CprE 288 – Introduction to Embedded Systems (UART Interface Overview)

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Announcement

- HW 4, Due Wed 6/13
- **Quiz 4 (15 min):** Monday 6/11 at beginning of class: in Canvas (**your one-side of 1 page of notes will be collected for Class Participation**)
  - Textbook reading:
    - Chapter 7.5: pages 446-479
    - TBA
- **Exam 1: Wed, June 6**
- **Exam 2: Friday, June 22**
- Lab 6: ADC (Analog to Digital Converter)
  - Textbook: Chapter 7.5: pages 446-479 (~35 pages, but quite a bit of redundancy)

Overview of the Lecture

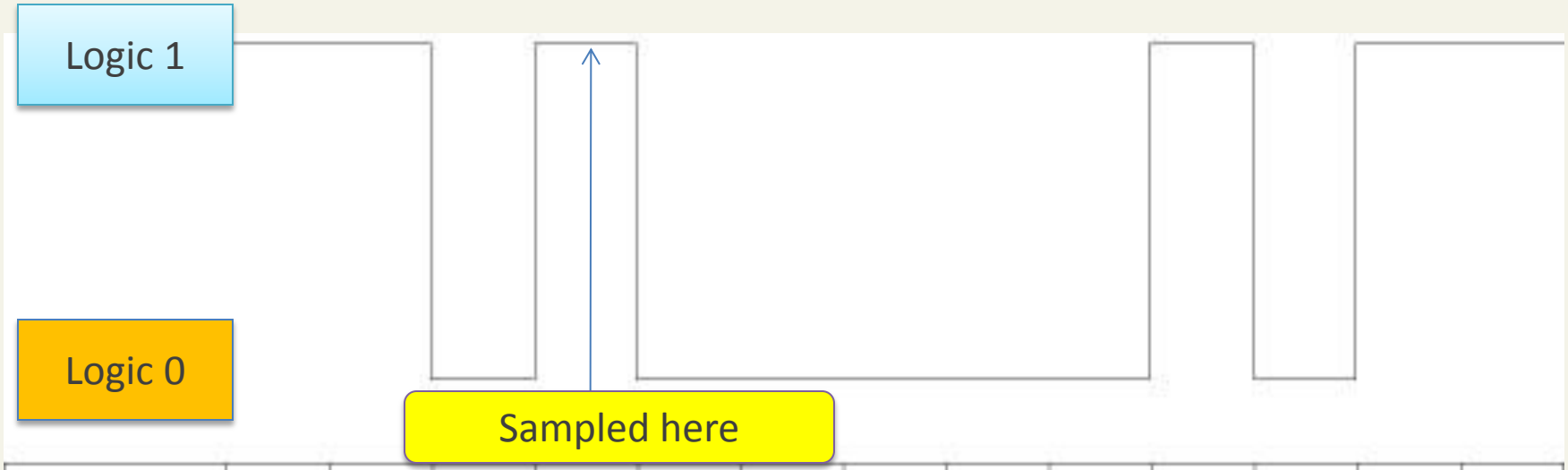
- Concepts behind Serial Communication
- TM4C123g UART Programming Interface
  - Textbook reading:
    - Section 8.5
- Initializing UART, transmitting and receiving data

Serial Communication

- USART = Universal Synchronous & Asynchronous Serial Receiver & Transmitter
- Asynchronous (no common clock)
- Can transmit over long link distances
- Uses *start* and *stop* to sandwich data bits
- *parity bit* can be used for error detection

- (on right) RS-232 Serial Cable

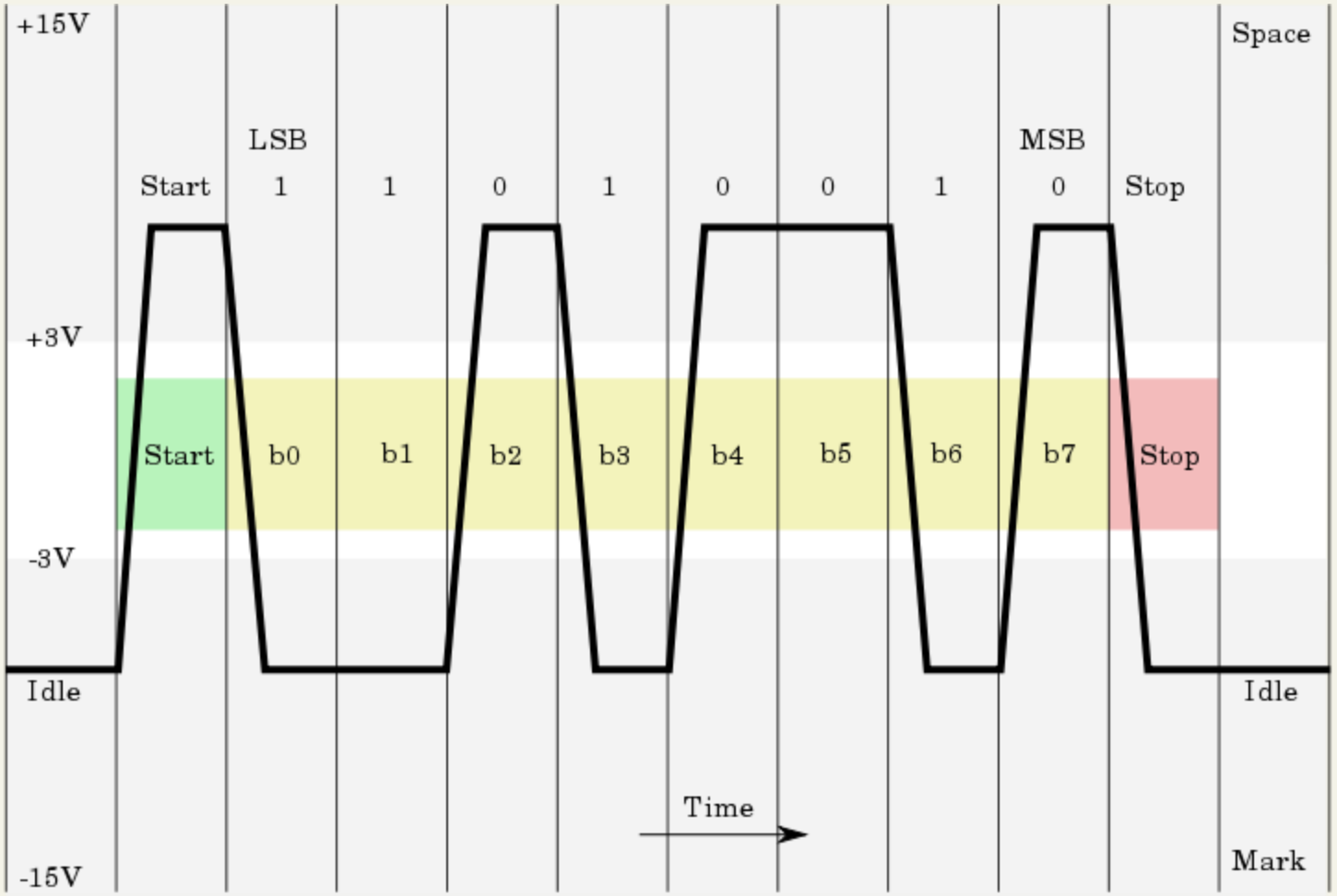
Serial Byte Format



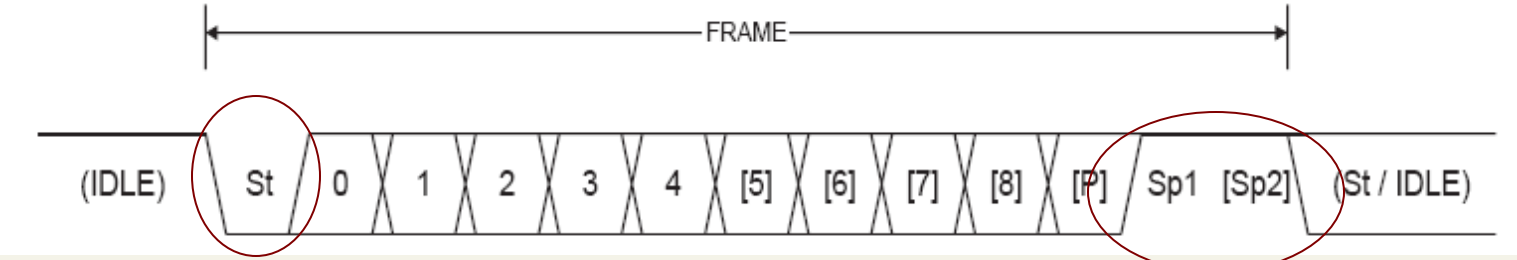
State	Idle	Idle	Active	Active	Active	Active	Active	Active	Active	Active	Active	Active	Idle
Logic Level	1	1	0	1	0	0	0	0	0	1	0	1	1
Bit Type			Start	Data	Data	Data	Data	Data	Data	Data	Data	Stop	
Data Bit Number				0	1	2	3	4	5	6	7		

Example: Sending byte value 01000001

Serial Communication



Start and Stop Bits

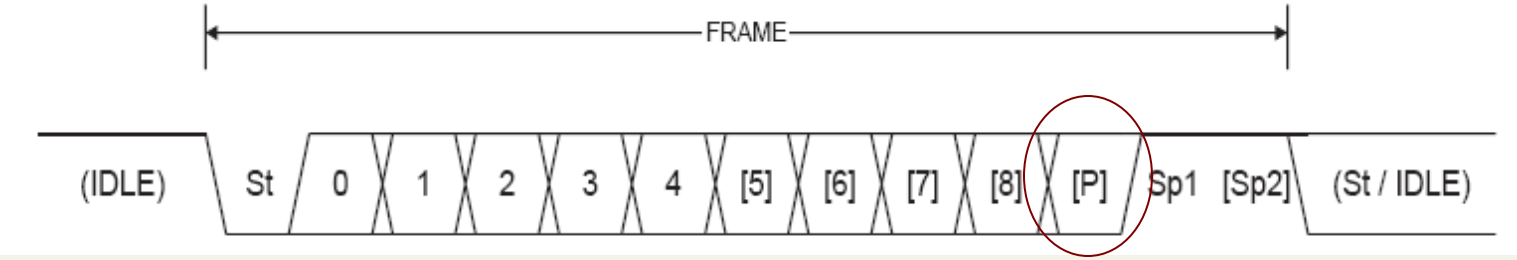


Idle period: logic high

Start bit: **logic low**, 1 bit

Stop bit: **logic high**, 1 bit or 2 bits

Parity Bit



Three choices: **even, odd, or none**

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

*If **one bit** is flipped, how to detect it?*

Baud Rate

How to define communication speed?

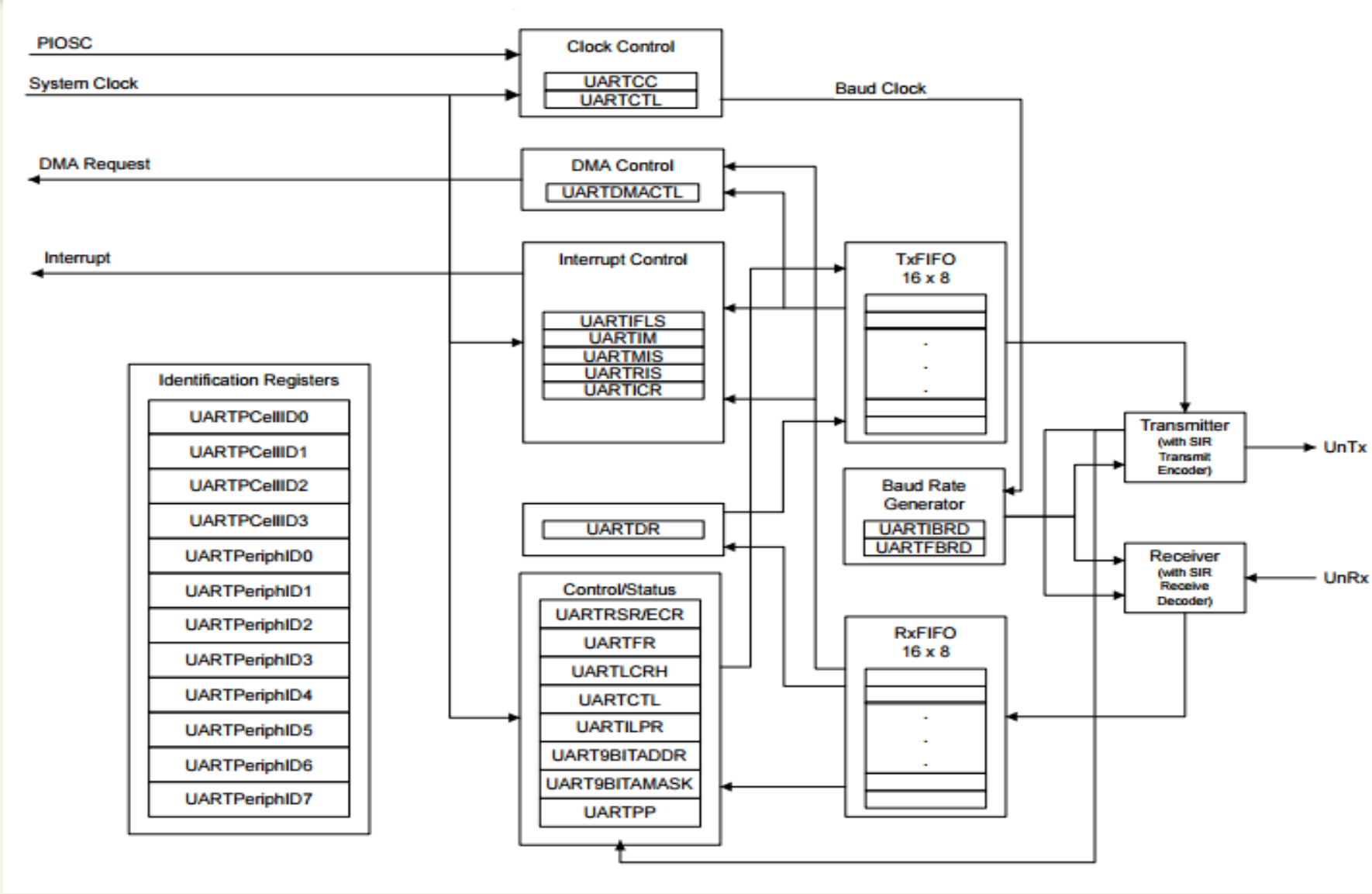
Baud rate: Number of symbols transferred per second

- Same as bit rate (bps) for USART

Baud rate is **not** data rate

With 56,000 bps, 8-data bit frame, two stop bits and parity bit used, what is the maximum data rate?

Diagram of UART Module (pg 644 in book)



Programming USART

Both sides of communication should use the same **frame format** and **baud rate**

Frame format:

- Number of **data** bits in the frame: 5, 6, 7, 8 or 9
- Number of stop bits: 1 or 2
- Parity bit: Odd, Even, or None

USART Programming Interface

Control and Status Registers:

UARTCTL, UARTCC, UARTLCRH, UARTFR

- 32-bit registers for control and status checking
- *n is 0 to 7*, e.g. is UART0_CTL_R for USART0
- There are eight USART units; UART4 used for communication with iRobot Create and UART1 will be used in lab

Baud Rate Registers:

UARTIBRD, UARTFBRD

- Two 32-bit registers used together to set baud rate

32-bit Register for reading and writing data:

UARTDR

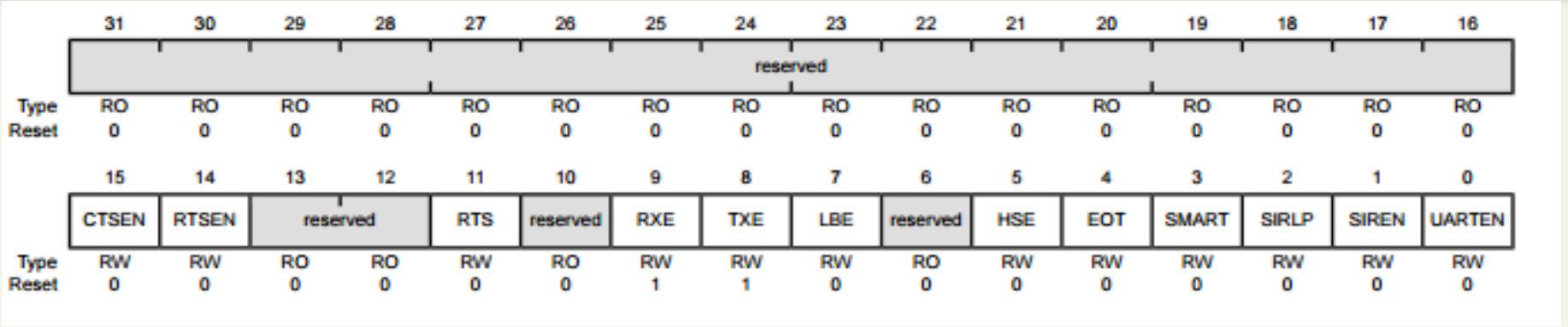
Page Numbers

- Trying to set Control Registers?
  - Review **pages 643 and 651 to 658** of the book
- Setting the baud rate registers?
  - See **section 8.5.3.7 on page 650** of the book
- Need code examples for reading / writing data?
  - **Figure 5.73 on Page 662** (explained on page 663) of the book
  - Also reproduced on upcoming slides

Serial (Tiva Launchpad)

- This time will be spent reviewing the individual bit positions inside of **UARTCTL, UARTCC, UARTLCRH, UARTFR** from **pages 643 and 651 to 658** of the book

UARTCTL: Control Register

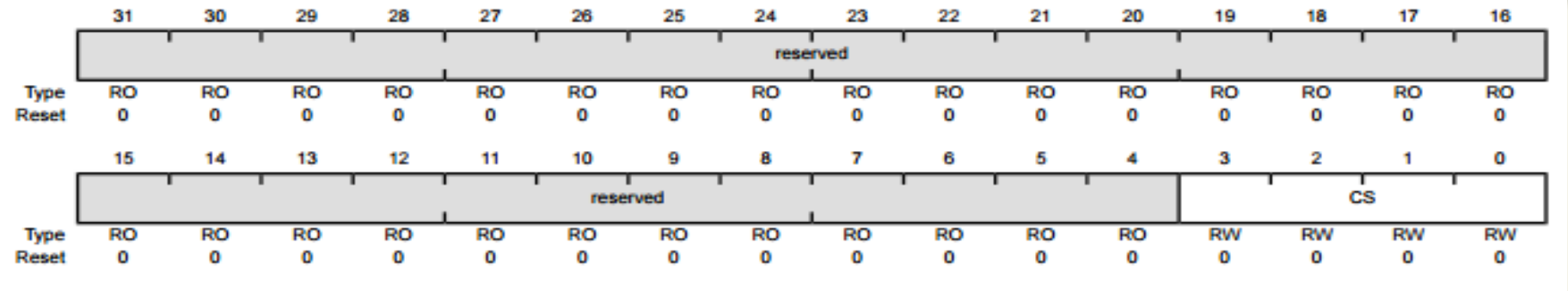


	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
	reserved															
Type	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO
Reset	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
	CTSEN	RTSEN	reserved		RTS	reserved	RXE	TXE	LBE	reserved	HSE	EOT	SMART	SIRLP	SIREN	UARTEN
Type	RW	RW	RO	RO	RW	RO	RW	RW	RW	RO	RW	RW	RW	RW	RW	RW
Reset	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0

15 CTSEN – Enable clear to send
14 RTSEN – Enable request to send
11 RTS – Request to send
9 RXE – UART receive enable
8 TXE – UART transmit enable
7 LBE – UART loop back enable
5 HSE – High-Speed enable
4 EOT – End of transmission
3 SMART – Smart card support
2 SIRLP – UART SIR low-power mode
1 SIREN – UART SIR enable
0 UARTEN – UART enable
31:16, 13:12, 10, 6 Reserved – Read only

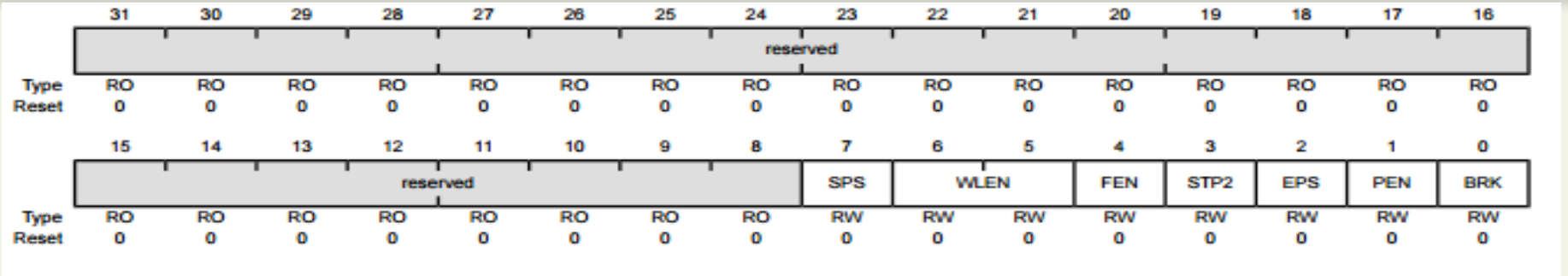
UARTCC: Control Register



3:0 UART - baud clock source

31:4 Reserved

UARTLCRH: Control Register



	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
	reserved															
Type	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO
Reset	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
	reserved								SPS	WLEN		FEN	STP2	EPS	PEN	BRK
Type	RO	RO	RO	RO	RO	RO	RO	RO	RW	RW	RW	RW	RW	RW	RW	RW
Reset	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

7 SPS – UART stick parity select

6:5 WLEN – UART word length

4 FEN – UART enable FIFOs

3 STP2 – UART two stop bits select

2 EPS – UART even parity select

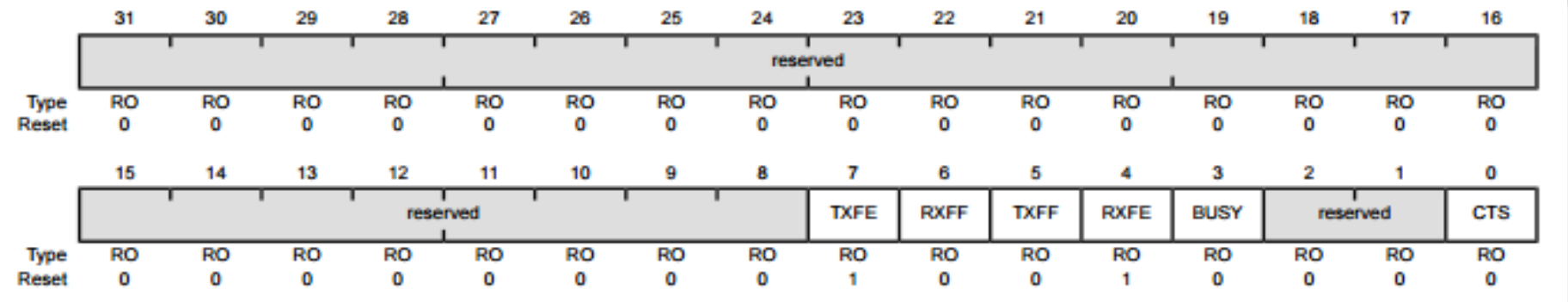
1 PEN – UART parity enable

0 BRK – UART send break

31:8 Reserved

Everything else will default to 1 stop bit, no parity, no FIFO

UARTFR: Status Register



	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
	reserved															
Type	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO
Reset	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
	reserved								TXFE	RXFF	TXFF	RXFE	BUSY	reserved		CTS
Type	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO
Reset	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0

7 TXFE – UART transmit FIFO empty

6 RXFF – UART receive FIFO full

5 TXFF – UART transmit FIFO full

4 RXFE – UART receive FIFO empty

3 BUSY – UART busy

0 CTS – Clear to send

31:8, 2:1 Reserved

Serial (TM4C123g)

- Baud rate
  - 1 *baud* = 1 *symbol per second*
  - In our case, 8 data bits are book ended by start and stop bits

- **Baud rate** is different from **data rate**
  - Baud rate includes overhead of start/stop/parity bits

Calculating Baud

- Two 32 bit registers UARTIBRD and UARTFBRD
- BRDI = integer portion, BRDF = fractional portion
- Baud Rate = UARTSysClk/((BRD) * ClkDiv)
  - UARTSysClk = 16Mhz
  - ClkDiv = 16 with HSE bit = 0 (8 with HSE bit = 1)
  - Baud Rate used in lab = 115200
- BRDI = (int)(BRD)
- BRDF = (int)(fraction of BRD)*64 +.5)

Example BRDI and BRDF

- Set a baud rate of 9600 bps for 16Mhz SysClk, HSE = 0
- BRD = 16,000,000 / (16 * 9600) = 104.16666
- BRDI = 104
- BRDF = .1666*64+.5 = 11.16666 = 11

Initialization part 1: GPIO (mostly)

```
//Initialize USART1 to a given baud rate
void uart_init(void) {
      //enable clock to GPIO, R1 = port B
   SYSCTL_RCGCGPIO_R |= SYSCTL_RCGCGPIO_R1;

   //enable clock to UART1, R1 = UART1. ***Must be done before setting Rx and Tx (See DataSheet)
   SYSCTL_RCGCUART_R |= SYSCTL_RCGCUART_R1;

   //enable alternate functions on port b pins 0 and 1
   GPIO_PORTB_AFSEL_R |= (BIT0 | BIT1);

   //enable Rx and Tx on port B on pins 0 and 1
   GPIO_PORTB_PCTL_R |= 0x00000011;

   //set pin 0 and 1 to digital
   GPIO_PORTB_DEN_R |= (BIT0 | BIT1);

   //set pin 0 to Rx or input
   GPIO_PORTB_DIR_R &= ~BIT0;

   //set pin 1 to Tx or output
   GPIO_PORTB_DIR_R |= BIT1;

       //continued on next slide
```

Initialization part 2: UART

```
    //calculate baudrate
    uint16_t iBRD = //use equations
  uint16_t fBRD =  //use equations
    //turn off uart1 while we set it up
    UART1_CTL_R &= ~(UART_CTL_UARTEN);
    //set baud rate
    UART1_IBRD_R = iBRD;
    UART1_FBRD_R = fBRD;
    //set frame, 8 data bits, 1 stop bit, no parity, no FIFO
    UART1_LCRH_R = UART_LCRH_WLEN_8 ;
    //use system clock as source
    UART1_CC_R = UART_CC_CS_SYSCLK;
   //re-enable enable RX, TX, and uart1
    UART1_CTL_R = (UART_CTL_RXE | UART_CTL_TXE | UART_CTL_UARTEN);

}//END of uart_init()
```

Transmitting

```
//Blocking call that sends 1 char over UART 1
void uart_sendChar(char data)
{
  //wait until there is room to send data
  while(UART1_FR_R & 0x20)
  {
  }

  //send data
  UART1_DR_R = data;
}
```

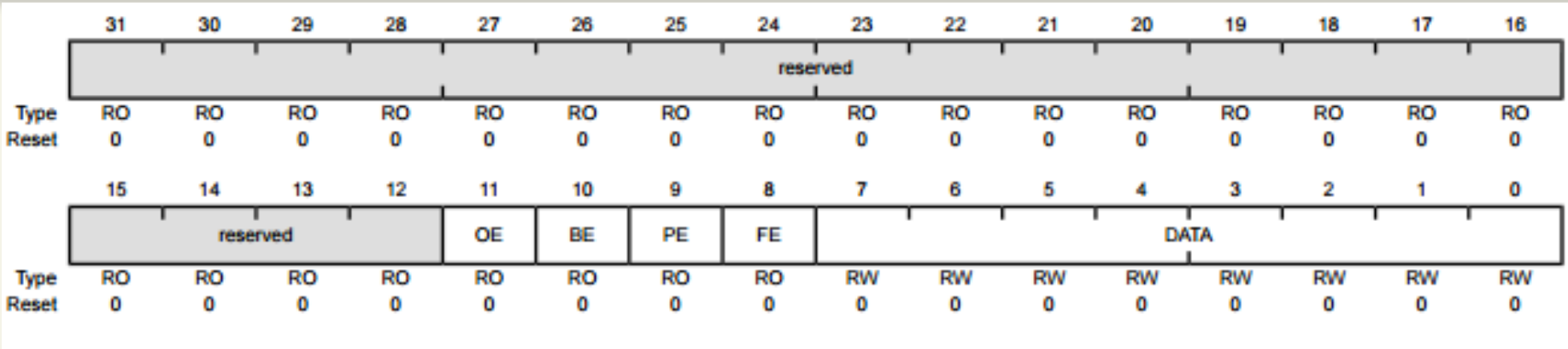
Receiving

```
//Blocking call to receive over uart1
//returns char with data
char uart_receive(void){
    char data = 0;

   //wait to receive
  while(UART1_FR_R & UART_FR_RXFE)
  {
  }
     //mask the 4 error bits and grab only 8 data bits
     data = (char)(UART1_DR_R & 0xFF);

   return data;
}
```

UARTDR Warning!



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	reserved															
Type	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO
Reset	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
	reserved				OE	BE	PE	FE	DATA							
Type	RO	RO	RO	RO	RO	RO	RO	RO	RW	RW	RW	RW	RW	RW	RW	RW
Reset	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

- UARTDR is a 32 bit register that uses 12 bits
- 4 error bits and 8 data bits
  - OE and BE deal with FIFO operations
  - PE is Parity Error
  - FE is Framing Error

UART Interrupts part 1: Initialize

```
 //turn off uart1 while we set it up
UART1_CTL_R &= ~(UART_CTL_UARTEN);

//clear interrupt flags
UART1_ICR_R = (UART_ICR_TXIC | UART_ICR_RXIC);

//enable send and receive raw interrupts
UART1_IM_R |= UART_IM_TXIM | UART_IM_RXIM;

//set priority of usart1 interrupt to 1. group 1 bits 21-23
NVIC_PRI1_R |= 0x00200000;

//enable interrupt for IRQ 6 set bit 6
NVIC_EN0_R |= 0x00000040;

//tell cpu to use ISR handler for uart1
IntRegister(INT_UART1, UART1_Handler);

//enable global interrupts
IntMasterEnable();

//re-enable enable RX, TX, and uart1
UART1_CTL_R = (UART_CTL_RXE | UART_CTL_TXE | UART_CTL_UARTEN);
```

UART Interrupts part 2: Interrupt Handler

```
//Interrupt handler for uart1
void UART1_Handler(void){

    //received a byte
    if(UART1_MIS_R & UART_MIS_RXMIS){

    //do something

    UART1_ICR_R |= UART_ICR_RXIC; //clear interrupt

    }
    //sent a byte
    else if(UART1_MIS_R & UART_MIS_TXMIS){

    //Do something

    UART1_ICR_R |= UART_ICR_TXIC; //clear interrupt
    }
}
```

Lab 5

- Part I. Receive and Display Text
  - Check frame format and baud rate
  - Optional: Use interrupt
- Part II. Provide Character Echo
  - Send back received characters
- Part III. Push Button Response
  - Send back special messages when a push button is pressed
  - Part II should still work
- Part IV. WiFi (115200 baud)
  - Perform UART communication on top of WiFi