



Lab 6: UART Communications

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Lab 6: UART Communications

Lab 6

- ◆ In this lab, you will design a circuit to perform UART I/O. Your circuit will do the following things:
 - Read two **unsigned** 16-bit decimal numbers from the UART port connected to a PC terminal window. The numbers range from 0 to 65535.
 - Compute the **integer** division of these two numbers, and print the quotient to the UART terminal in hexadecimal format
- ◆ The lab file submission deadline is on 11/18 by 6:00pm.

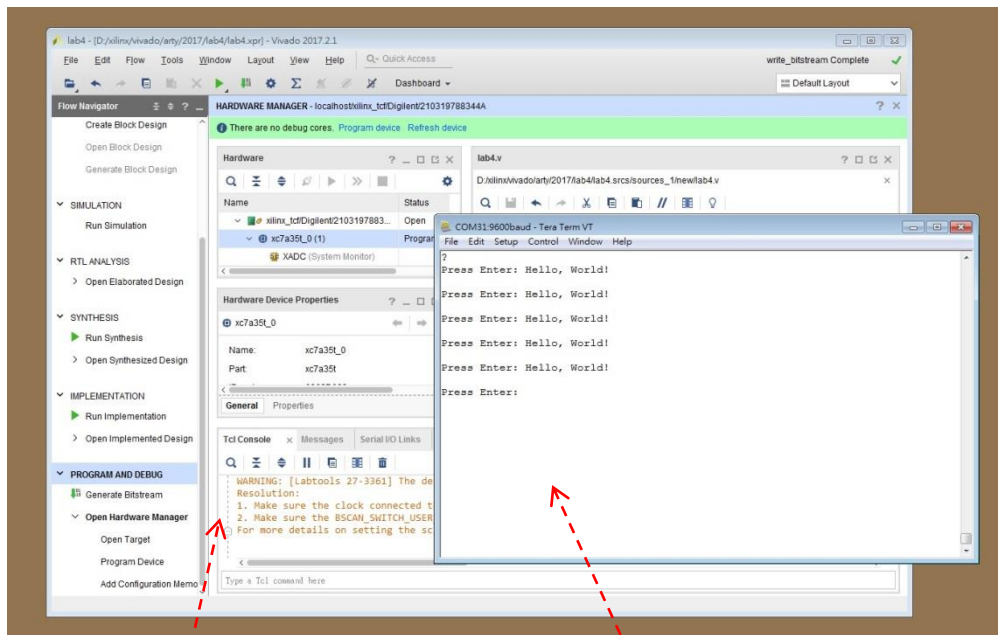
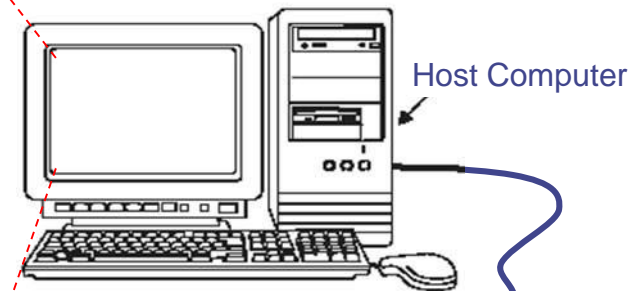
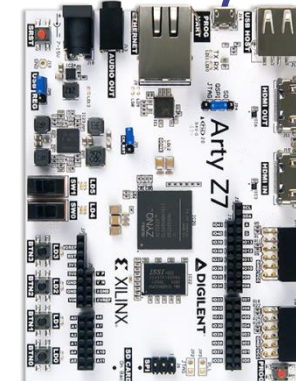




Setup of Lab 6

Lab 6

- Lab 6 tests the communications between the PC and the FPGA through the UART devices (i.e., RS-232):

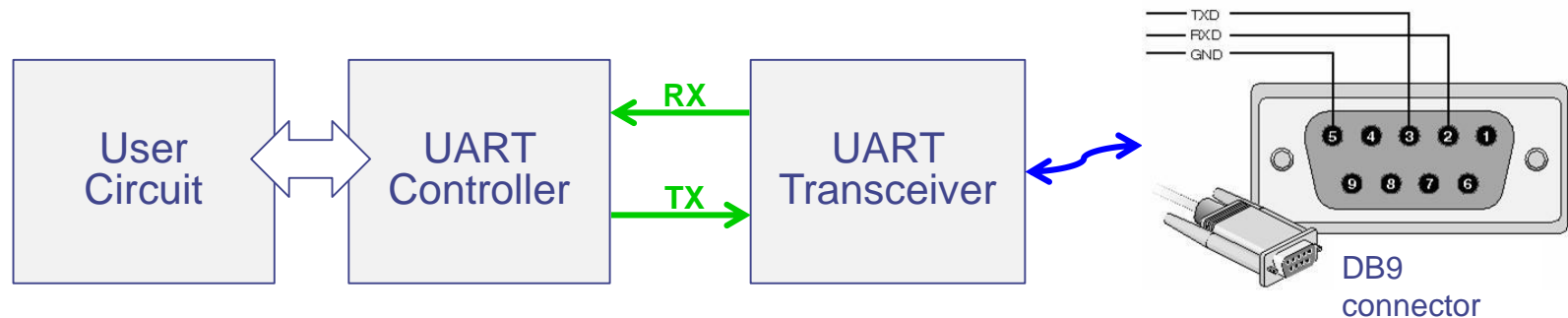
Vivado
IDETera Term terminal
emulation programCombined
RS-232 (UART)
and JTAG cable



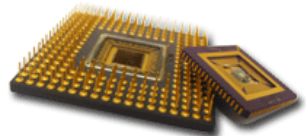
Traditional UART Devices

Lab 6

- ◆ Universal Asynchronous Receiver/Transmitter (UART) is one of the most popular I/O devices in small systems



- ◆ In simple systems, the UART transceiver can simply be a voltage translator IC

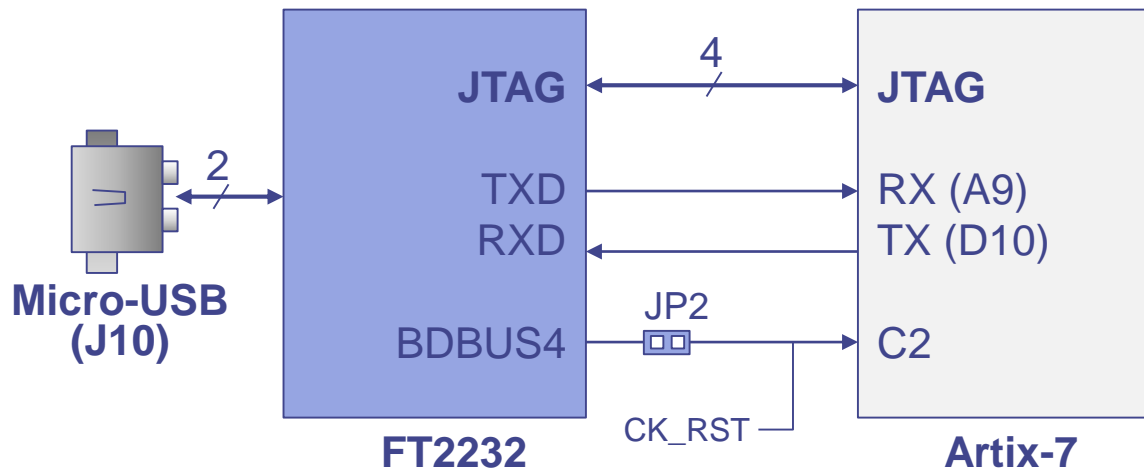




UART Devices on ARTY

Lab 6

- ◆ On Arty, the digital UART signals are converted to the USB data frames through a FTDI FT2232HQ USB-UART bridge IC
 - There is no traditional DB9 connector on ARTY!

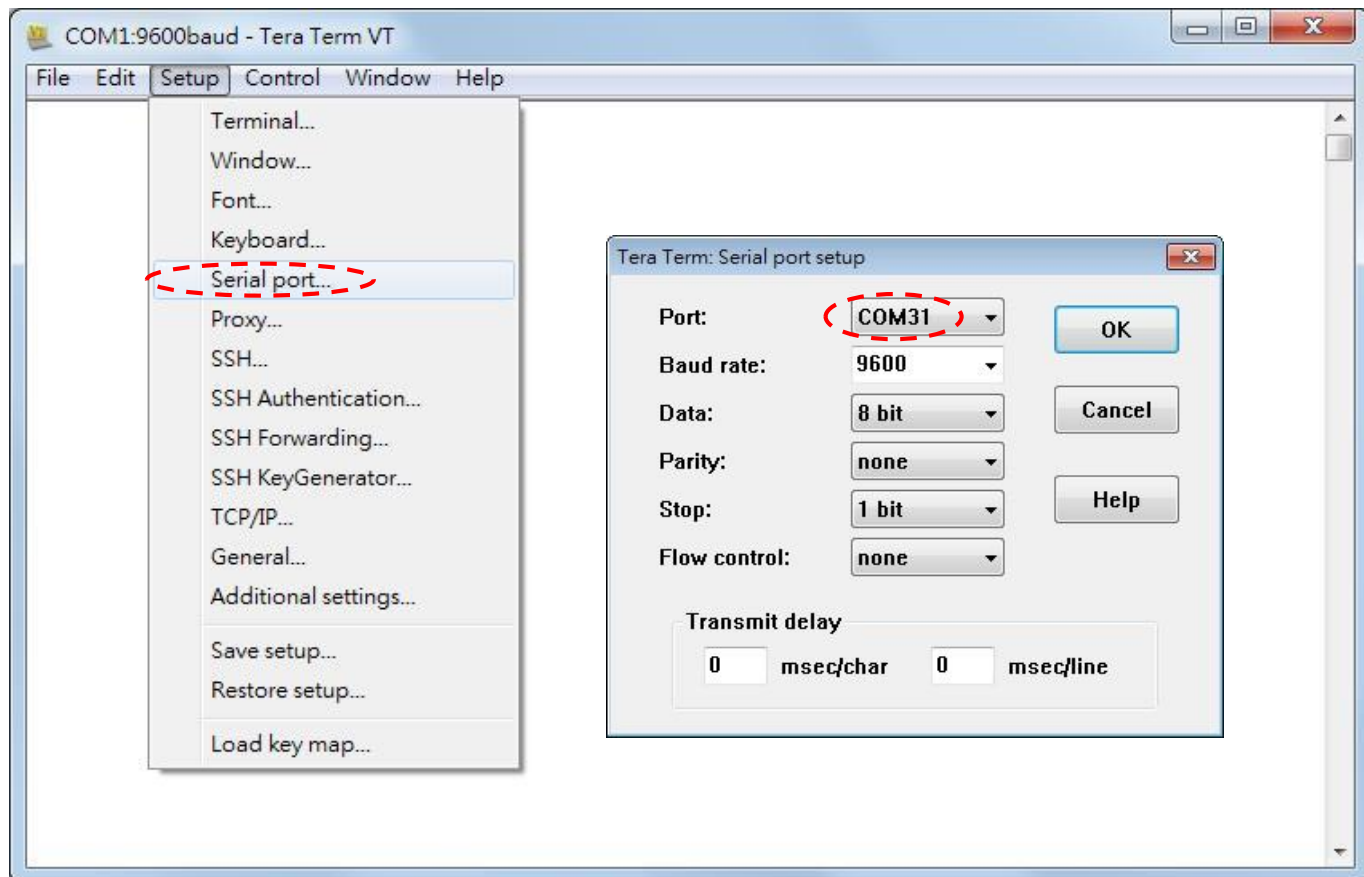




Running TeraTerm on the PC Side

Lab 6

- ◆ On the PC connected to the Arty board, we run TeraTerm to send/receive data through RS-232:

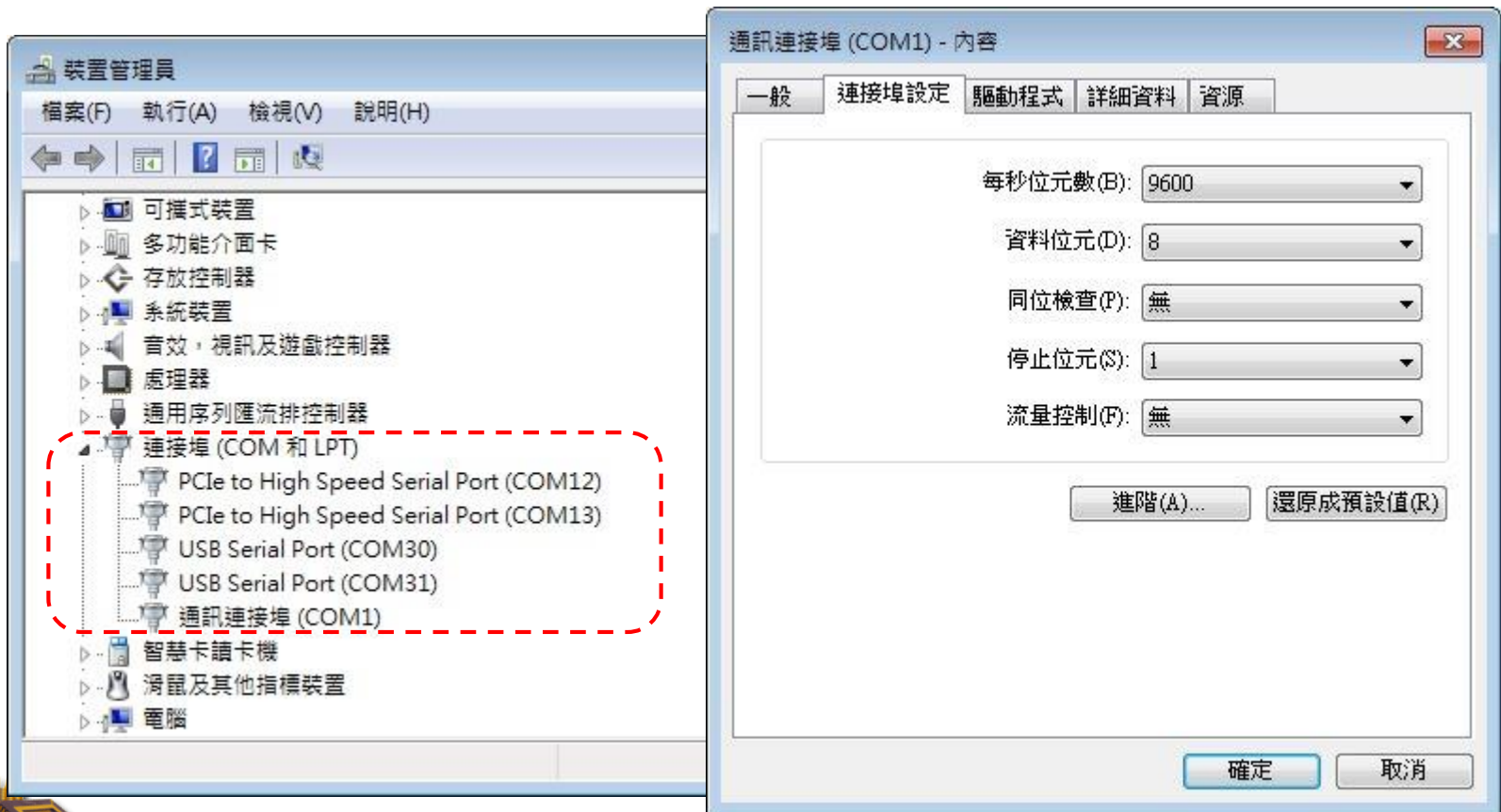




Check COM Port Number

Lab 6

- ◆ The COM port number of your computer can be obtained from the device manager as follows:

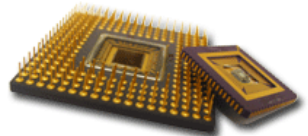




UART Physical Layer

Lab 6

- ◆ UART is a **asynchronous** transmission standard, thus, there is no common clock signal for synchronization
- ◆ The most popular physical layer for the UART transmission line is the RS-232 standard
 - Common baud rates for RS-232 signals range from 4800 bps to 115200 bps
 - RS-232 voltages are $(-15V, -3V)$ for '1' and $(3V, 15V)$ for '0'

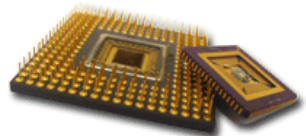




UART Link Layer

Lab 6

- ◆ The serial line is 1 when it is idle
- ◆ The transmission starts with a start bit, which is 0, followed by data bits and an optional parity bit, and ends with stop bits, which are 1
- ◆ The number of data bits can be 6, 7, or 8
- ◆ The optional parity bit is used for error detection
 - For odd parity, it is set to 0 when the data bits have an odd number of 1's
 - For even parity, it is set to 0 when the data bits have an even number of 1's
- ◆ The number of stop bits can be 1, 1.5, or 2

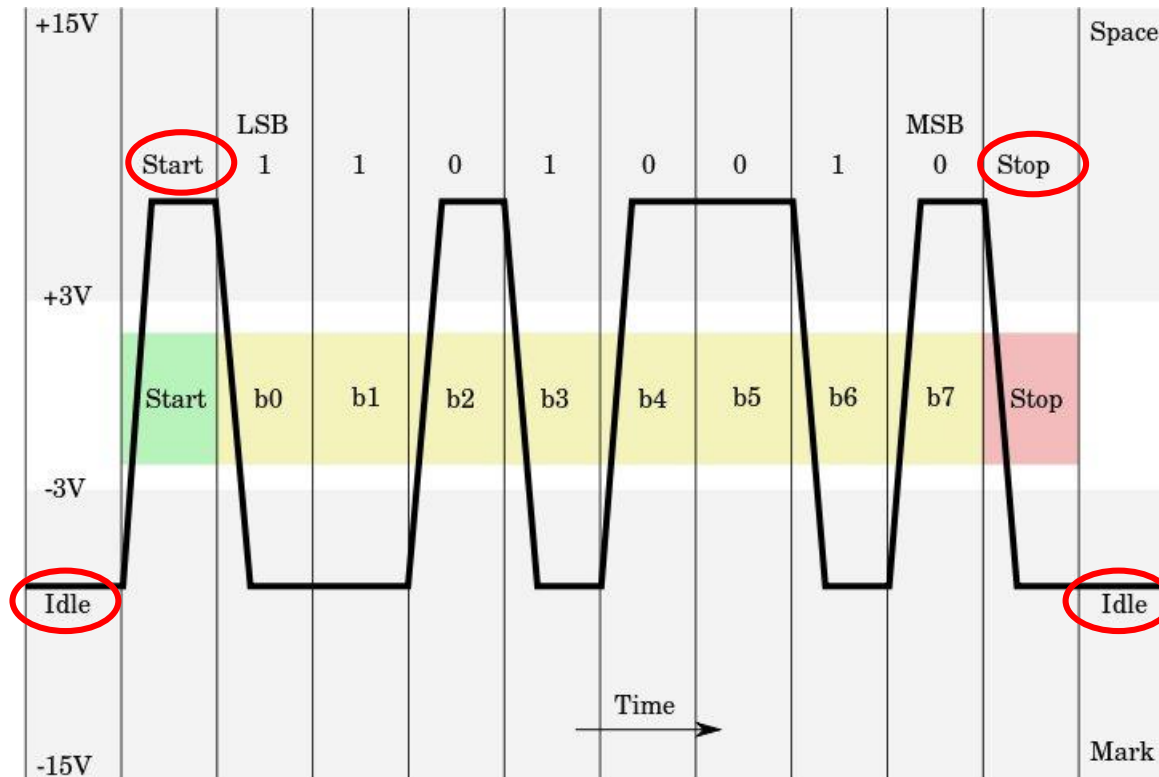




RS-232 Transmission Example

Lab 6

- ◆ An example of the RS-232 transmission signals:





Out-of-Band Parameter Setting

Lab 6

- ◆ UART control parameters such as: bit-rate, #data bits, #stop bits, and types of parity-check must be set on both side of the serial transmission line before the communication begins
- ◆ Implicit clocks must be generated on both sides for correct transmissions
 - Bit rate per second (bps), or baud rate, is used to imply the clock on both end of the transmission line
 - Common baud rates are 4800, 9600, ..., 57600, 115200, etc.
 - This clock is often called the baud rate generator



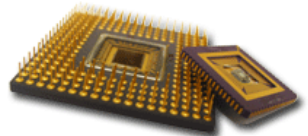


UART Controller

Lab 6

- ◆ A UART controller performs the following tasks
 - Convert 8-bit parallel data to a serial bit stream and vice versa
 - Insert (or remove) start bit, parity bit, and stop bit for every 8 bits of data
 - Maintain a local clock for data transmission at correct rate

- ◆ A UART controller includes a transmitter, a receiver, and a baud rate generator
 - The transmitter is essentially a special shift register that loads data in parallel and then shifts it out bit by bit at a specific rate
 - The receiver, on the other hand, shifts in data bit by bit and then reassembles the data

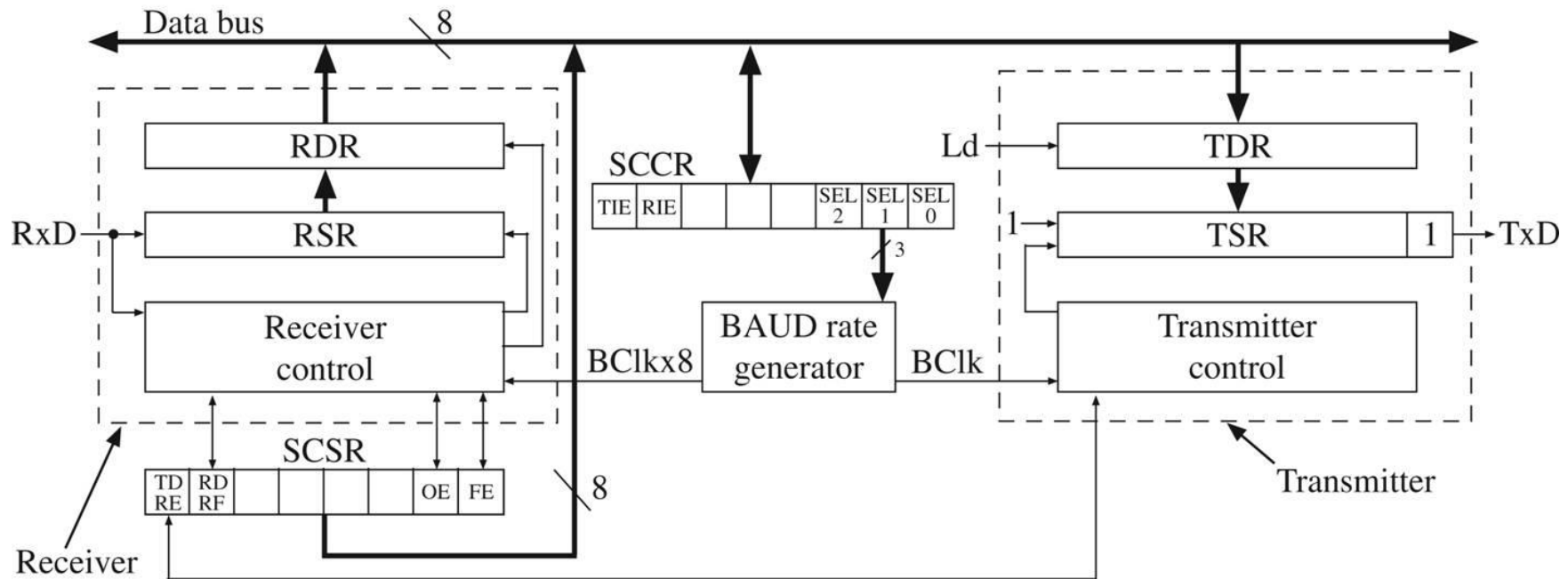




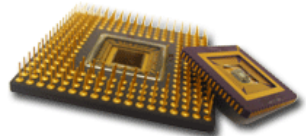
An Example of UART Controller

Lab 6

- ◆ The following diagram shows a typical UART controller:



RSR – Receive shift register
 TSR – Transmit shift register
 RDR – Receive data register
 TDR – Transmit data register
 SCCR – Serial communications control register
 SCSR – Serial communications status register

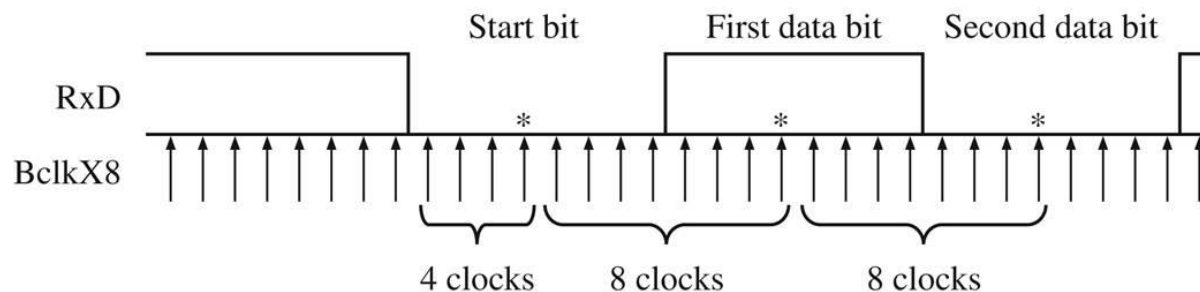




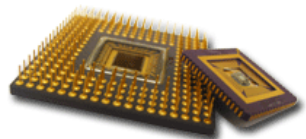
Clock Synchronization Problem

Lab 6

- ◆ Since there is no explicit clock signal between the transmitter and the receiver, the receiver can not simply read incoming bits based on its system clock
- ◆ To solve this problem, we sample the incoming data multiple times per baud rate clock cycle
 - Typical up-sampling rates are 4x, 8x, or 16x sampling
- ◆ Take 8× sampling for example, the fourth sample of each bit time will be read as a data bit



*Read data at these points

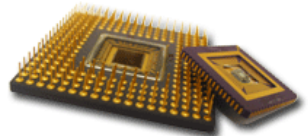




Baud Rate Generator

Lab 6

- ◆ Since the system clock rate is often much higher than the baud rate, we must slow down the system clock to generate a UART clock.
- ◆ For example, if a 16x baud rate clock is used:
 - If baud rate is 9600 bps, $9600 \times 16 = 153600$
 - If the system clock is 100 MHz, the clock divisor should be:
 $100 \text{ M} / 153600 = 651.041 \approx 651$
- ◆ In the UART controller (uart.v) in Lab5, 651 is used as the system clock divisor to generate a baud rate clock @ 153.6 kHz



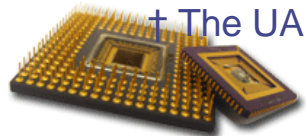


About the Lab 6 Sample Package

Lab 6

- ◆ The package contains a Vivado project files that shows you how to use a circuit to read a decimal number from the user keyboard inputs and then print the number in hexadecimal base through the UART controller
- ◆ The source files are as follows:
 - `lab6.v` → Top-level module, with two FSMs for flow control
 - `uart.v` → An UART controller[†]
 - `lab6.xdc` → the constraint file

[†] The UART controller is based on a controller by Timothy Goddard downloaded from www.opencores.org.

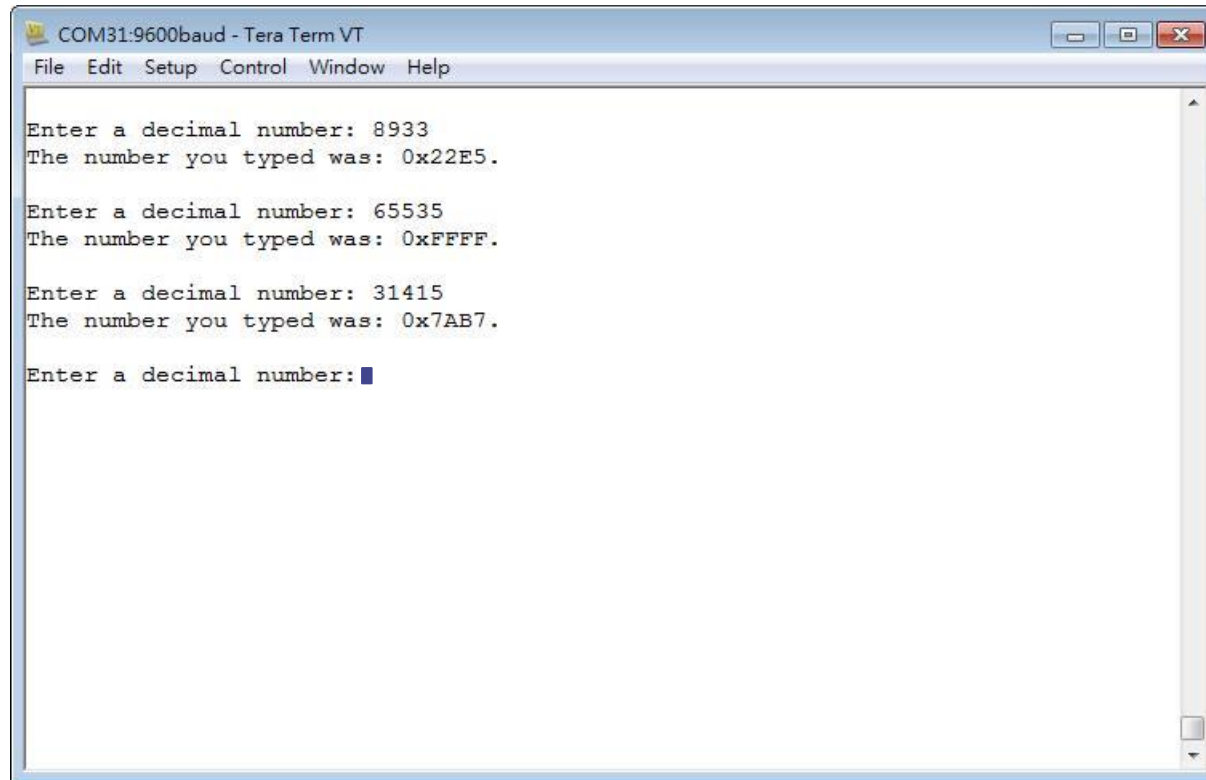




Screen Shot of Lab 6 Sample Code

Lab 6

- ◆ The TeraTerm window prints “Hello, World!” every time an “Enter” key is pressed:



```
COM31:9600baud - Tera Term VT
File Edit Setup Control Window Help

Enter a decimal number: 8933
The number you typed was: 0x22E5.

Enter a decimal number: 65535
The number you typed was: 0xFFFF.

Enter a decimal number: 31415
The number you typed was: 0x7AB7.

Enter a decimal number: █
```

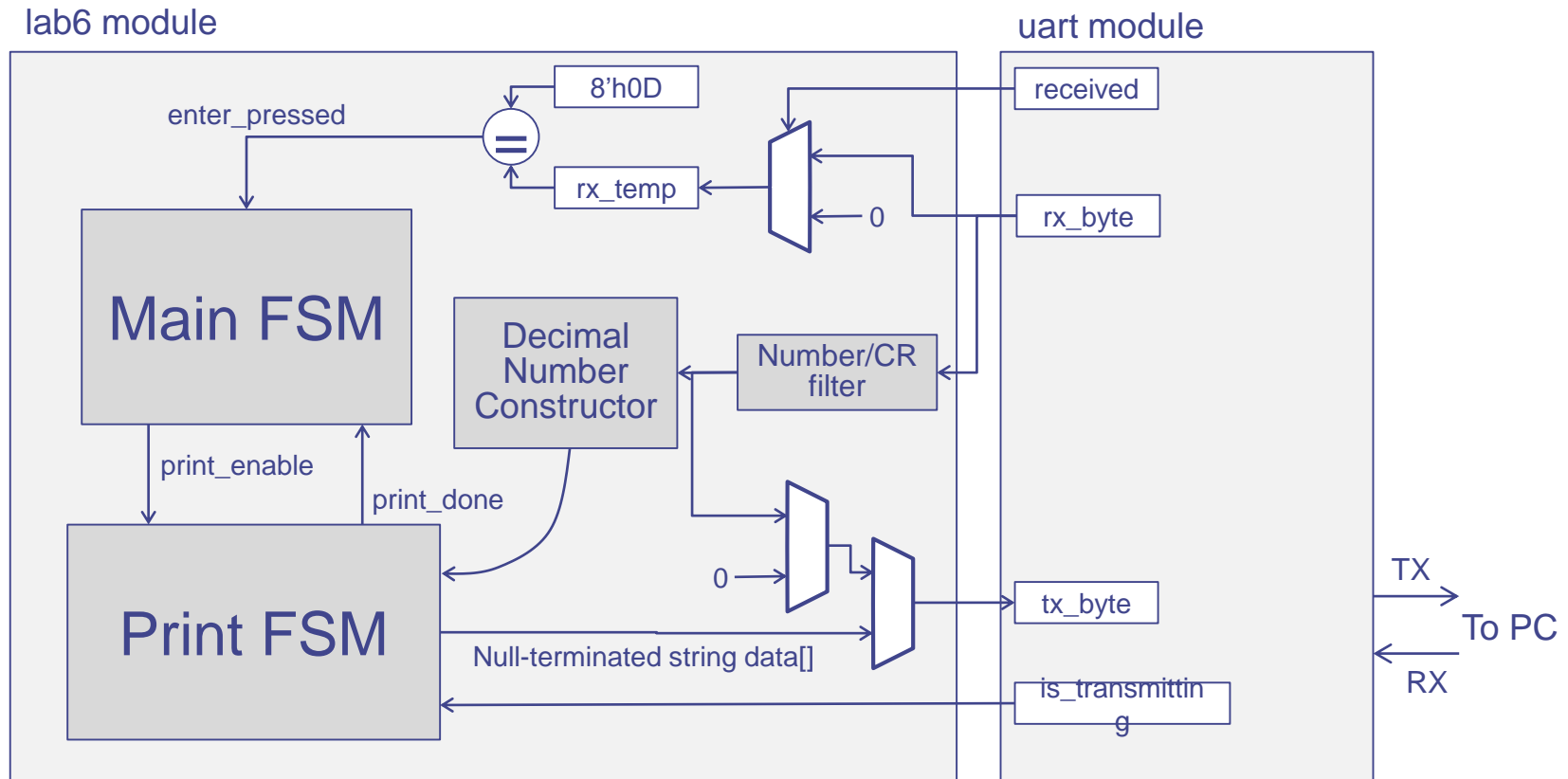




Top-Level Block Diagram of Lab 6

Lab 6

- ◆ The block diagrams of the different circuit blocks in the lab 6 sample code:

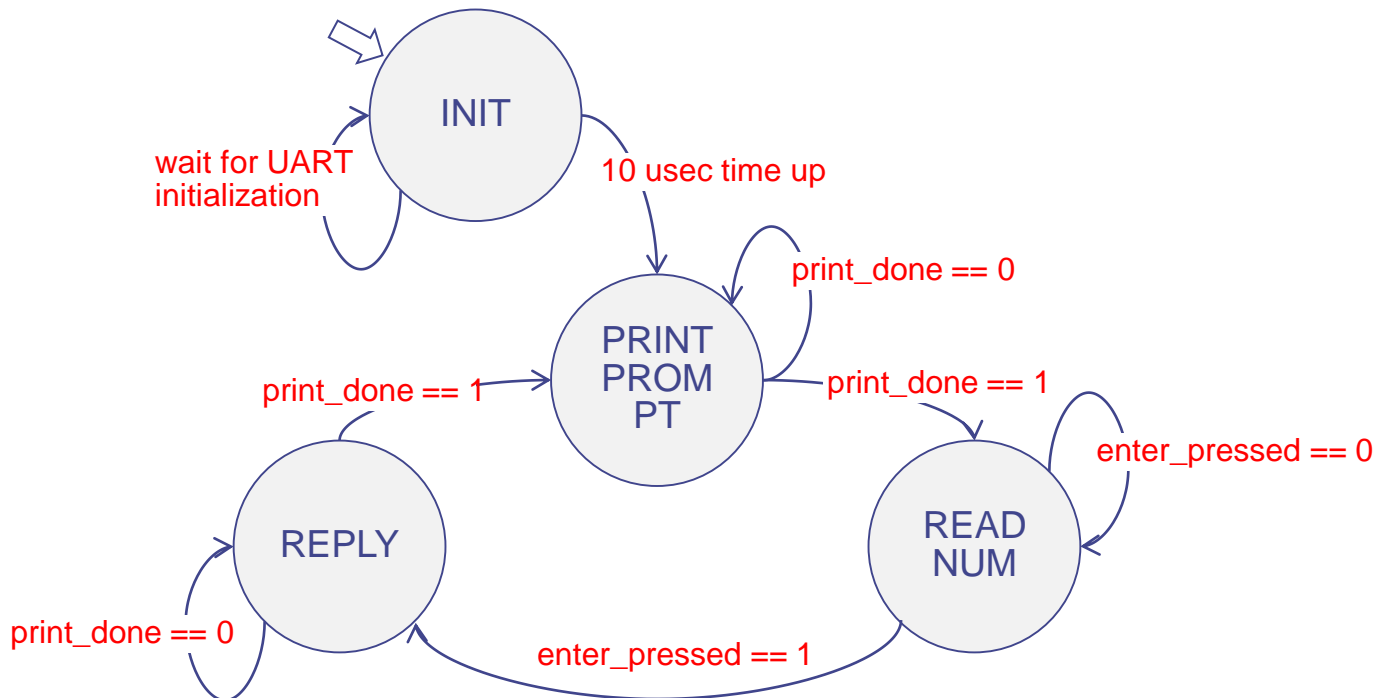




FSMs of the Sample Code

Lab 6

- ◆ There are two FSMs in the sample code
 - The first one controls the main program flow
 - The second one controls the print string function
- ◆ The main FSM is as follows:

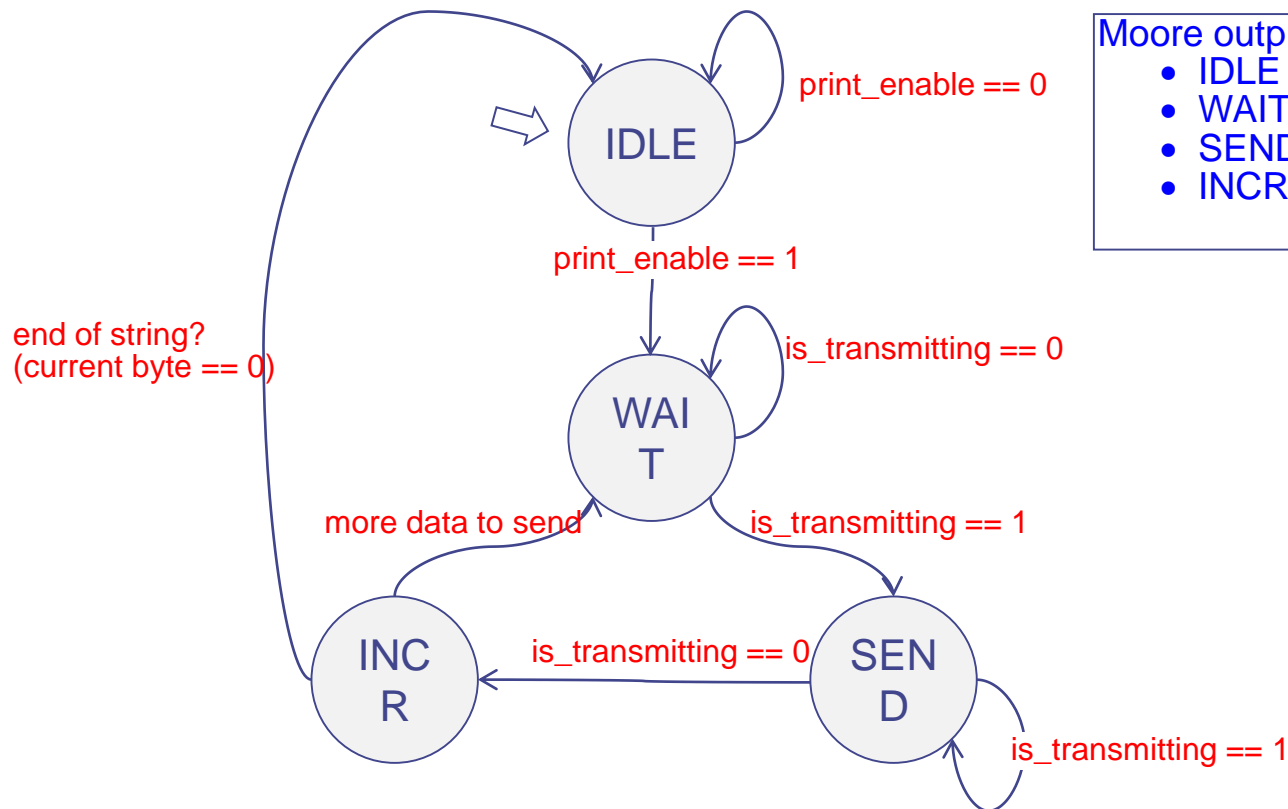




The Print String FSM

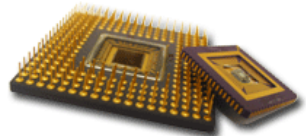
Lab 6

- ◆ We can send data to the UART controller when it is not busy:



Moore output actions:

- IDLE : $\text{transmit} \leftarrow 0$;
- WAIT: $\text{transmit} \leftarrow 1$;
- SEND: $\text{transmit} \leftarrow 0$;
- INCR : $\text{transmit} \leftarrow 0$, $\text{send_counter}++$;





Your Task in Lab 6

Lab 6

- ◆ Design a circuit to read two decimal numbers from the UART terminal, compute the integer quotient, then print it in hexadecimal format to the UART terminal
 - The first input number is the dividend, and the second one is the divisor
- ◆ Your screen outputs may look as follows:

```
Enter the first decimal number: 8976
Enter the second decimal number: 96
The integer quotient is: 0x005D

Enter the first decimal number: _
```





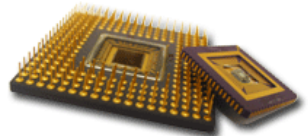
About Division Circuit

Lab 6

- ◆ The simplest way to compute 16-bit unsigned integer divisions is Successive Subtraction:
 - Too slow to use! DO NOT use this method!

```
// Division of A/B
// Q: quotient
// R: remainder

Q ← 0, R ← 0;
while (A ≥ B)
    A ← A - B;
    Q++;
end
R ← A;
```



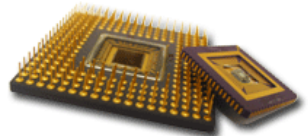


Long Division

Lab 6

- ◆ A more efficient way is to use a shift-and-subtraction algorithm
 - Much more efficient than successive subtraction
 - Need a shift register

```
// A is an N-bit number,  
// B is an M-bit number, compute A / B  
  
Q = 0, R = 0;  
for (i = N-1; i ≥ 0; i--) {  
    R = R << 1; // left-shift R by 1 bit  
    R(0) = A(i); // R(0) is 0th bit of R,  
                // A(i) is i-th bit of A  
  
    if (R ≥ B) {  
        R = R - B;  
        Q(i) = 1;  
    }  
}
```





Requirements for Lab 6

Lab 6

- ◆ There is one requirement for lab 6:
 1. You must use long division to implement your division circuit

