CprE 288 – Introduction to Embedded Systems
Exam 2 Review

Instructor:
Dr. Phillip Jones
Announcements
EXAM
Announcements

• Exam 2: Thurs 11/3, in class
  – Open textbook, 1 page of notes, and calculator allowed
  – 75 minutes
  – Electronic textbook is fine. But nothing else on your electronic device can be used or you will receive an F for CPRE 288
Exam Topics

Programming TMC4123 I/O modules and functions

– USART
– ADC
– Input capture (Timer/Counter)
– Output compare (Timer/Counter)
  • Generating waves (PWM mode, Periodic Mode)
– General Timer Modes
– GPIO Configuration

On each subject, be familiar with

– Application background, working principles, and related concepts
– Programming interface
– Writing C functions for common purposes
– Typical application scenarios
Exam Questions

Some common question styles

• Short questions
  – Conceptual
  – Analysis
  – Calculation

• Programming: for a given application
  – Initialize an I/O module
  – Access I/O data
  – Interrupt programming

And others
Exam Questions: Data Sheet, Read it & ask questions

• Flavors of some potential Exam 2 questions
  – Program configuration registers to meet given requirements
    • UART, ADC, Input Capture, Output Compare, Timers, Interrupts
    • There is a section for each device mentioned above in the data sheet
  – Based on a given configuration, answer questions about how a program will behave
    • E.g. How long will something take to occur?
    • E.g. How many times a second will something occur?
  – Explain why a given configuration is incorrect for implementing a specified behavior
  – Assuming a given configuration, write a short program to implement a specific behavior
  – ADC calculation problems

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Exam Preparation

**How to prepare**

- Review Labs
- Review the lecture slides
  - Read datasheet when needed
- Review/redo homework
  - Proficiency and efficiency are importance
- Ask questions
  - Office hour visits
  - Appointments
  - Emails

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USART
USART: Serial Communication

• USART = Universal Synchronous & Asynchronous Serial Receiver & Transmitter
  – We only studied the Asynchronous part (UART)

• Serial communication: Data is transmitted bit by bit at the physical layer of network
  – Can transmit over long link distances
  – Uses start and stop to sandwich data bits
  – parity bit can be used for error detection
Important concepts

• **Baud rate**: Number of symbols transmitted per second from the transmitter to the receiver
  – It’s also the rate of symbol changes to the transmission media

• **Frame format**: The format of a single data packet
  – USART transmits one data packet per request
  – One data packet contains a single data character, plus start bit, stop bit(s), and optional parity bit
Frame Format

Start bit: logic low, 1 bit
Data bits: 5, 6, 7, 8, or 9 bits
Parity bit: Optional 1 bit, Odd, Even or none
Stop bit: logic high, 1 bit or 2 bits

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

Temperature Sensor

Temperature vs. Voltage (Sensor Specification)

- \( T_{\text{min}} = 0 \, \text{C} \)
- \( T_{\text{max}} = 200 \, \text{C} \)
- Sensor_V_{\text{min}} = 0 \, \text{V}
- Sensor_V_{\text{max}} = 3.3 \, \text{V}

A/D Input (V)
- \( \text{A/D}_V_{\text{min}} = 0 \, \text{V} \)
- \( \text{A/D}_V_{\text{max}} = 3.3 \, \text{V} \)

Digital Output (D)
- \( D = 0 \)
- \( D_{\text{max}} = 1023 \)

A/D: Analog Input vs. Digital Output
\( M = 2^n - 1 \) steps (or bins): \( D_{\text{max}} = V_{\text{max}} \)
Sensor and ADC

Temperature Sensor

**Sensor vs. Voltage (Sensor Specification)**
- \( T_{\text{min}} = 0 \, \text{C} \)
- \( T_{\text{max}} = 200 \, \text{C} \)
- \( \text{Sensor}_{\text{Vmin}} = 0 \, \text{V} \)
- \( \text{Sensor}_{\text{Vmax}} = 3.3 \, \text{V} \)

**Temperature vs. Voltage**
- \( \text{Slope} = \text{Sensitive} \, 60.61 \, \text{C/V} \)

**A/D: Analog Input vs. Digital Output**
- \( \text{A/D}_{\text{Vmax}} = 3.3 \, \text{V} \)
- \( \text{A/D}_{\text{Vmin}} = 0 \, \text{V} \)
- \( \text{Dmax} = 1023 \)
- \( \text{D} = 0 \)
- \( \text{Slope} = \text{Resolution} \, 0.0032 \, \text{V/bit} \)

**Digital Output**
- \( +5 \, \text{V} \)
- \( 10 \, \text{bit} \)
- \( \text{Digital Output} = 515 \)
### Sampling and Conversion

#### Mapping between Analog and Digital

**Proportionality**

<table>
<thead>
<tr>
<th>Analog Input (V)</th>
<th>Digital Output (D)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.5V</td>
<td>1111</td>
</tr>
<tr>
<td>7.0V</td>
<td>1110</td>
</tr>
<tr>
<td>6.5V</td>
<td>1101</td>
</tr>
<tr>
<td>6.0V</td>
<td>1100</td>
</tr>
<tr>
<td>5.5V</td>
<td>1011</td>
</tr>
<tr>
<td>5.0V</td>
<td>1010</td>
</tr>
<tr>
<td>4.5V</td>
<td>1001</td>
</tr>
<tr>
<td>4.0V</td>
<td>1000</td>
</tr>
<tr>
<td>3.5V</td>
<td>0111</td>
</tr>
<tr>
<td>3.0V</td>
<td>0110</td>
</tr>
<tr>
<td>2.5V</td>
<td>0101</td>
</tr>
<tr>
<td>2.0V</td>
<td>0100</td>
</tr>
<tr>
<td>1.5V</td>
<td>0011</td>
</tr>
<tr>
<td>1.0V</td>
<td>0010</td>
</tr>
<tr>
<td>0.5V</td>
<td>0001</td>
</tr>
<tr>
<td>0V</td>
<td>0000</td>
</tr>
</tbody>
</table>

**Proportionality**

<table>
<thead>
<tr>
<th>Analog Input (V)</th>
<th>Digital Output (D)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.0V</td>
<td>0000</td>
</tr>
</tbody>
</table>

**Digital sampling of an analog signal**

**Digital generation of an analog signal**

**Analog to digital**

**Digital to analog**

*Embedded Systems Design: A Unified Hardware/Software Introduction, (c) 2000 Vahid/Givargis*
Assume linear sensor, ADC is always linear

\[
\frac{a}{A_{\text{max}}} \frac{A_{\text{min}}}{A_{\text{min}}} = \frac{v}{V_{\text{max}}} \frac{V_{\text{min}}}{V_{\text{min}}} = \frac{d}{M}
\]

- Sensor converts analog signal to electrical signal (voltage)
- ADC converts an electrical signal (voltage) to a digital number
Constructing the ADC (Successive Approximation)

It’s built upon a DAC

**Analog Input**

$V_{\text{max}} = 16 \text{V}$

$V_{\text{min}} = 0 \text{V}$

Let $M = 2^n$

$\text{Guess} = 9 \text{V}$

Let $M = 2^n$

$\text{State machine}$

Timing control

$\text{SAR BUF}$

SAR: Successive approximation register

Digital output

1001

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<table>
<thead>
<tr>
<th>Step</th>
<th>Range</th>
<th>Mid (digital)</th>
<th>Mid (voltage)</th>
<th>Is a $\geq$ Guess (voltage)?</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0bxxxxx</td>
<td>0b1000</td>
<td>8 Volts</td>
<td>Yes</td>
</tr>
<tr>
<td>1</td>
<td>0b1xxx</td>
<td>0b1100</td>
<td>12 Volts</td>
<td>No</td>
</tr>
<tr>
<td>2</td>
<td>0b10xx</td>
<td>0b1010</td>
<td>10 Volts</td>
<td>No</td>
</tr>
<tr>
<td>3</td>
<td>0b100x</td>
<td>0b1001</td>
<td>9 Volts</td>
<td>Yes</td>
</tr>
<tr>
<td>4</td>
<td>0b1001</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
INPUT CAPTURE AND OUTPUT COMPARE
Input Capture and Output Compare

Input capture and output compare work with digital waveforms.

IC: Recognize waveforms by capturing the time of events.
OC: Generate waveforms by setting the time of events.

TMC4123 has several Timer modes.

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