EE 109 Unit 5

Analog-to-Digital Conversion

ANALOG TO DIGITAL CONVERSION

Electric Signals

- Information is represented electronically as a time-varying voltage
  - Each voltage level may represent a unique value
  - Frequencies may represent unique values (e.g. sound)

Sound converted to electronic signal (voltage vs. time)

Electronic Information

- Digital Camera
  - CCD’s (Charge-Coupled Devices) output a voltage proportional to the intensity of light hitting it
  - 3 CCD’s filtered for measuring Red, Green, and Blue light produce 1 color pixel

[http://www.microscopy.fsu.edu/primer/digitalimaging/concepts/ccdanatomy.html](http://www.microscopy.fsu.edu/primer/digitalimaging/concepts/ccdanatomy.html)
Signal Types

- **Analogue signal**
  - Continuous time signal where each voltage level has a unique meaning
  - Most information types are inherently analog
- **Digital signal**
  - Continuous signal where voltage levels are mapped into 2 ranges meaning 0 or 1
  - Possible to convert a single analog signal to a set of digital signals

Signals and Meaning

- Each voltage value has unique meaning
- Each voltage maps to '0' or '1'
  - Illegal

Analog to Digital Conversion

- 1 Analog signal can be converted to a set of digital signals (0's and 1's)
- 3 Step Process
  - Sample
  - Quantize (Measure)
  - Digitize

Sampling

- Measure (take samples) of the signals voltage at a regular time interval
- Sampling converts the continuous time scale into discrete time samples
**Quantization**

- Voltage scale is divided into a set of finite numbers (e.g. 256 values: 0 – 255)
- Each sample is rounded to the nearest number on the scale
- Quantization converts continuous voltage scale to a discrete (finite) set of numbers

**Digitization**

- The measured number from each sample is converted to a set of 1’s and 0’s

**Error**

- Error is introduced because the discrete time and quantized samples only approximate the original analog signal

**Sampling Rates and Quantization Levels**

- Higher sampling rates and quantization levels produce more accurate digital representations
Digital Sound

- CD Quality Sound
  - 44.1 Kilo-samples per second
  - 65,536 quantization levels (16-bits per sample)
  - 44.1KSamples * 16-bits/sample = 705 Kbps
- MP3 files compress that information to 128Kbps – 320 Kbps

ADC Module

- Your Atmel micro has an A-to-D Converter (ADC) built in
- The ADC module can be used to convert an analog voltage signal into ______ digital numbers.
- Not _____________ for video or audio.
- Controlled by a set of six registers which you must program appropriately

Note

- Microcontroller modules often come with many adjustable features and settings to make it useful to a wide variety of applications
- In EE 109 we may not want to use all that functionality so we have to ______________ ______ those features or alter certain settings
- How do we do this? By ________ bits in specific _____________
  - The values we program into the registers ____________ how the hardware works!
ADC Registers

- ADC is primarily controlled by two registers whose bits control various aspects of the ADC
  - ADMUX – ADC Multiplexor Selection Register
  - ADCSRA – ADC Control and Status Register A
- We will see what these bits means as we continue through our slides...

<table>
<thead>
<tr>
<th></th>
<th>7</th>
<th>6</th>
<th>5</th>
<th>4</th>
<th>3</th>
<th>2</th>
<th>1</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADMUX</td>
<td>REFS1</td>
<td>REFS2</td>
<td>ADLAR</td>
<td>MUX3</td>
<td>MUX2</td>
<td>MUX1</td>
<td>MUX0</td>
<td></td>
</tr>
<tr>
<td>ADSCRA</td>
<td>ADEN</td>
<td>ADSC</td>
<td>ADATE</td>
<td>ADIF</td>
<td>ADIE</td>
<td>ADPS2</td>
<td>ADPS1</td>
<td>ADPS0</td>
</tr>
</tbody>
</table>

ADC Voltage Reference

- The ADC can only measure voltages in the range of $V_{hi}$ to $V_{low}$
  - If the voltage is higher than _____ it just converts to ___________
  - If the voltage is lower than _____ it just converts to ____
  - Voltages between the limits are converted _______ to digital values.
- Samples will be taken either at regular intervals or just when you tell it to take a sample

![Input Voltage Diagram](image.png)

ADC Input Selection

- The ADC has _____ input channels/pins that can be connected to the one built-in converter
- Only one channel can be _____________ at any one time
- Channel _____________ controlled by bits in a register

- The low reference is fixed at ground = _____.
- High reference is _____________
  - AVCC (connected to VCC)
    - Usually the one _____________
  - AREF
    - Internal 1.1V reference
- Reference selection controlled by bits in a register
- Simplest: Use AVCC to give analog range of 0-5V
ADC Clock Generation

• The ADC needs a clock in the range ______________ in order to operate.
• Clock is generated from the CPU clock (16Mhz)
• __________ (a.k.a. divider) reduces the clock to a _________ frequency by dividing its frequency
• Divide by 2, 4, 8, 16, 32, 64, or 128
  \[ ADC \text{ Freq} = \frac{CPU \text{ Clock Freq}}{\text{Precalar}} \]
  If Precalar=32 then ADC Freq =

ADC Registers

• The 8- or 10-bit result of the conversion is stored in the ADCH and ADCL registers (collectively known as the ADC Data Register)
  – If using all 10-bits, result is _____ into both registers with 2 MSBs in ADCH and 8 LSBs in ADCL (shown in green)
  – If only using 8-bits, results can be _______ from just the ADCH (shown in red)
  – Use the ADLAR bit in the ADMUX register to tell the ADC if you want 8 or 10-bit accuracy [ADLAR=__ (10-bit) or __ (8-bit)]

Scale

• Analogy: Some scales give your weight to the nearest pound (137) while others are accurate to the tenth of pound (137.6)
  – It’s nice to have accuracy but for most of us we are content with the accuracy just at the nearest pound
• Our ADC can provide readings up to _____ accuracy (on a scale from 1023)...
• ...but it can also drop the lower 2 bits to provide readings of ______ accuracy (on a scale from 256)
• The question is simply do we need 10-bit accuracy or is 8-bit accuracy sufficient
  – Usually ________ accuracy is sufficient

ADC Register Review

• ADMUX – ADC Multiplexor Selection Register
  – REFS - Voltage reference selection (bits 7-6)
    • 01 to select AVCC, connected to VCC (+5V) on µC
  – ADLAR - Left adjust results (bit 5)
    • 0 = "right adjust" for 10-bit result
    • 1 = "left adjust" for 8-bit result
  – MUX - Input channel selection (bits 3-0)
    • Use values 0000 to 0101 to select pins A0 to A5

ADC Register Review

<table>
<thead>
<tr>
<th>ADMUX</th>
<th>7</th>
<th>6</th>
<th>5</th>
<th>4</th>
<th>3</th>
<th>2</th>
<th>1</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>REFS1</td>
<td>REFS2</td>
<td>ADLAR</td>
<td>MUX3</td>
<td>MUX2</td>
<td>MUX1</td>
<td>MUX0</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ADCH</th>
<th>7</th>
<th>6</th>
<th>5</th>
<th>4</th>
<th>3</th>
<th>2</th>
<th>1</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADCL</td>
<td>A0</td>
<td>A1</td>
<td>A2</td>
<td>A3</td>
<td>A4</td>
<td>A5</td>
<td>A6</td>
<td>A7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ADCH</th>
<th>7</th>
<th>6</th>
<th>5</th>
<th>4</th>
<th>3</th>
<th>2</th>
<th>1</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADCL</td>
<td>A0</td>
<td>A1</td>
<td>A2</td>
<td>A3</td>
<td>A4</td>
<td>A5</td>
<td>A6</td>
<td>A7</td>
</tr>
</tbody>
</table>
**ADC Register Review**

- **ADCSRA** – ADC Control and Status Register A
  - **ADEN** – ADC Enable (bit 7)
    - Set to 1 to turn on the ADC (must do)
  - **ADSC** – ADC Start Conversion (bit 6)
    - Set to 1 to start a conversion
    - When goes to a zero, conversion is complete
  - **ADPS** – Prescaler selection (bits 2-0)
    - Selects the clock divisor used in the prescaler
    - Other bits for generating interrupts (to be discussed later)

<table>
<thead>
<tr>
<th>ADSCRA</th>
<th>7</th>
<th>6</th>
<th>5</th>
<th>4</th>
<th>3</th>
<th>2</th>
<th>1</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ADEN</td>
<td>ADSC</td>
<td>ADATEx</td>
<td>ADIF</td>
<td>ADIE</td>
<td>ADPS2</td>
<td>ADPS1</td>
<td>ADPS0</td>
</tr>
</tbody>
</table>

**ADC Programming**

- Initialize the ________ Register to select:
  - Input pin/channel to use (0-5)
  - Voltage reference source (probably AVCC)
  - 8-bit or 10-bit results
- Initialize the ________ Register to select
  - Prescaler value to get a clock in the correct range
- Set the ADEN bit (in ADCSRA reg.) to 1 to ________ the ADC.
- To ______ a conversion, set ADSC bit (also in ADCSRA) to a 1.
- Loop and monitor the ADSC bit
  - When it goes to a _______ the conversion is complete (or alternatively, while it is still a ‘1’ keep looping...don’t do anything in your loop)
- Read the result from ADCH (8-bit) or ADCH:ADCL (10-bit) into a variable and do something with it...
- Loop back to start the next conversion if desired