

Microprocessors B (17.384)

Spring 2011

Lecture Outline

Class # 06

March 01, 2011

Dohn Bowden

Today's Lecture

- **Administrative**
- **Microcontroller Hardware and/or Interface**
- **Programming/Software**
- **Lab**
- **Homework**

Course Admin

Administrative

- Admin for tonight ...
 - Syllabus Highlights
 - Lab #2 is due March 22nd
 - We shall finish Lab #2 this week and start Lab #3
 - *Exam #1 is next week ... March 8th*
 - Spring Break is the following week ... March 15th
 - March 22nd will be lab #3 continuation
 - Project information will be provided on March 22nd

Syllabus Review

<i>Week</i>	<i>Date</i>	<i>Topics</i>	<i>Lab</i>	<i>Lab Report Due</i>
1	01/25/11	PIC pin out, C programming, Watchdog Timer, Sleep		
2	02/01/11	General-purpose IO, LED/switch IO, FSM	1	
3	02/08/11	Lab	1 con't	
4	02/15/11	Interrupts, Timers, interrupt-driven IO	2	
5	02/22/11	Lab	2 con't	1
6	03/01/11	Asynchronous and Synchronous Serial IO (UART, I ² C, SPI)	3	
7	03/08/11	Examination 1		
X	03/15/11	No Class – Spring Break		
8	03/22/11	Lab	3 con't	2
9	03/29/11	Serial EEPROM operation, DAC, DC motor control, Servos, Stepper motor control	4	3
10	04/05/11	Lab	4 con't	
11	04/12/11	Advanced Hardware Topics	Project	4
12	04/19/11	Examination 2		
13	04/26/11	Work on Course Project	Project	
14	05/03/11	Final Exam/Course Project Brief and Demonstration	Demo	
				5

Chat Page

- Still looking into what is available through the school
 - More to follow as it develops

Microcontroller Hardware and / or Interfaces

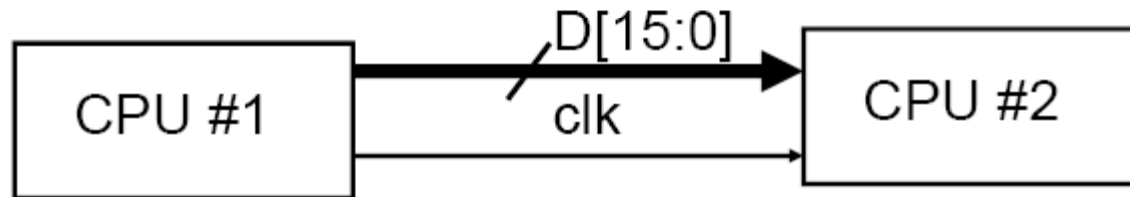
Input / Output ...

Input / Output Review

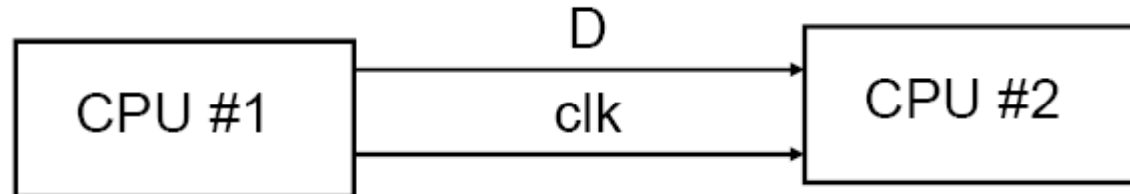
- **Thus far we have looked at parallel input/output**
 - **Data sent over a group of parallel wires**
 - **Typically ... a clock is used for synchronization**
- **Next ... We shall look at serial input/output**
 - **Data sent one bit at a time, over a single wire**
 - **A clock may or may not be used for synchronization**

Parallel and Serial Input / Output

- Parallel ...



- Serial ...



Parallel vs. Serial IO

Parallel IO Pros/Cons

Pros: Speed, can increase bandwidth by either making data channel wider or increasing clock frequency

Cons: Expensive (wires cost money!). Short distance only – long parallel wire causes crosstalk, data corruption.

Serial IO Pros/Cons

Pros: Cheap, very few wires needed. Good for long distance interconnect.

Cons: Speed; the fastest serial link will typically have lower bandwidth than the fastest parallel link. However, for long distances (meters), new fast serial IO standards (USB2, Firewire) have replaced older parallel IO standards.

Baud Rate vs Bits Per Second

- Baud rate is the rate at which signaling events are sent
 - Bits per second (bps) is ...
 - The number of bits transferred per second ...
 - any type of bits ... data ... or ... overhead bits

Baud Rate vs Bits Per Second

- If only a '1' or '0' is sent for each signaling event ... then ...
 - baud rate = bps
- A signaling protocol that transfers multiple bits per signaling event ... i.e. ...
 - use 4 different voltage levels, send two bits of data per signaling event (00 = -15v, 01 = -5v, 10 = +5v, 11 = 5v)
 - In this case ... bit rate will be double the baud rate
- The effective data rate is the rate at which data is transferred, minus the overhead bits (ie. start and stop bits)

Serial Buses ...

Serial Buses

- Serial buses can be either ...
 - Asynchronous ... or ... synchronous
- Asynchronous serial connection ...
 - Data is sent without using a common timing clock signal
- Synchronous serial connection ...
 - Typically uses a separate clock signal to synchronize the receiver with the sender

Asynchronous Serial Connection

- To align the receiver with the sender ...
 - There is some sort of start condition ...
 - To signify when the transmission begins ... and ...
 - A stop condition ...
 - To indicate the end of transmission.

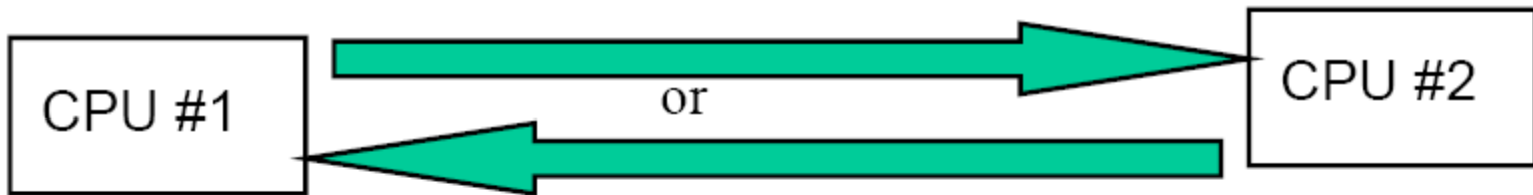
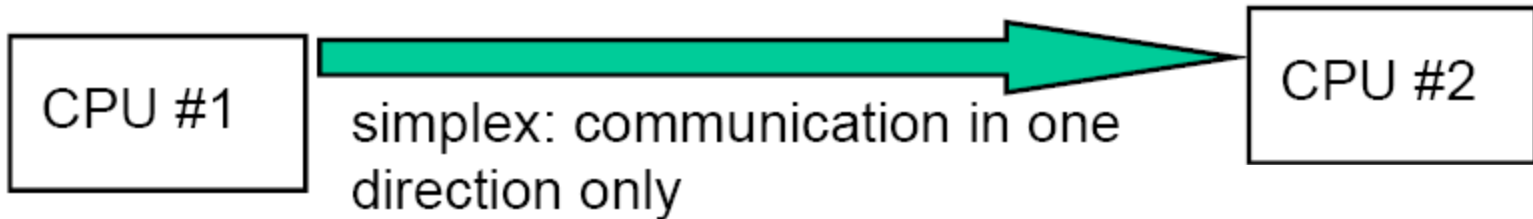
Synchronous Serial Connection

- A synchronous serial connection typically uses a separate clock signal to synchronize the receiver with the sender
- Synchronous connections may also use a start and stop condition to synchronize the receiver and sender ...
 - After which the sender must send characters one right after the other
- A serial interface that can send and receive data at the same time is called full-duplex. A serial interface that must alternate between sending and receiving data is called half-duplex.

Types of Serial Connections

- **Full-Duplex ...**
 - A serial interface that can send and receive data at the same time
- **Half-Duplex ...**
 - A serial interface that must alternate between sending and receiving data
- **Simplex ...**
 - Communication in one direction only

Types of Serial Connections



Half-duplex: communication in either direction, but only one way at a time



Full-duplex: communication in both directions at same time.

PIC24 Serial On-Chip Peripherals ...

PIC24 Serial On-Chip Peripherals

- **UART ...**
 - **Universal Asynchronous Receiver Transmitter**
 - **Pronounced ... “you-art”**
- **RS-232 Standard**
 - **Requires a driver to convert between RS-232 logic levels and CMOS logic levels**

PIC24 Serial On-Chip Peripherals

- SPI ...
 - Serial Peripheral Interface
 - Pronounced ... “spy”
- I²C Bus ...
 - Inter-Integrated Circuit
 - Pronounced ... “eye squared see”

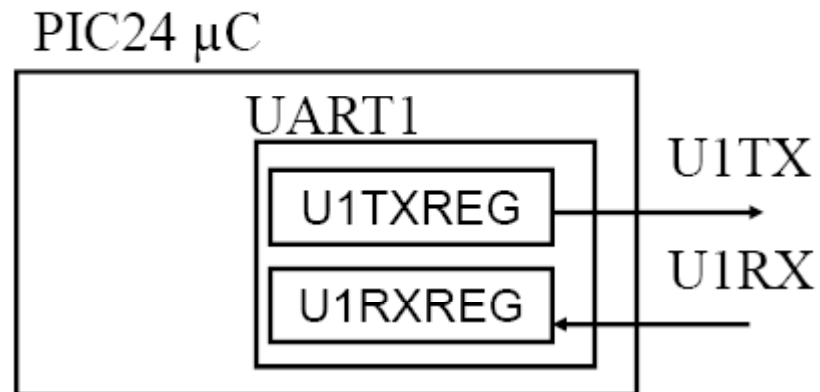
UART ...

UART

- **UART ... Universal Asynchronous Receiver Transmitter**
- **Hardware module that implements asynchronous serial IO**
- **Referred to as UART x ...**
 - **As there may be multiple UART modules on one PIC24 μ C**
- **Frees the processor from having to implement software delay loops ...**
 - **Receive/transmit done by UART while processor can do other tasks**

UART

- Will always use 8-bit no parity for PIC24 asynchronous serial IO

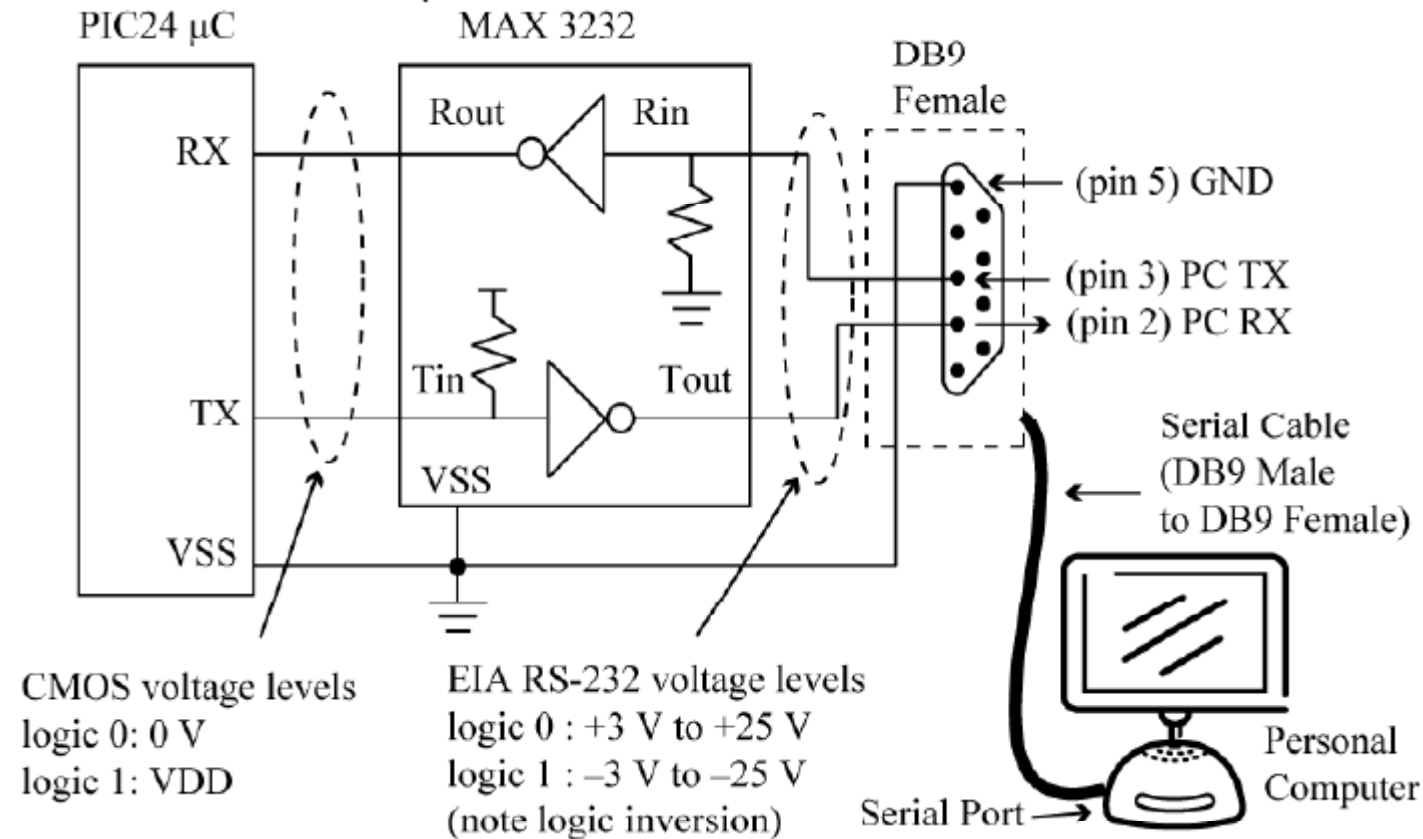


RS-232 ...

RS-232

- **RS-232 ... Recommended Standard 232**
 - The traditional name for a series of standards for ...
 - Serial binary single-ended data ... and... control signals connecting between ...
 - a DTE (Data Terminal Equipment ... and ...
 - DCE ... Data Circuit-terminating Equipment
- Commonly used in computer serial ports

PIC24 μ C to PC Serial Input / Output Connection



Our USB-to-Serial cable uses CMOS voltage levels. Other cables may use RS-232 voltage levels, which require conversion to CMOS levels!

RS-232

- **An interface standard originally used to connect PCs to modems**
- **The standard defines voltage levels, cable length, connector pinouts, etc**
- **There are other signals in the standard beside TX, RX, Gnd**
- **The other signals are used for modem control (Data Carrier Detect, Ring Indicator, etc) and flow control (flow control signals are used to determine if a device is ready to accept data or not)**
- **We will not cover the other signals in the RS232 standard**

SPI ...

SPI

- Another serial bus that is commonly used in embedded systems is the ...
 - Motorola serial peripheral interface ... SPI

SPI

- SPI can operate at data rates up to 1 Mbps
- It can operate in full-duplex mode
 - Making it better suited than I²C for applications where data is constantly flowing

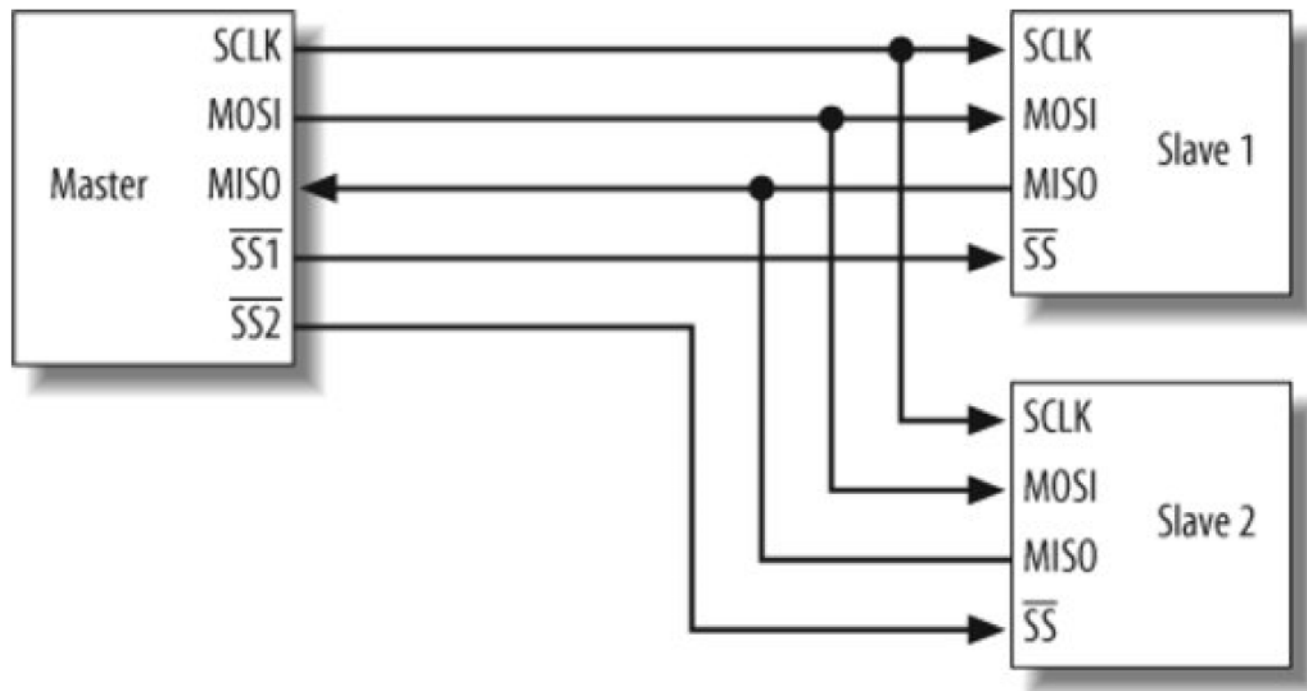
SPI

- I²C ...
 - Uses fewer signals than SPI
 - Can communicate over several feet ... a meter or more
..... and ...
 - Has a well defined specification

SPI

- **SPI ...**
 - **Has a limited communication length of a few inches**
 - **SPI does not support multiple masters ...or ... specify a device addressing scheme ...**
 - **Therefore ... additional hardware signals are needed in order to select specific slaves**
 - **This lack of addressing can be a benefit because it reduces the overhead in single-master, single-slave SPI interfaces**

SPI



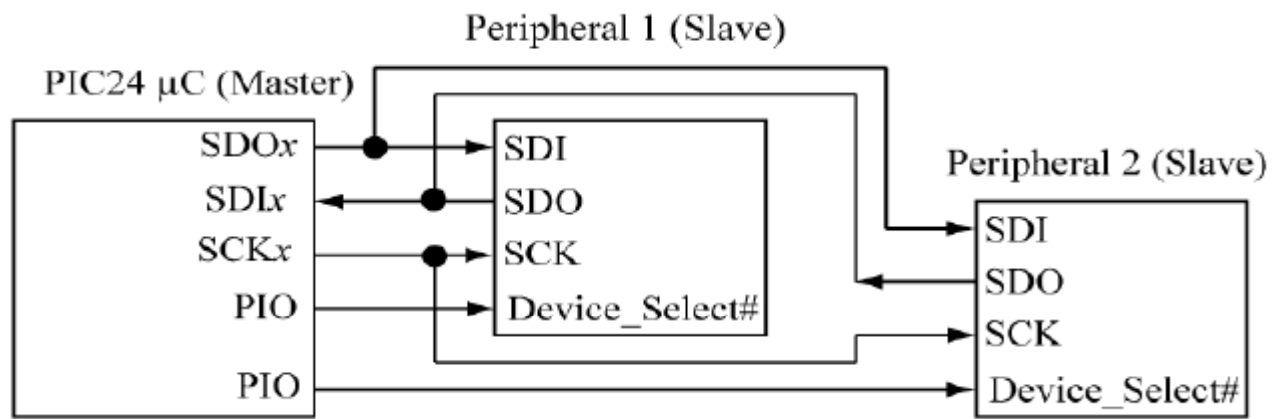
SPI

- The SPI port requires ...
 - A minimum of three wires ... and ... usually 4 ... and ...
 - Is technically duplex, even though most transfers are half-duplex
- Its top speed on the PIC24 μ C is 10 MHz
- Best for high-speed serial transfer
- Very simple

SPI and the I²C Comparison

- **In contrast to the SPI ... the I²C port requires ...**
 - **Only two wires regardless of the number of peripherals**
 - **Is half-duplex**
 - **Top speed is 1 MHz**
- **Best if you are trying to reduce external pin usage**

SPI / PIC24 Connections

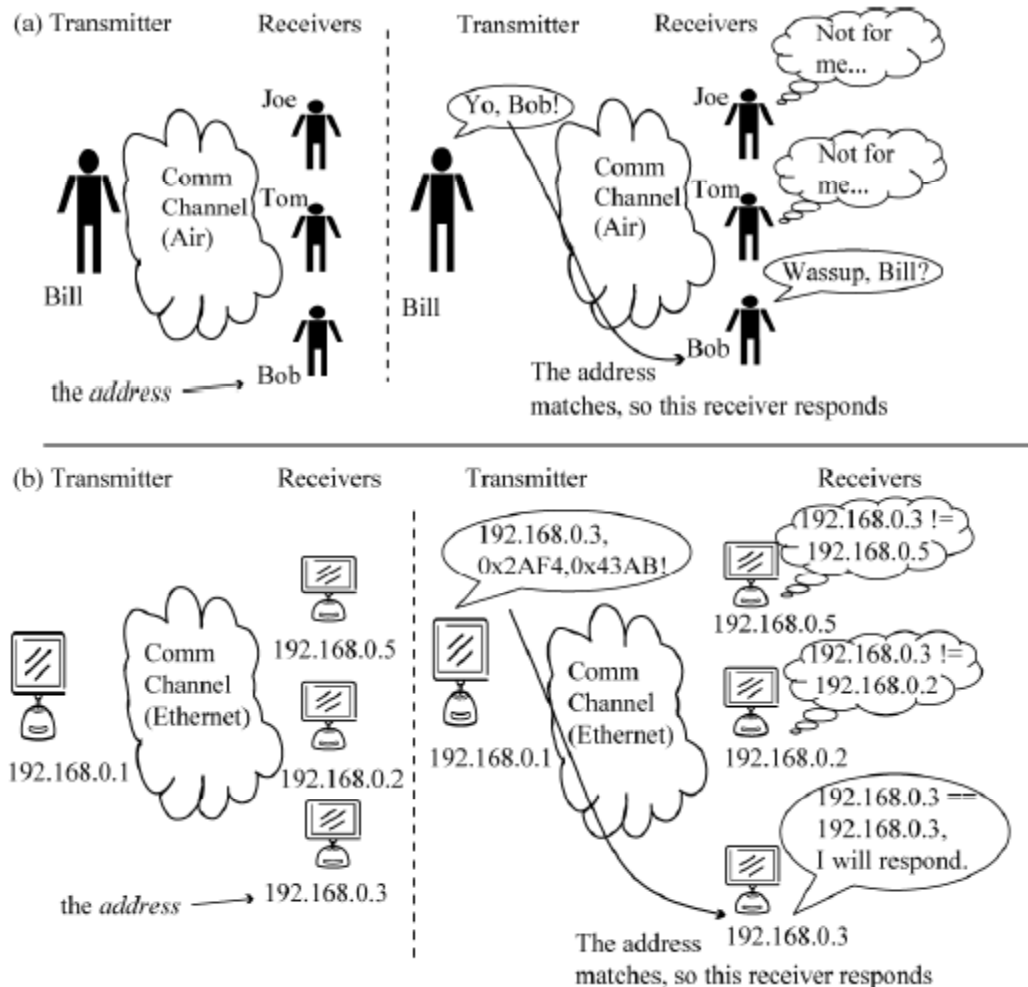


I²C Serial Bus ...

I²C Serial Bus

- I²C ... Inter-Integrated Circuit ...
 - Pronounced “eye squared see”
- Provides a means of exchanging data between ...
 - Peripheral devices ... and ... Microcontrollers ...
 - Using software addressing
- Only two signals are required ...
 - Data ... Clock

I²C Serial Bus



When a device on a bus talks, all hear what is said.

An *address* is used to specify what device the communication is intended for.

I²C Serial Bus

- **I²C**
 - **Does not require much in the way of hardware resources**
 - **Ideal for ...**
 - **Low speed**
 - **Short distance communications**

I²C Serial Bus

- Created by Philips
- Capable of addressing multiple devices on the same bus ...
 - Up to 127 devices in Standard-mode
 - 1024 in extended mode

I²C Serial Bus

- Various maximum data rates are supported by different revisions to the I²C specification
- These data rates are ...
 - Up to 100 Kbps for Standard-mode
 - 400 Kbps for Fast-mode ... and ...
 - 3.4 Mbps for High-speed mode
- Devices of different data rates can be mixed on the same bus

I²C Serial Bus

- The I²C specification can be found online at ...
 - <http://www.semiconductors.philips.com>
- More specifically ... (also on the course web page)
- <http://ics.nxp.com/support/documents/interface/pdf/i2c.bus.specification.pdf>

I²C Serial Bus

- Some devices that typically contain I²C bus interfaces are ...
 - EEPROMs ... and ...
 - Real-time clock chips

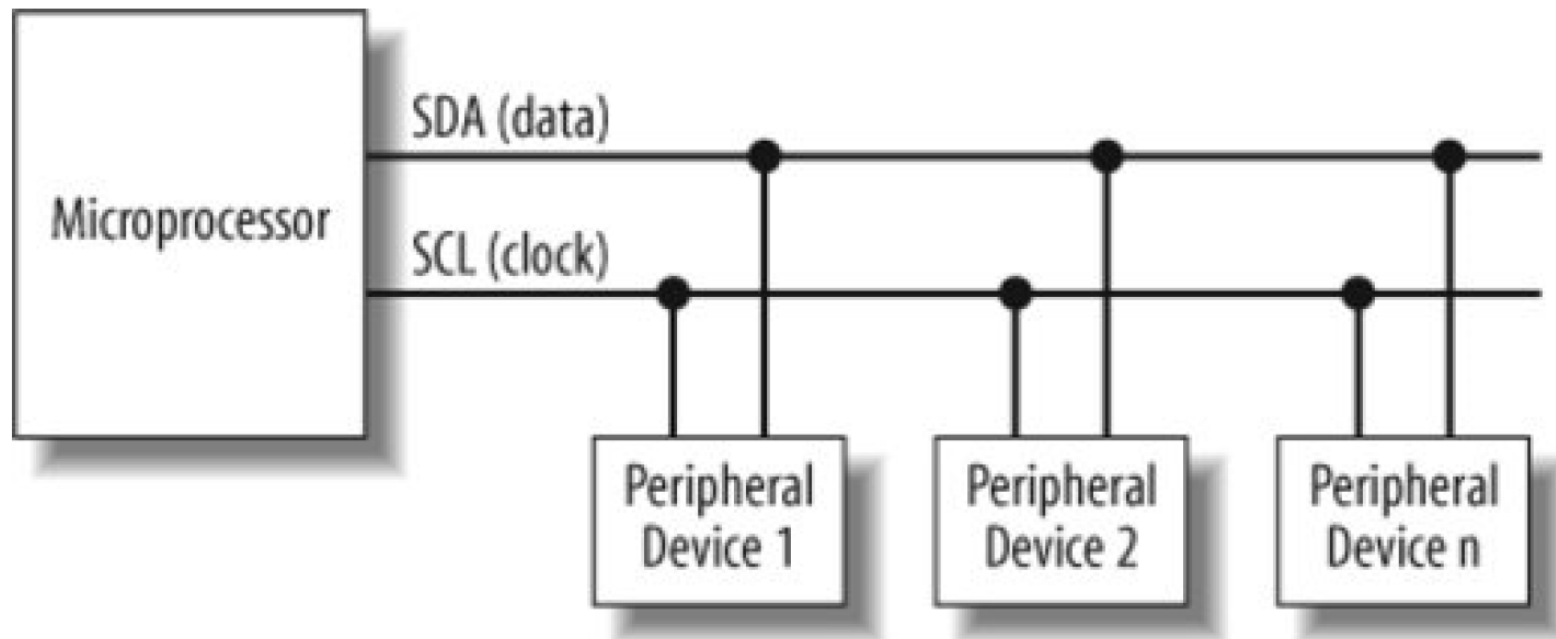
I²C Serial Bus

- The two I²C bus signals are ...
 - Serial data (SDA) ... and ...
 - Serial clock (SCL)
- The *master* on the bus initiates all transfers ...
 - Other devices on the bus are called *slaves*

I²C Serial Bus

- On the next slide ...
 - The microprocessor is the master ... and ...
 - The other devices are the slaves
- Both master and slaves can receive and transmit data on the bus
- The master ...
 - Initiates transactions on the bus and controls the clock signal

I²C Serial Bus

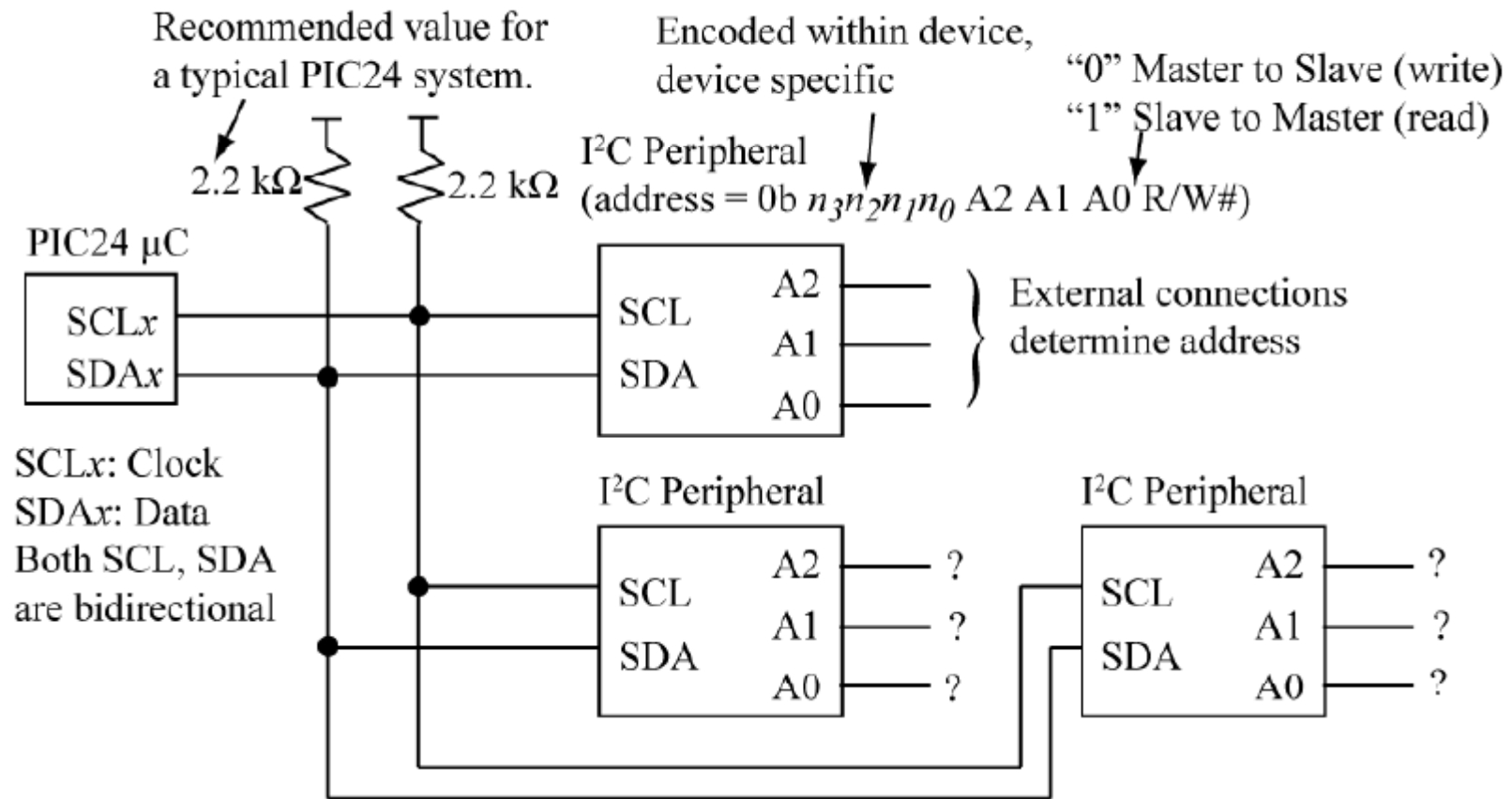


I²C Serial Bus

- Below is the format of an I²C bus transaction
- All data on the bus is communicated most significant bit first (MSB)



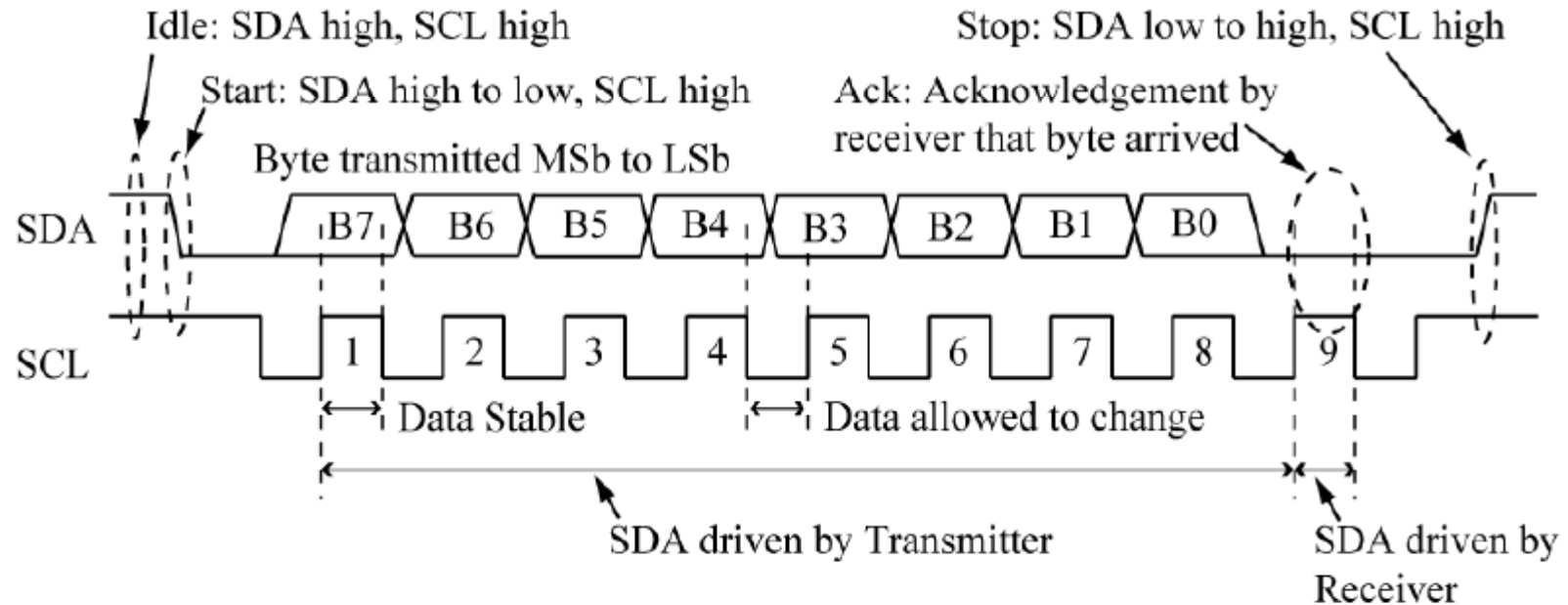
I²C Serial Bus



I²C Communications

- 1. Master initiates a start condition**
- 2. Master sends the 7-bit unique address of the device**
- 3. Master outputs the read or write bit**
- 4. Slave sends an acknowledge bit**
- 5. Byte of data is exchanged followed by an acknowledgement**
 - Continues until all data is sent**
- 6. Transaction ends with the master device causing a stop condition**

I²C Bus Signaling



Every byte transferred takes 9 bits because of acknowledgement bit.

I²C Communications

1. Master initiates a start condition

- An I²C bus data transaction begins by the master initiating a start condition**
- A start condition occurs when the master causes a high-to-low transition on the data line while the clock line is held high**

I²C Communications

- 2. Master sends the 7-bit unique address of the device**
 - 7-bit unique address of the device is sent out by the master device**
 - Each device on the bus checks this address with its own to determine whether the master is communicating with it**
 - I²C slave devices come with a predefined device address**
 - The lower bits of this address are sometimes configurable in hardware**

I²C Communications

3. Master outputs the read or write bit

- The master outputs the read or write bit
 - If the bit is high ... the transaction is a read ...
 - Where data goes from the slave to the master device
 - If the bit is low ... the transaction is a write ...
 - From the master to the slave device

I²C Communications

4. Slave sends an acknowledge bit
 - For the acknowledge bit ...
 - The data line is kept low while the clock signal is high
 - Acknowledge bits always are sent by the slave device

I²C Communications

- 5. Byte of data is exchanged followed by an acknowledgement**
 - Depending on the type of transaction ... read ... or ... write**
 - The transmitter ... which can be slave or master ... begins sending a byte of data ... starting with the MSB**
 - At the end of the data byte ... the receiver ... either slave or master ... issues an acknowledge bit**
 - This pattern is continued until all of the data has been transferred**

I²C Communications

- 6. Transaction ends with the master device causing a stop condition
 - A stop condition occurs when the master causes a low-to-high transition on the data line while holding the clock line high
- **Note that the I²C protocol supports multiple masters**

EEPROM Interface

- We shall look into using the I²C bus to communicate with a serial EEPROM
- The EEPROM is the 24LC515

EEPROM - 24LC515

- **Is a 64K x 8 (512K bit) Serial Electrically Erasable PROM ...**
- **capable of operation across a broad voltage range (1.8V to 5.5V)**
- **Has both byte write and page write capability of up to 64 bytes of data**
- **Capable of both random and sequential reads**
- **Reads may be sequential within address boundaries ...**
 - **0000h to 7FFFh ... and ... & 8000h to FFFFh**

EEPROM - 24LC515

- **Functional address lines allow up to four devices on the same data bus**
 - **This allows for up to 2 Mbits total system EEPROM memory**

EEPROM - 24LC515

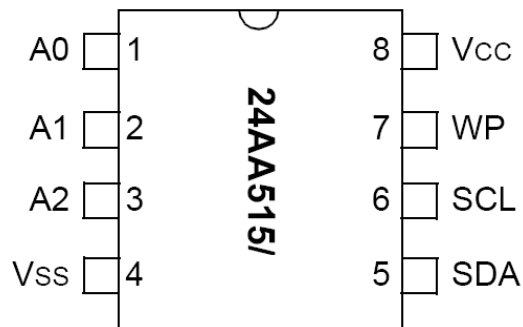
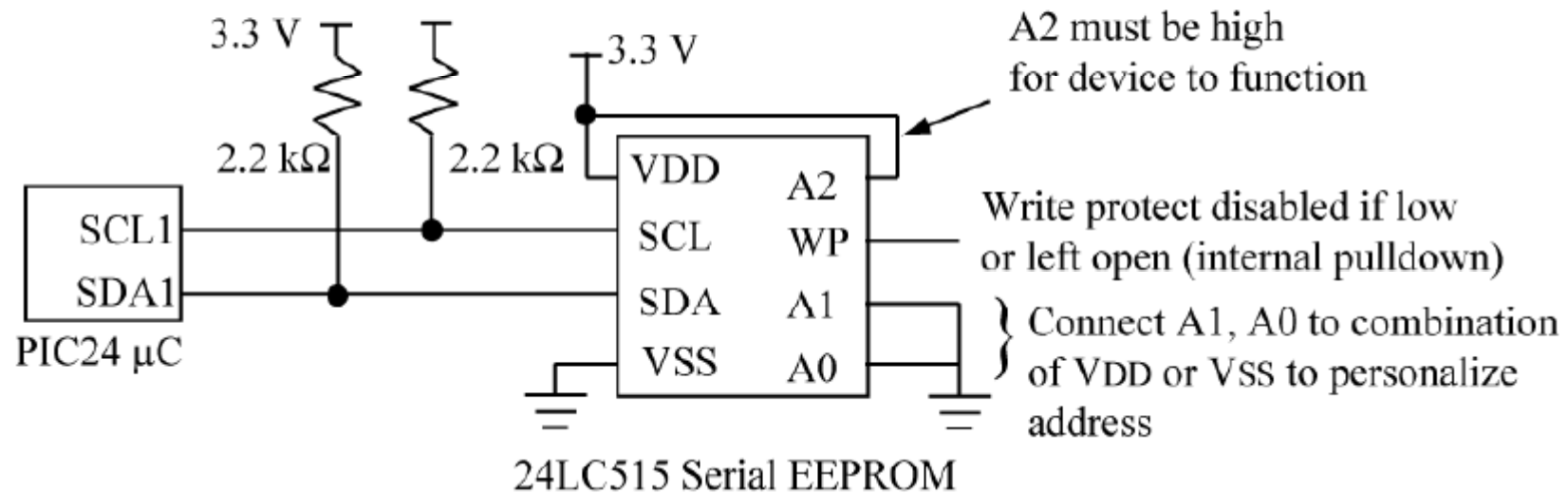


TABLE 2-1: PIN FUNCTION TABLE

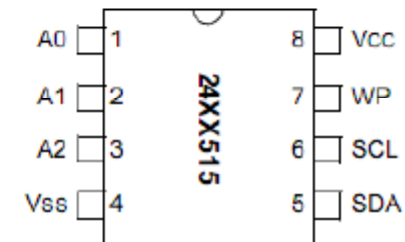
Name	PDIP	SOIC	Function
A0	1	1	User Configurable Chip Select
A1	2	2	User Configurable Chip Select
A2	3	3	Non-Configurable Chip Select. This pin must be hard wired to logical 1 state (Vcc). Device will not operate with this pin left floating or held to logical 0 (Vss).
Vss	4	4	Ground
SDA	5	5	Serial Data
SCL	6	6	Serial Clock
WP	7	7	Write-Protect Input
Vcc	8	8	+1.8 to 5.5V (24AA515) +2.5 to 5.5V (24LC515) +4.5 to 5.5V (24FC515)

PIC24 μ C Master to 24LC515 Serial EEPROM

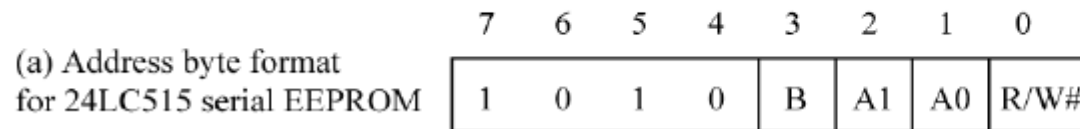


EEPROM is 64 Ki x 8 , internally arranged as two separate 32 Ki x 8 memories.

NOTE: The diagram above is a logical layout, not the physical pinout, shown on the right.



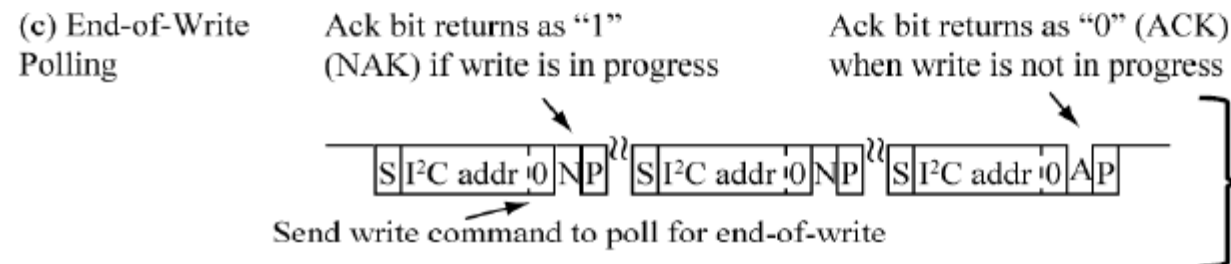
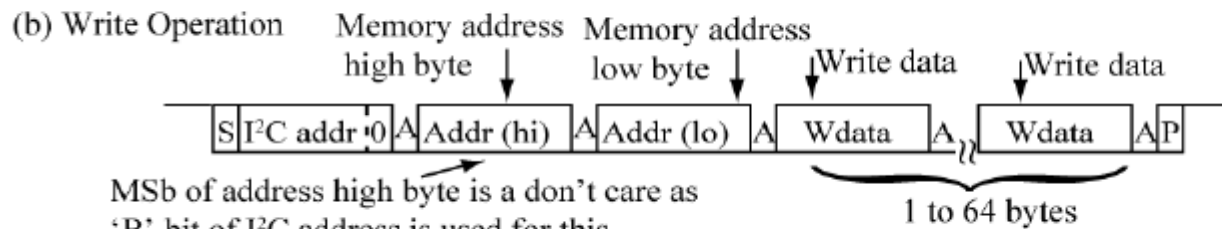
24LC515 I²C Address Format, Write Operation



B : Memory block select, if “0” then operation is to low memory block (0x0000-0x7FFF), if “1” then operation is to high memory block (0x8000-0xFFFF)

A1, A0: Used to personalized address, up to four LC515 EEPROMs can be on bus.

R/W#: “1” if read operation, “0” if write operation

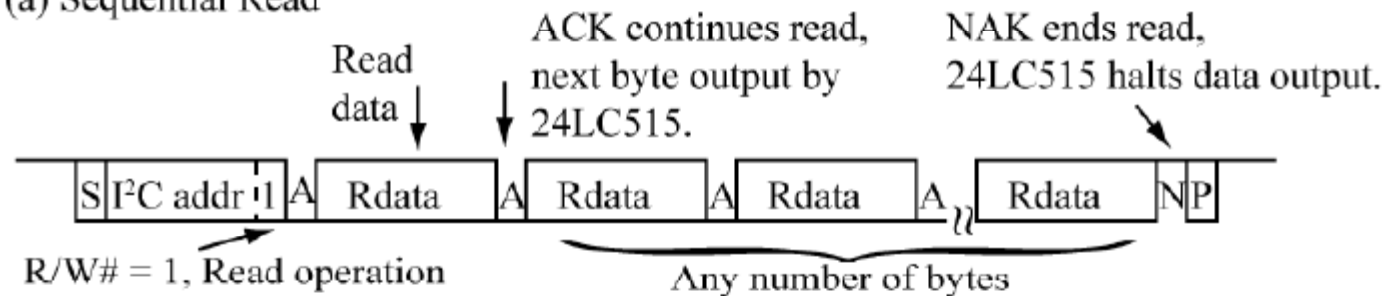


Most efficient to write 64 bytes at a time as write takes 3 – 5 ms to complete.

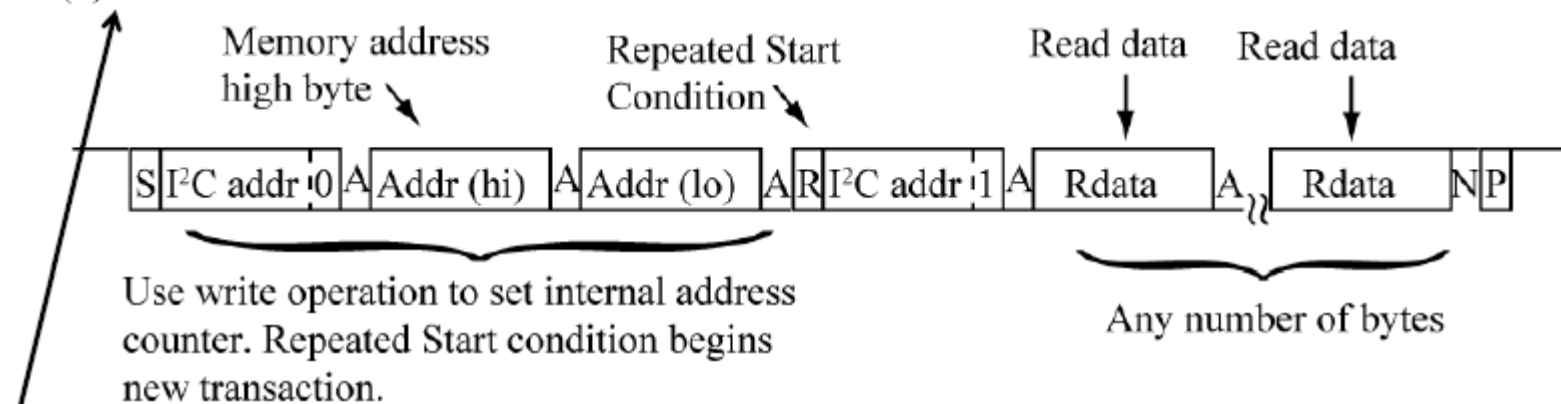
Poll device to see when the write is finished.

24LC515 I²C Read Operation

(a) Sequential Read



(b) Random Read



We will do this to read the device, and always will read 64 bytes at a time.

Programming/Software

Programming/Software

- **No topics for discussion**

Lab

Peer Review of Software ...

Peer Review of Software Developed

- How did you write your code?
- What problems did you encountered?
- Any questions that you need resolved?

Lab #3 ...

Lab #3

- **I²C interface with a serial EEPROM**
 - **Will write data to the EEPROM**
 - **Then read data from the EEPROM**
- **Display the data on a Bar Graph display**
 - **Could add a LCD display to perform the same function**

Next Class

Next Class Topics

- **Exam #1**
 - Up to ... but ... not including today's material
- **March 15th ... No class – Spring break**
- **March 22nd ... continue with Lab #3**

Homework

Homework

- Study for Exam #1 ... next week ... March 8th
- Labs ...
 - Code development for Lab #3
 - Lab #2 Report ... due March 22nd

**Time to start
the lab ...**

Lab

- **Continue Lab #2, if needed**
- **Start Lab #3**

White Board ...

References

References

1. None