Analogue Input

Steve Gunn
Interfacing with the Physical World

E.g. a sensor with an output voltage proportional to temperature
How do we represent this signal in bits?
Quantisation

- How many bits should be used?
Sampling

- How fast should we sample?
Resources Used

• AVR Datasheet
  Section 22: ADC (Analogue-to-Digital Converter)
  Section 21: Analogue Comparator

• AVR Libc
  ```
  #include <avr/io.h>
  ```

• Il Matto Quick Reference
  Analogue
<table>
<thead>
<tr>
<th>Port</th>
<th>Pin</th>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>PA7</td>
<td>ADC7</td>
<td>ADC input channel 7</td>
</tr>
<tr>
<td></td>
<td>PA6</td>
<td>ADC6</td>
<td>ADC input channel 6</td>
</tr>
<tr>
<td></td>
<td>PA0</td>
<td>ADC0</td>
<td>ADC input channel 0</td>
</tr>
<tr>
<td></td>
<td>PB7</td>
<td>SCK</td>
<td>SPI Bus Master clock input</td>
</tr>
<tr>
<td></td>
<td>PB6</td>
<td>MISO</td>
<td>SPI Bus Master Input/Slave Output</td>
</tr>
<tr>
<td></td>
<td>PB5</td>
<td>MOSI</td>
<td>SPI Bus Master Output/Slave Input</td>
</tr>
<tr>
<td></td>
<td>PB4</td>
<td>S5</td>
<td>SPI Slave Select input</td>
</tr>
<tr>
<td></td>
<td>PB3</td>
<td>AIN1</td>
<td>Analog Comparator Negative Input</td>
</tr>
<tr>
<td></td>
<td>PB2</td>
<td>AIN0</td>
<td>Analog Comparator Positive Input</td>
</tr>
<tr>
<td></td>
<td>PB1</td>
<td>INT2</td>
<td>External Interrupt 2 Input</td>
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<tr>
<td></td>
<td>PB0</td>
<td>T1</td>
<td>Timer/Counter 1 External Counter Input</td>
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<tr>
<td></td>
<td></td>
<td>CLK0</td>
<td>Divided System Clock Output</td>
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<tr>
<td></td>
<td>PB0</td>
<td>T0</td>
<td>Timer/Counter 0 External Counter Input</td>
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<tr>
<td></td>
<td></td>
<td>XCK0</td>
<td>USART0 External Clock Input/Output</td>
</tr>
<tr>
<td>B</td>
<td>PC7</td>
<td>TOSC2</td>
<td>Timer Oscillator pin 2</td>
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<tr>
<td></td>
<td>PC6</td>
<td>TOSC1</td>
<td>Timer Oscillator pin 1</td>
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<td></td>
<td>PC5</td>
<td>TD1</td>
<td>JTAG Test Data Input</td>
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<td></td>
<td>PC4</td>
<td>TD0</td>
<td>JTAG Test Data Output</td>
</tr>
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<td>PC3</td>
<td>TMS</td>
<td>JTAG Test Mode Select</td>
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<td></td>
<td>PC2</td>
<td>TCK</td>
<td>JTAG Test Clock</td>
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<td></td>
<td>PC1</td>
<td>SDA</td>
<td>2-wire Serial Bus Data Input/Output Line</td>
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<tr>
<td></td>
<td>PC0</td>
<td>SCL</td>
<td>2-wire Serial Bus Clock Line</td>
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<tr>
<td>C</td>
<td>PD7</td>
<td>OC2A</td>
<td>Timer/Counter2 Output Compare Match A Output</td>
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<td>PD6</td>
<td>ICP1</td>
<td>Timer/Counter1 Input Capture Trigger</td>
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<td>PD5</td>
<td>OC2B</td>
<td>Timer/Counter2 Output Compare Match B Output</td>
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<td>PD4</td>
<td>OC1A</td>
<td>Timer/Counter1 Output Compare Match A Output</td>
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<tr>
<td></td>
<td>PD4</td>
<td>OC1B</td>
<td>Timer/Counter1 Output Compare Match B Output</td>
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<tr>
<td></td>
<td>PD3</td>
<td>XCK1</td>
<td>USART1 External Clock Input/Output</td>
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<tr>
<td></td>
<td>PD2</td>
<td>INT1</td>
<td>External Interrupt1 Input</td>
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<tr>
<td></td>
<td>PD1</td>
<td>TXD1</td>
<td>USART1 Transmit Pin</td>
</tr>
<tr>
<td></td>
<td>PD0</td>
<td>RXD1</td>
<td>USART1 Receive Pin</td>
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<td></td>
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<td>TXD0</td>
<td>USART0 Transmit Pin</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RXD0</td>
<td>USART0 Receive Pin</td>
</tr>
</tbody>
</table>

Notes: Each pin also has a pin change interrupt. Each pin can also be configured as GPIO.
ADC
Analogue-to-Digital Converter
ADC Overview

- Eight single-ended channels
- 10-bit resolution (0-1023)
- Up to 15 kSPS at Maximum Resolution
- 8 Multiplexed Single Ended Input Channels
- Free Running or Single Conversion Mode
- 0 – Vcc Input Voltage Range
Figure 22-1. Analog-to-digital Converter Block Schematic

ADC
Successive Approximation ADC
Starting a conversion
Configuring the ADC Clock Source
ADC Timing

Figure 22-5. ADC Timing Diagram, Single Conversion
AVR ADC Control

\[ \text{ADC} \ (n \in \{0, 1, \ldots, 7\}, \ F\_\text{ADC} = F\_\text{CPU}/d, \ d \in \{2, 4, 8, 16, 32, 64, 128\}) \]

\begin{verbatim}
ADCSRA |= _BV(ADPS2) | _BV(ADPS1); /* F_ADC = F_CPU/64 */
ADMX = n; /* Select channel n */
ADMX |= _BV(REFS0); /* AVCC reference */
ADMX |= _BV(ADLAR); /* ADCH contains 8 MSBs */
ADCSRA |= _BV(ADFR); /* Free-Running Mode */
ISR(ADC_vect) { /* ADCH & ADCL contain result */ }
ADCSRA |= _BV(ADEN); /* Enable ADC */
ADCSRA |= _BV(ADSC); /* Start Conversions */
ADCSRA |= _BV(ADIE); /* Enable interrupt */
\end{verbatim}
AC
Analogue Comparator
Analogue Comparator Overview

• Compares the voltage on two pins (AIN\textsubscript{n})

• Output can trigger an interrupt

• Application Example:
  – Analogue pressure sensor connected to AIN0.
  – Reference voltage set on AIN1.
  – If system becomes over pressure interrupt generated which can shut down the system safely.
AC Connection

**Figure 21-1. Analog Comparator Block Diagram**

- **BANDGAP REFERENCE**
- **ACBG**
- **AIN0**
- **AIN1**
- **ACME**
- **ADEN**
- **ADC MULTIPLEXER OUTPUT**
- **ACD**
- **VCC**
- **INTERRUPT SELECT**
- **ACIS1**
- **ACIS0**
- **ACIE**
- **ANALOG COMPARATOR IRQ**
- **ACI**
- **ACIC**
- **ACO**
- **TO T/C1 CAPTURE TRIGGER MUX**
Il Matto Specifics

- AINn shared with USB
- Cannot use USB simultaneously
- Note R3
AVR AC Configuration

Comparator \( \{A+ \in \{\text{AIN0, VBG}\}, \text{A-} \in \{\text{AIN1, PA_n}\}, \ n \in \{0, \ldots, 7\}, \ c \in \{\_\_\, \_\, \_\_\, \} \}\) 

ACSR &= \_BV(ACBG); /* AIN0 Select */
ADCSRB &= \_BV(ACME); /* AIN1 Select */
ACSR |= \_BV(ACBG); /* Analog Comparator Bandgap Select (1.1V) */
ADCSRA &= \_BV(ADEN); /* Disable ADC */
ADCSRB |= \_BV(ACME); /* Analog Comparator Multiplexer Enable */
ADMUX = n; /* Select input PA_n */
ACSR &= \_BV(ACIE); /* Disable Interrupt */
ISR(ANALOG_COMP_vect) { /* Handler code */ }
ACSR |= \_BV(ACIS1) | \_BV(ACIS0); /* c=\_\_ */
ACSR |= \_BV(ACIE); /* Enable Interrupt */

The AC pins AIN0 and AIN1 are shared with the USB connection on the Il Matto board. Do not use these inputs when the USB cable is connected.