODE = 0x8080;           //Enable Uart for 8-bit data
                               //no parity,1 STOP bit,wake enabled

U1STAbits.UTXEN = 1;        //Enable Transmit
IEC0bits.U1TXIE = 1;        //Enable Transmit Interrupt
IEC0bits.U1RXIE = 1;        //Enable Receive Interrupt
```


21.10 OTHER FEATURES OF THE UART

21.10.1 UART in Loopback Mode

Setting the LPBACK bit enables this special mode in which the UxTX output is internally connected to the UxRX input. When configured for the Loopback mode, the UxRX pin is disconnected from the internal UART receive logic. However, the UxTX pin still functions normally.

To select this mode:

1. Configure UART for the desired mode of operation.
2. Enable transmission as defined in **Section 21.5 “UART Transmitter”**.
3. Set LPBACK = 1 (UxMODE<6>) to enable Loopback mode.

The Loopback mode is dependent on the UEN<1:0> bits, as shown in Table 21-3.

Table 21-3: Loopback Mode Pin Function

UEN<1:0>	Pin Function, LPBACK = 1 ⁽¹⁾
00	UxRX input connected to UxTX; UxTX pin functions; UxRX pin ignored; UxCTS/UxRTS unused
01	UxRX input connected to UxTX; UxTX pin functions; UxRX pin ignored; UxRTS pin functions; UxCTS unused
10	UxRX input connected to UxTX; UxTX pin functions; UxRX pin ignored; UxRTS pin functions; UxCTS input connected to UxRTS; UxCTS pin ignored
11	UxRX input connected to UxTX; UxTX pin functions; UxRX pin ignored; BCLKx pin functions; UxCTS/UxRTS unused

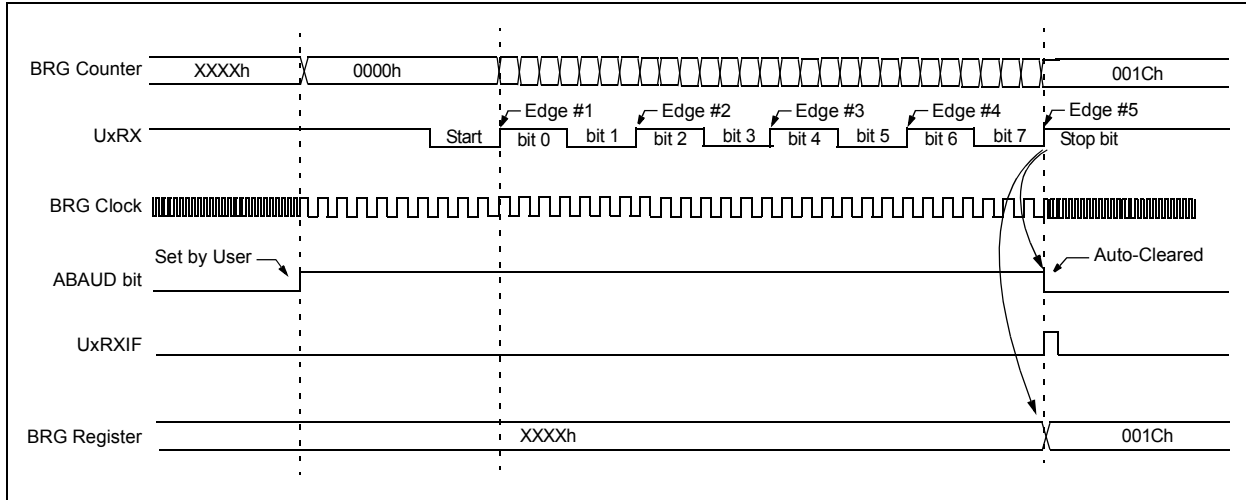
Note 1: LPBACK = 1 should be set only after enabling the other bits associated with the UART module.

21.10.2 Auto-Baud Support

To allow the system to determine baud rates of the received characters, the ABAUD bit is enabled. The UART will begin an automatic baud rate measurement sequence whenever a Start bit is received when the Auto-Baud Rate Detect is enabled (ABAUD = 1). The calculation is self-averaging. This feature is active only while the auto-wake-up is disabled (WAKE = 0). In addition, LPBACK must equal '0' for the auto-baud operation. Once the ABAUD bit is set, the BRG counter value will be cleared and will look for a Start bit, which in this case, is defined as a high-to-low transition followed by a low-to-high transition.

Following the Start bit, the auto-baud expects to receive an ASCII “U” (“55h”) in order to calculate the proper bit rate. The measurement is taken over both the low and high bit time in order to minimize any effects caused by asymmetry of the incoming signal. At the end of the Start bit (rising edge), the BRG counter begins counting up using a T_{cy}/8 clock. On the 5th UxRX pin rising edge, an accumulated BRG counter value totalling the proper BRG period is transferred to the UxBRG register. The ABAUD bit is automatically cleared. If the user clears the ABAUD bit prior to sequence completion, unexpected module behavior can result. Refer to Figure 21-11 for the ABD sequence.

Figure 21-11: Automatic Baud Rate Calculation



While the auto-baud sequence is in progress, the UART state machine is held in Idle. The UxRXIF interrupt is set on the 5th UxRX rising edge, independent of the URXISEL<1:0> settings. The receiver FIFO is not updated.

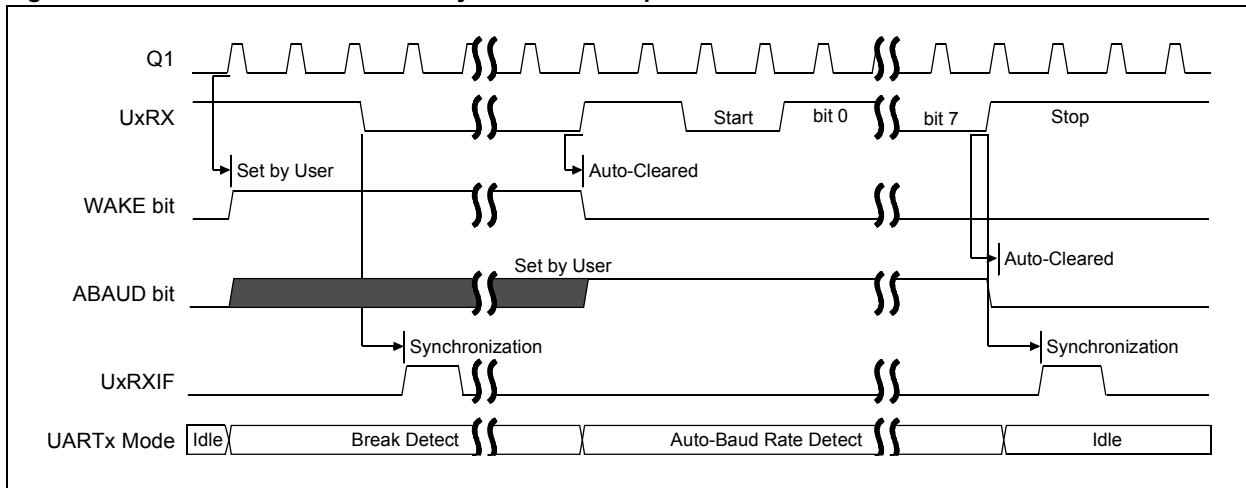
21.10.2.1 BREAK DETECT SEQUENCE

The user can configure the auto-baud to occur immediately following the Break detect. This is done by setting the ABAUD bit with the WAKE bit set. Figure 21-12 shows a Break detect followed by an auto-baud sequence. The WAKE bit takes priority over the ABAUD bit setting.

Note: If the WAKE bit is set with the ABAUD bit, Auto-Baud Rate Detection will occur on the byte following the Break character. The user has to make sure that the incoming character baud rate is within the range of the selected UxBRG clock source, considering the baud rate possible with the given clock.

The UART transmitter cannot be used during an auto-baud sequence. Furthermore, the user should assure that the ABAUD bit is not set while a transmit sequence is already in progress. The UART can exhibit unpredictable behavior otherwise.

Figure 21-12: Break Detect Followed by Auto-Baud Sequence



21.11 UART OPERATION DURING CPU SLEEP AND IDLE MODES

The UART does not function in Sleep mode. If entry into Sleep mode occurs while a transmission is in progress, then the transmission is aborted and the UxTX pin is driven to logic '1'. Similarly, if entry into Sleep mode occurs while a reception is in progress, then the reception is aborted.

The UART will reset itself during Sleep.

The $\overline{\text{UxRTS}}$ pin is driven to '0' if in Power-Down mode; otherwise, it is driven to the value specified in **Section 21.12 "Operation of UxCTS and UxRTS Control Pins"**.

The BCLKx pin (if enabled) is driven to '0'. The following registers are not affected by going into Sleep mode or coming out of Sleep mode:

- UxMODE and UxSTA registers
- Transmit and Receive registers and buffers
- UxBRG register

There is no automatic way to prevent Sleep entry if a transmission or reception is pending. The user can check the RIDLE bit before going to Sleep to avoid reception abortion. The user is in control of the transmitter, so the user software must synchronize Sleep entry with UART operation to make sure that transmission is not aborted.

For the UART, the USIDL bit selects if the module will stop on Idle or continue on Idle. If USIDL = 0, the module will continue operation in Idle. If USIDL = 1, the module will stop on Idle. The UART module will perform the same procedures when stopped in Idle mode (USIDL = 1) as for Sleep mode.

21.11.1 Auto-Wake-up on Sync Break Character

The auto-wake-up feature is enabled with the WAKE bit (UxMODE<7>). Once WAKE is active, the typical receive sequence on UxRX is disabled. Following the wake-up event, the module generates the UxRXIF interrupt.

LPBACK bit (UxMODE<6>) must equal '0' for wake-up to operate.

A wake-up event consists of a high-to-low transition on the UxRX line. This coincides with the start of a Sync Break or a Wake-up Signal character for the LIN protocol. When WAKE is active, the UxRX line is monitored independently from the CPU mode. The UxRXIF interrupt will be generated synchronously to the Q clocks in normal user mode, and asynchronously, if the module is disabled due to Sleep or Idle mode. To assure that no actual data is lost, the WAKE bit should be set just prior to entering the Sleep mode, and while the UART module is in Idle.

The WAKE bit is automatically cleared once a low-to-high transition is observed on the UxRX line following the wake-up event. At this point, the UART module is in Idle mode and is returned to normal operation. This signals to the user that the Sync Break event is over. If the user clears the WAKE bit prior to sequence completion, unexpected module behavior can result.

The wake-up event causes a receive interrupt by setting the UxRXIF bit. The Receive Interrupt Select mode bits (URXISEL<1:0>) are ignored for this function. If the UxRXIF interrupt is enabled, then this will wake-up the device.

Note: The Sync Break (or Wake-up Signal) character must be of sufficient length to allow enough time for the selected oscillator to start and provide proper initialization of the UART. To assure that the part woke up in time, the user should read the value of the WAKE bit. If it is clear, it is possible that the UART was not ready in time to receive the next character and the module might need to be resynchronized to the bus.

PIC24F Family Reference Manual

Figure 21-13: Auto-Wake-up Bit (WAKE) Timings During Normal Operation

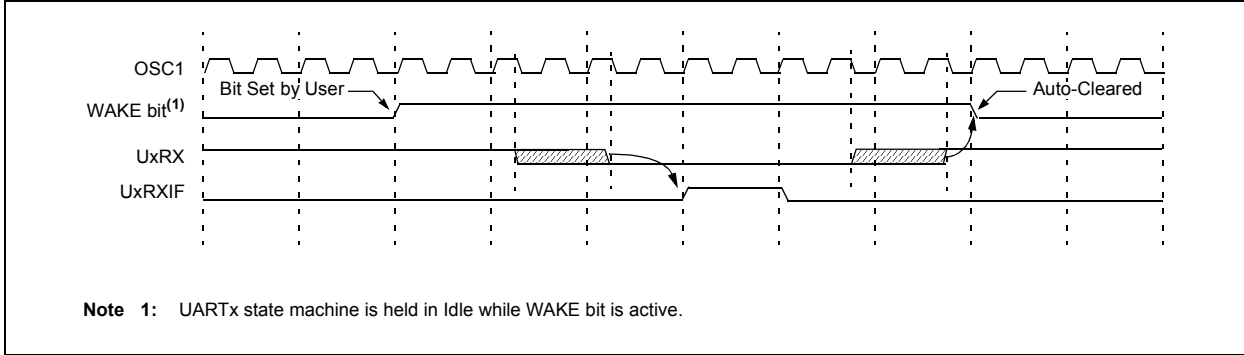
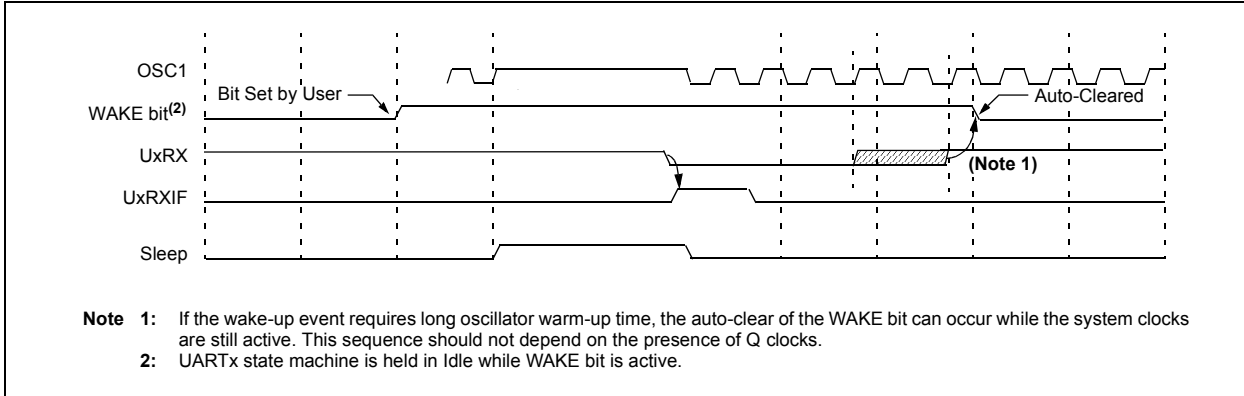


Figure 21-14: Auto-Wake-up Bit (WAKE) Timings During Sleep



21.12 OPERATION OF $\overline{\text{UxCTS}}$ AND $\overline{\text{UxRTS}}$ CONTROL PINS

$\overline{\text{UxCTS}}$ (Clear to Send) and $\overline{\text{UxRTS}}$ (Request to Send) are the two hardware controlled pins which are associated with the UART module. These two pins allow the UART to operate in Simplex and Flow Control modes, which are explained in detail in **Section 21.12.2 “UxRTS Function in Flow Control Mode”** and **Section 21.12.3 “UxRTS Function in Simplex Mode”**, respectively. They are implemented to control the transmission and reception between the DTE (Data Terminal Equipment).

21.12.1 $\overline{\text{UxCTS}}$ Function

In the UART operation, the $\overline{\text{UxCTS}}$ acts as an input pin which can control the transmission. This pin is controlled by another device (typically a PC). The $\overline{\text{UxCTS}}$ pin is configured using $\text{UEN}\langle 1:0 \rangle$. When $\text{UEN}\langle 1:0 \rangle = 10$, $\overline{\text{UxCTS}}$ is configured as an input. If $\overline{\text{UxCTS}} = 1$, then the transmitter will go as far as loading the data in the Transmit Shift Register, but will not initiate a transmission. This will allow the DTE to control and receive the data accordingly from the controller per its requirement.

The $\overline{\text{UxCTS}}$ pin is sampled at the same time as when the transmit data changes (i.e., at the beginning of the 16 baud clocks). Transmission will begin only when the $\overline{\text{UxCTS}}$ is sampled low. The $\overline{\text{UxCTS}}$ is sampled internally with a Q clock, which means that there should be a minimum pulse width of $1 T_{CY}$ on $\overline{\text{UxCTS}}$. However, this cannot be a specification as the T_{CY} can vary depending on the clock used.

The user can also read the status of the $\overline{\text{UxCTS}}$ by reading the associated port pin.

21.12.2 $\overline{\text{UxRTS}}$ Function in Flow Control Mode

In the Flow Control mode, the $\overline{\text{UxRTS}}$ of one DTE is connected to the $\overline{\text{UxCTS}}$ of the PIC24F, and the $\overline{\text{UxCTS}}$ of the DTE is connected to the $\overline{\text{UxRTS}}$ of the PIC24F, as shown in Figure 21-15. The $\overline{\text{UxRTS}}$ signal indicates that the device is ready to receive the data. The $\overline{\text{UxRTS}}$ pin is driven as an output whenever $\text{UEN}\langle 1:0 \rangle = 01$ or 10 . The $\overline{\text{UxRTS}}$ pin is asserted (driven low) whenever the receiver is ready to receive data. When the RTSMD bit = 0 (when the device is in Flow Control mode), the $\overline{\text{UxRTS}}$ pin is driven low whenever the receive buffer is not full or the OERR bit is not set. When the RTSMD bit = 1, the $\overline{\text{UxRTS}}$ pin is driven high whenever the device is not ready to receive (i.e., when the receiver buffer is either full or in the process of shifting).

Since the $\overline{\text{UxRTS}}$ of the DTE is connected to the $\overline{\text{UxCTS}}$ of the PIC24F, the $\overline{\text{UxRTS}}$ will drive the $\overline{\text{UxCTS}}$ low whenever it is ready to receive the data. Transmission of the data will begin when the $\overline{\text{UxCTS}}$ goes low, as explained in **Section 21.12.1 “UxCTS Function”**.

21.12.3 $\overline{\text{UxRTS}}$ Function in Simplex Mode

In the Simplex mode, the $\overline{\text{UxRTS}}$ of the DCE is connected to the $\overline{\text{UxRTS}}$ of the PIC24F, and the $\overline{\text{UxCTS}}$ of the DCE is connected to the $\overline{\text{UxCTS}}$ of the PIC24F, respectively, as shown in Figure 21-16. In the Simplex mode, the $\overline{\text{UxRTS}}$ signal indicates that the DTE is ready to transmit. The DCE will reply to the $\overline{\text{UxRTS}}$ signal with the valid $\overline{\text{UxCTS}}$ whenever the DCE is ready to receive the transmission. When the DTE receives a valid $\overline{\text{UxCTS}}$, it will begin transmission.

As shown in Figure 21-17, the Simplex mode is also used in IEEE-485 systems to enable transmitters. When $\overline{\text{UxRTS}}$ indicates that the DTE is ready to transmit, the $\overline{\text{UxRTS}}$ signal will enable the driver.

The $\overline{\text{UxRTS}}$ pin is configured as an output and is driven whenever $\text{UEN}\langle 1:0 \rangle = 01$ or 10 . When $\text{RTSMD} = 1$, the $\overline{\text{UxRTS}}$ is asserted (driven low) whenever the data is available to transmit ($\text{TRMT} = 0$). When $\text{RTSMD} = 0$, $\overline{\text{UxRTS}}$ is deasserted (driven high) when the transmitter is empty ($\text{TRMT} = 1$).

PIC24F Family Reference Manual

Figure 21-15: $\overline{UxRTS}/\overline{UxCTS}$ Flow Control for DTE-DTE (RTSMD = 0, Flow Control Mode)

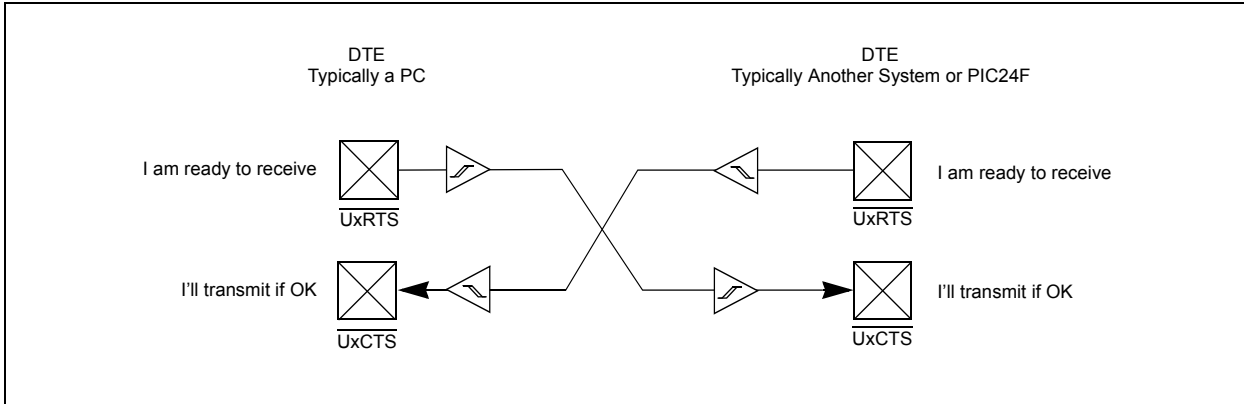


Figure 21-16: $\overline{UxRTS}/\overline{UxCTS}$ Handshake for DTE-DCE (RTSMD = 1, Simplex Mode)

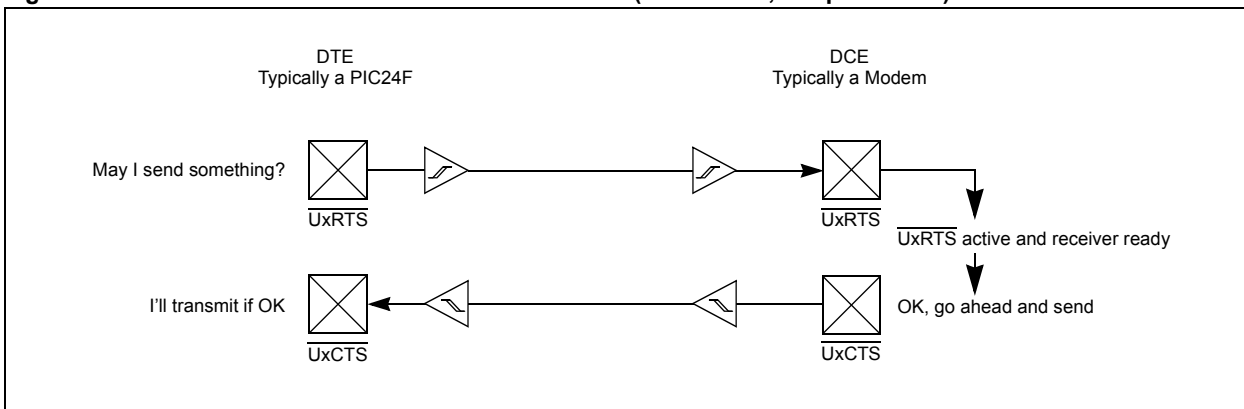
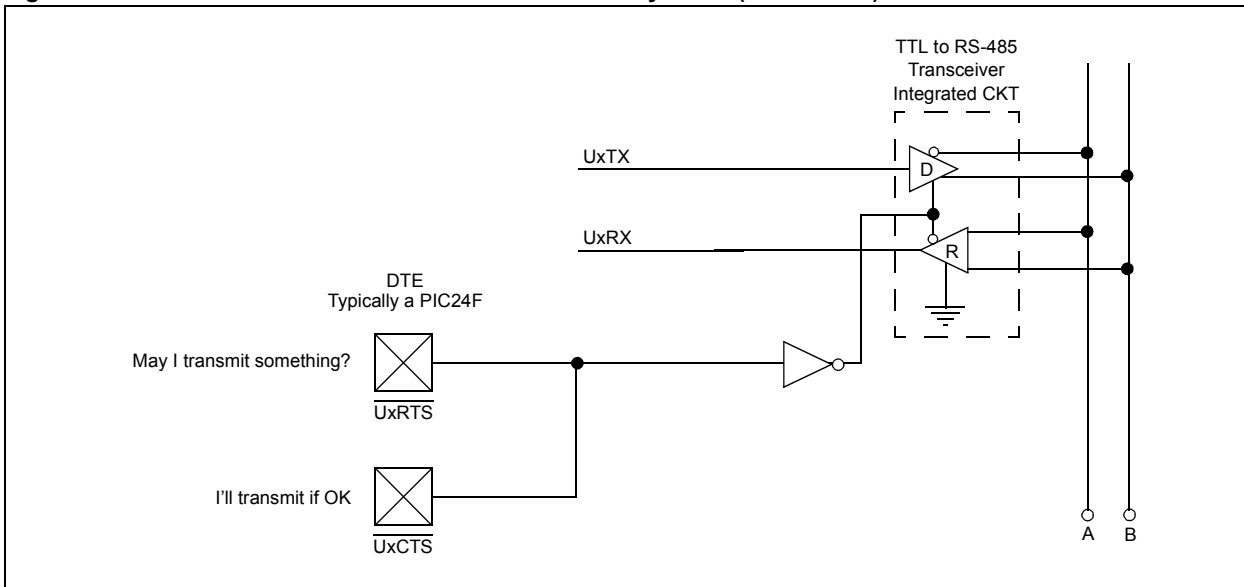


Figure 21-17: $\overline{UxRTS}/\overline{UxCTS}$ Bus Enable for IEEE-485 Systems (RTSMD = 1)



21.13 INFRARED SUPPORT

The UART module provides two types of infrared UART support: one is the IrDA clock output to support external IrDA encoder and decoder devices (legacy module support) and the other is the full implementation of the IrDA encoder and decoder.

21.13.1 External IrDA Support – IrDA Clock Output

To support external IrDA encoder and decoder devices, the BCLKx pin can be configured to generate the 16x baud clock. When $UEN<1:0> = 11$, the BCLKx pin will output the 16x baud clock if the UART module is enabled; it can be used to support the IrDA codec chip.

21.13.2 Built-In IrDA Encoder and Decoder

The UART has full implementation of the IrDA encoder and decoder as part of the UART module. The built-in IrDA encoder and decoder functionality is enabled using the IREN bit ($UxMODE<12>$). When enabled ($IREN = 1$), the receive pin ($UxRX$) acts as the input from the infrared receiver. The transmit pin ($UxTX$) acts as the output to the infrared transmitter.

This mode is available only if the UART Baud Rate Generator is in 16x Baud Clock mode. This is when the BRGH bit ($UxMODE<3>$) is '0'.

21.13.2.1 IrDA ENCODER FUNCTION

The encoder works by taking the serial data from the UART and replacing it as explained below.

Transmit bit data of '1' gets encoded as '0' for the entire 16 periods of the 16x baud clock. Transmit bit data of '0' gets encoded as '0' for the first 7 periods of the 16x baud clock, as '1' for the next 3 periods and as '0' for the remaining 6 periods. See Figure 21-18 and Figure 21-20 for details.

21.13.2.2 IrDA TRANSMIT POLARITY

The IrDA transmit polarity is selected using the UTXINV bit ($UxSTA<14>$). This bit only affects the module when the IrDA encoder and decoder are enabled ($IREN = 1$). This bit neither affects the receiver nor the module operation for normal transmission and reception. When $UTXINV = 0$, the Idle state of the $UxTX$ line is '0' (see Figure 21-18). When $UTXINV = 1$, the Idle state of the $UxTX$ line is '1' (see Figure 21-19).

Figure 21-18: IrDA® Encode Scheme

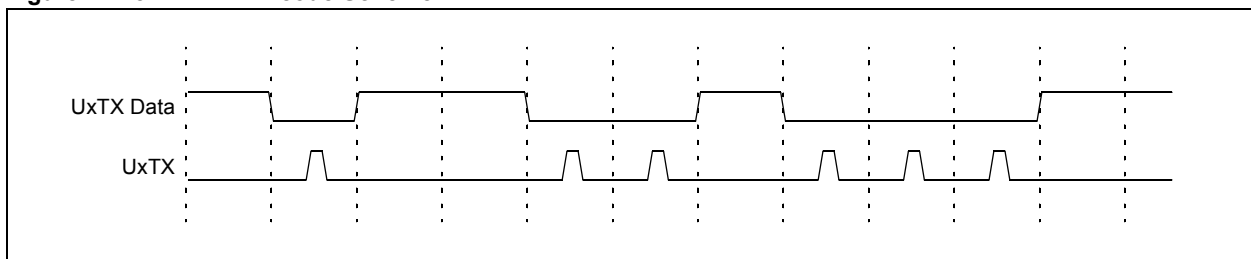


Figure 21-19: IrDA® Encode Scheme for '0' Bit Data

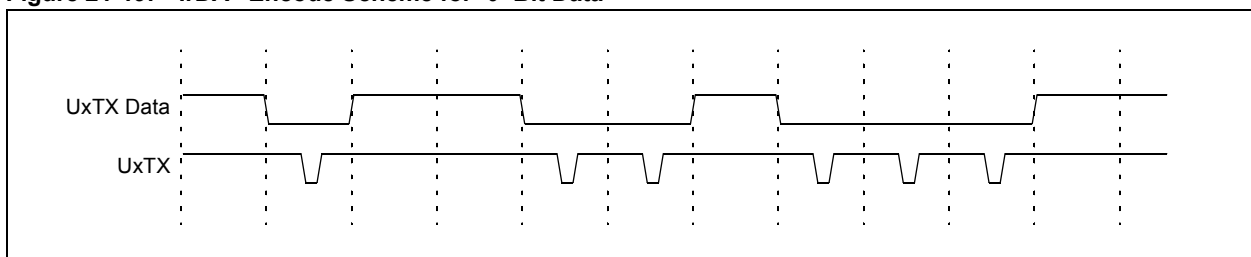
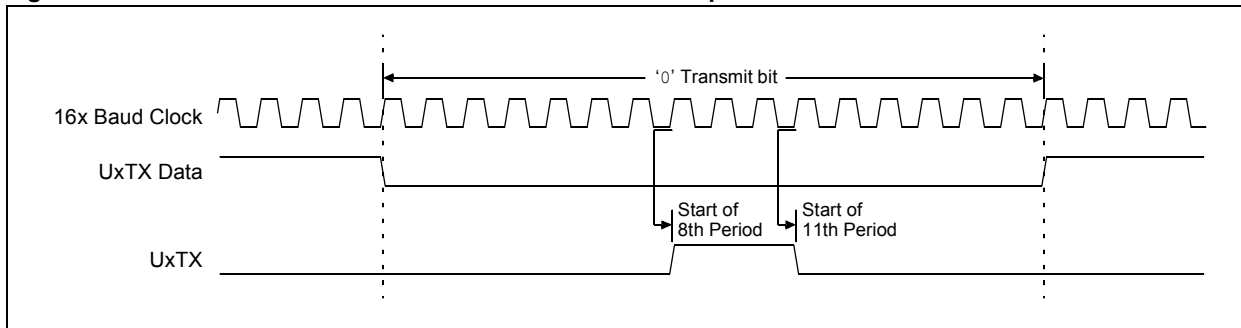


Figure 21-20: IrDA® Encode Scheme for '0' Bit Data with Respect to 16x Baud Clock



21.13.2.3 IrDA DECODER FUNCTION

The decoder works by taking the serial data from the UxRX pin and replacing it with the decoded data stream. The stream is decoded based on falling edge detection of the UxRX input.

Each falling edge of UxRX causes the decoded data to be driven low for 16 periods of the 16x baud clock. If, by the time the 16 periods expire, another falling edge has been detected, the decoded data remains low for another 16 periods. If no falling edge was detected, the decoded data is driven high.

Note that the data stream into the device is shifted anywhere from 7 to 8 periods of the 16x baud clock from the actual message source. The one clock uncertainty is due to the clock edge resolution (see Figure 21-21 for details).

21.13.2.4 IrDA RECEIVE POLARITY

The input of the IrDA signal can have an inverted polarity. The same logic is able to decode the signal train, but in this case, the decoded data stream is shifted from 10 to 11 periods of the 16x baud clock from the original message source. Again, the one clock uncertainty is due to the clock edge resolution (see Figure 21-22 for details).

21.13.2.5 CLOCK JITTER

Due to jitter, or slight frequency differences between devices, it is possible for the next falling bit edge to be missed for one of the 16x periods. In that case, a one clock wide pulse appears on the decoded data stream. Since the UART performs a majority detect around the bit center, this does not cause erroneous data (see Figure 21-23 for details).

Figure 21-21: Macro View of IrDA® Decoding Scheme

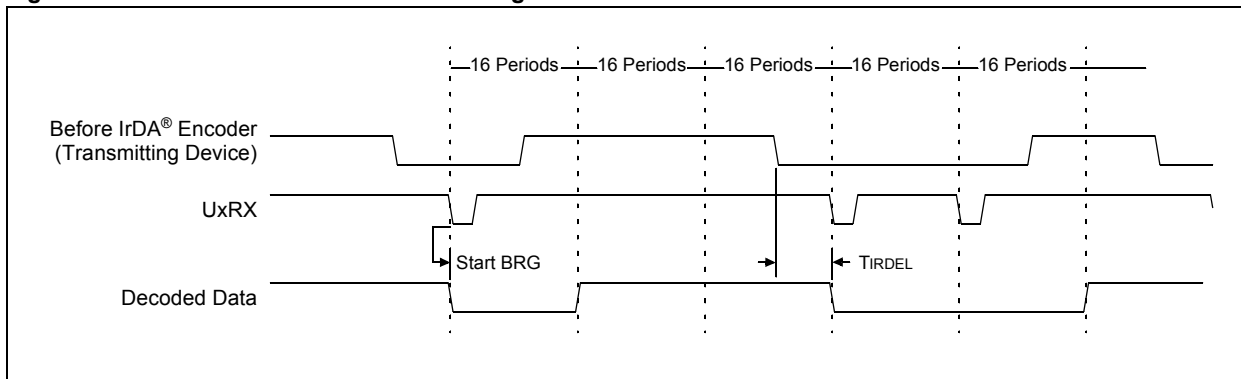


Figure 21-22: Inverted Polarity Decoding Results

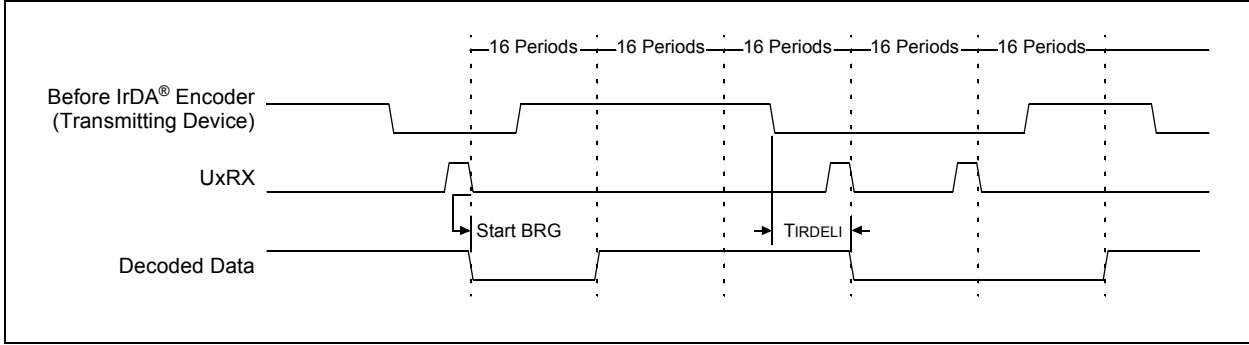
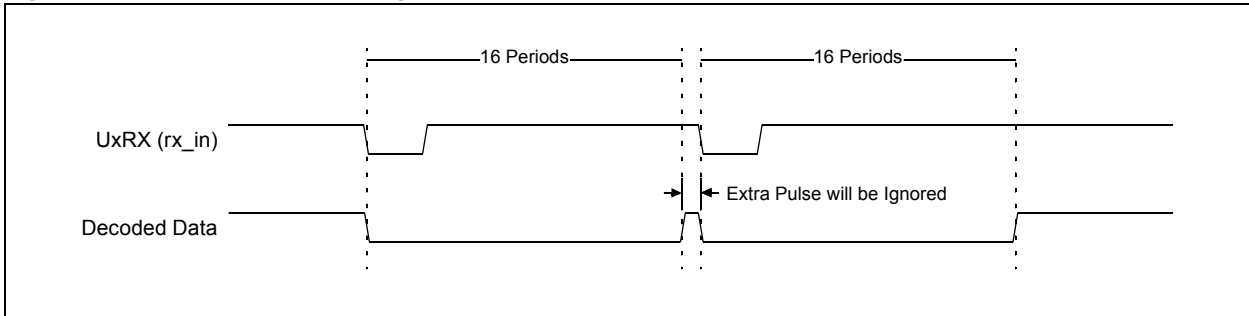


Figure 21-23: Clock Jitter Causing a Pulse Between Consecutive Zeros



21.14 REGISTERS ASSOCIATED WITH THE UART MODULE

A summary of the registers associated with the PIC24F UARTx is provided in Table 21-4.

Table 21-4: Registers Associated with UARTx⁽¹⁾

SFR Name	Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	All Resets	
UxMODE	UARTEN	UFRZ	USIDL	IREN ⁽²⁾	RTSMD	ALTIO ⁽³⁾	UEN1	UEN0	WAKE	LPBACK	ABAUD	RXINV	BRGH	PDSEL1	PDSEL0	STSEL	0000	
UxSTA	UTXISEL1	UTXINV	UTXISEL0	—	UTXBRK	UTXEN	UTXBF	TRMT	URXISEL1	URXISEL0	ADDEN	RIDLE	PERR	FERR	OERR	URXDA	0110	
UxTXREG	—	—	—	—	—	—	—	UTX8	—	—	—	—	Transmit Register				xxxxx	
UxRXREG	—	—	—	—	—	—	—	URX8	—	—	—	—	Receive Register				0000	
UxBRG	—	—	—	—	—	—	—	—	Baud Rate Generator Prescaler									0000
IFS0	—	—	AD1IF	UxTXIF	UxRXIF	SPI1IF	SPF1IF	T3IF	T2IF	OC2IF	IC2IF	—	T1IF	OC1IF	IC1IF	INT0IF	0000	
IFS4	—	—	—	—	—	—	—	—	—	—	—	—	CRC1F	U2ERIF	UxERIF	—	0000	
IEC0	—	—	AD1IE	UxTXIE	UxRXIE	SPI1IE	SPF1IE	T3IE	T2IE	OC2IE	IC2IE	—	T1IE	OC1IE	IC1IE	INT0IE	0000	
IEC4	—	—	—	—	—	—	—	—	—	—	—	—	CRC1E	U2ERIE	UxERIE	—	0000	
IPC2	—	UxRXIP2	UxRXIP1	UxRXIP0	—	SPI1IP2	SPI1IP1	SPI1IP0	—	SPF1IP2	SPF1IP1	SPF1IP0	—	T3IP2	T3IP1	T3IP0	4444	
IPC3	—	—	—	—	—	—	—	—	—	AD1IP2	AD1IP1	AD1IP0	—	UxTXIP2	UxTXIP1	UxTXIP0	0044	
IPC16	—	CRCIP2	CRCIP1	CRCIP0	—	U2ERIP2	U2ERIP1	U2ERIP0	—	UxERIP2	UxERIP1	UxERIP0	—	—	—	—	4440	

Note 1: The registers associated with UARTx are shown for reference. See the device data sheet for the registers associated with other UART modules.

2: This feature is available only for the 16x BRG mode (BRGH = '0').

3: The alternate UART I/O pins are not available on all devices. See specific device data sheets for details.

21.15 ELECTRICAL SPECIFICATIONS

21.15.1 Timing Diagrams

Figure 21-24: Baud Rate Generator Output Timing

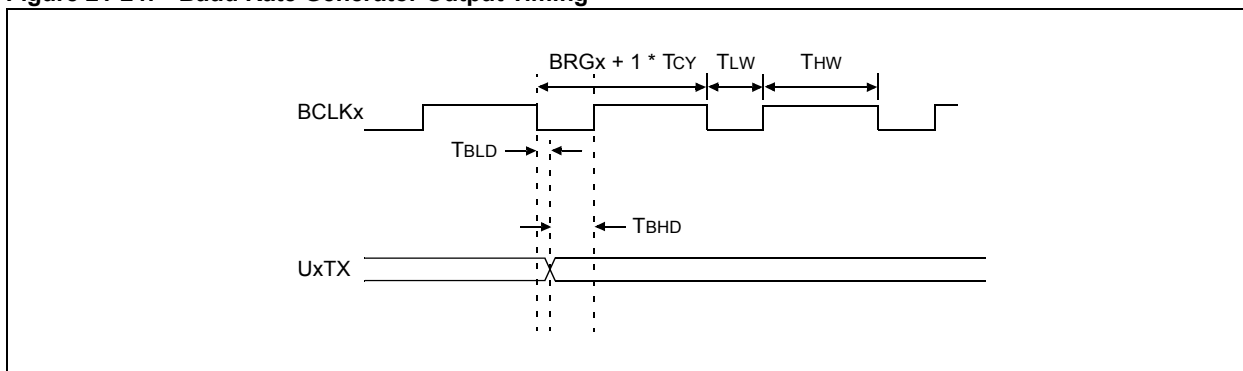


Figure 21-25: Start Bit Edge Detection

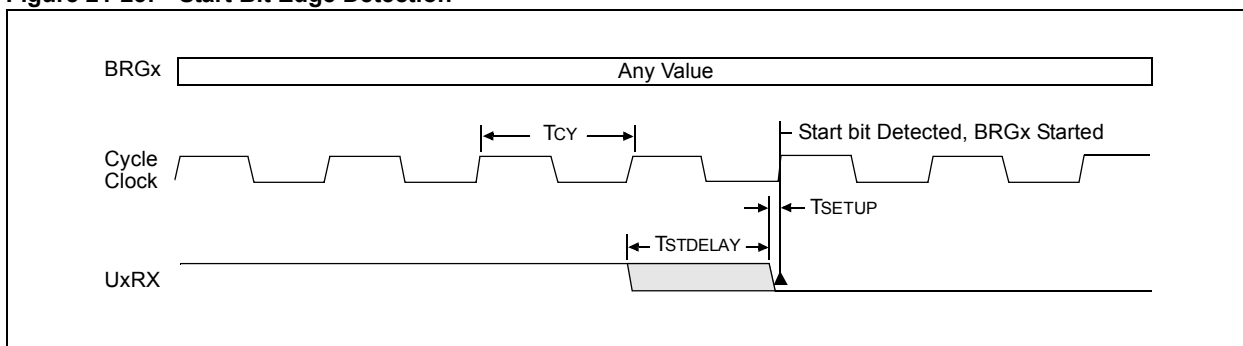


Table 21-5: AC Specifications

Symbol	Characteristics	Min	Typ	Max	Units
TLW	BCLKx High Time	20	$T_{CY}/2$	—	ns
THW	BCLKx Low Time	20	$(T_{CY} * BRGx) + T_{CY}/2$	—	ns
TBLD	BCLKx Falling Edge Delay from UxTX	-50	—	50	ns
TBHD	BCLKx Rising Edge Delay from UxTX	$T_{CY}/2 - 50$	—	$T_{CY}/2 + 50$	ns
TWAK	Min. Low on UxRX Line to Cause Wake-up	—	1	—	μ s
TCTS	Min. Low on \overline{UxCTS} Line to Start Transmission	T_{CY}	—	—	ns
TSETUP	Start bit Falling Edge to System Clock Rising Edge Setup Time	3	—	—	ns
TSTDELAY	Maximum Delay in the Detection of the Start bit Falling Edge	—	—	$T_{CY} + TSETUP$	ns

21.16 DESIGN TIPS

Question 1: *The data I transmit with the UART does not get received correctly. What could cause this?*

Answer: The most common reason for reception errors is that an incorrect value has been calculated for the UART Baud Rate Generator. Ensure the value written to the UxBRG register is correct.

Question 2: *I am getting framing errors even though the signal on the UART receive pin looks correct. What are the possible causes?*

Answer: Ensure the following control bits have been set up correctly:

- UxBRG: UART Baud Rate register
- PDSEL<1:0>: Parity and Data Size Selection bits
- STSEL: Stop bit Selection

21.17 RELATED APPLICATION NOTES

This section lists application notes that are related to this section of the manual. These application notes may not be written specifically for the PIC24F device family, but the concepts are pertinent and could be used with modification and possible limitations. The current application notes related to the UART module are:

Title

Application Note #

No related application notes at this time.

Note: Please visit the Microchip web site (www.microchip.com) for additional application notes and code examples for the PIC24F family of devices.

21.18 REVISION HISTORY

Revision A (April 2006)

This is the initial released revision of this document.

Revision B (September 2007)

Modified Register 21-1 and Register 21-2, the UARTx Mode and the UARTx Status and Control; Table 21-1 and Table 21-2, UART Baud Rates; **Section 21.5 “UART Transmitter”** and **Section 21.13 “Infrared Support”**.