Arbeitskreis Hardware

Prof. Dr. Michael Rohs, Dipl.-Inform. Sven Kratz
michael.rohs@ifi.lmu.de
MHCI Lab, LMU München
# Schedule (preliminary)

<table>
<thead>
<tr>
<th>Date</th>
<th>Topic (preliminary)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5.</td>
<td>Introduction to embedded interaction, microcontrollers, hardware &amp; software tools</td>
</tr>
<tr>
<td>9.5.</td>
<td><em>keine Veranstaltung (CHI)</em></td>
</tr>
<tr>
<td>16.5.</td>
<td>soldering ISP adapter, AVR architecture</td>
</tr>
<tr>
<td>23.5.</td>
<td>LED displays, LED multiplexing, transistors, electronics basics</td>
</tr>
<tr>
<td>30.5.</td>
<td>AVR architecture, AVR assembler, sensors: light, force, capacity, acceleration, etc.</td>
</tr>
<tr>
<td>6.6.</td>
<td>PCB design &amp; fabrication, EAGLE, 3D printing</td>
</tr>
<tr>
<td>13.6.</td>
<td><em>keine Veranstaltung (Pfingsten)</em></td>
</tr>
<tr>
<td>20.6.</td>
<td>I2C: interfacing to other chips (EEPROM, real-time clock, digital sensors)</td>
</tr>
<tr>
<td>27.6.</td>
<td>Displays (character LCDs, graphics LCDs), audio (speakers, amplification, op-amps)</td>
</tr>
<tr>
<td>4.7.</td>
<td>Actuation: stepper motors, servo motors</td>
</tr>
<tr>
<td>11.7.</td>
<td>Communication: fixed-frequency RF, ZigBee, Bluetooth</td>
</tr>
<tr>
<td>18.7.</td>
<td>Project</td>
</tr>
<tr>
<td>25.7.</td>
<td>Project</td>
</tr>
</tbody>
</table>
LEDs

• Quickly switchable, power-efficient light sources
  – different types covering different parts of the visible spectrum (and beyond: IR LEDs, UV LEDs)

• Anode (long lead) goes to positive potential

• Cathode (short lead) goes to negative potential

• LEDs operate like voltage-controlled switches
  – little current below turn-on voltage (silicon: 0.7V)
  – very high current above → LEDs need current-limiting resistors

• LEDs are diodes: no current in reverse direction

• Typical forward current: 20mA, typical forward voltage 2V
LEDs

- Intensity of light proportional to current
  - can also use PWM to control brightness
  - light covers narrow spectrum only, except for white LEDs

- Forward voltage drop depends on color, e.g.:

<table>
<thead>
<tr>
<th>Color</th>
<th>Fwd. current</th>
<th>Fwd. voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>red</td>
<td>20mA</td>
<td>2.0V</td>
</tr>
<tr>
<td>green</td>
<td>20mA</td>
<td>3.5V</td>
</tr>
<tr>
<td>blue</td>
<td>20mA</td>
<td>3.7V</td>
</tr>
<tr>
<td>white</td>
<td>20mA</td>
<td>3.5V</td>
</tr>
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</table>

- Can go up to 100mA (peak current)
Example: Blue LED Voltage Drop

- $U_f = 3.2\,\text{V}$, $I_f = 20\,\text{mA}$
- Current limiting resistor: $U_R = U - U_f = 5 - 3.2 = 1.8\,\text{V}$
  $R = \frac{U_R}{I} = \frac{1.8\,\text{V}}{0.020\,\text{A}} = 90\,\Omega$

$$R_f = \frac{U_f}{I}$$
LED Brightness Experiment

• Assume LED brightness is proportional to current
• Is PWM duty cycle proportional to brightness? Hypothesis?
• For increasing values of PWM duty cycle value $d$
  – Set $d$ for LED$_1$
  – Control current through LED$_2$ to match brightness of LED$_1$
    • Match brightness with potentiometer
    • Measure current

• Draw curve
  – x-axis = current
  – y-axis = matching PWM duty cycle value

• Check whether duty cycle is proportional to current (and thus brightness)
RGB LEDs

• Red, green, and blue in one package
• Different forward voltages ($I_f = 20\text{mA}$):
  - $U_{f,\text{red}} = 2.0\text{V}$
  - $U_{f,\text{green}} = 2.2\text{V}$
  - $U_{f,\text{blue}} = 3.8\text{V}$

• Example (right): $30^\circ$ angle, 2x blue

Source: Kingbright Datasheet
LED Displays: 7-Segment, 10-Bar

- **7-segment display (green)**
  - $U_f = 2.2V$, $I_f = 20mA$

- **10-bar display (red)**
  - $U_f = 2.0V$, $I_f = 20mA$

Source: Kingbright Datasheet
LED Displays: 5x7-Matrix

- 5x7 dot matrix display (red)
  - $U_f = 2.25\,\text{V}$, $I_f = 20\,\text{mA}$

- Check total power consumption
  - ATtiny can only drive up to 40mA per pin
  \[\rightarrow\] use transistor if necessary

Source: Kingbright Datasheet
More LEDs than µC Pins

- 8-bit serial-in, parallel-out shift register 74LS164N

- \( Q_A = A \) and \( B \), unused input must be \( H \)
- CLK: low-to-high shifts data one place right
- maximum clock frequency: 25 MHz
- \( V_{cc} = 5V \), \( I_{cc} = 16mA \)
- \( I_{os} = -10..-27.5mA \) (short-circuit output current)
Driving more LEDs with a transistor

- Given
  VCC = 5V
  red LEDs: $U_F = 2V$, $I_F = 20mA$
  BC548A: $I_{C,max} = 100mA$, current gain $\beta = h_{FE} = 110..220$

- Drive 5 LEDs: 100mA
  $h_{FE} = 120$ (@$I_C = 100mA, V_{CE} = 5V$)
  $V_{CE(sat)} = 0.2V$ (@$I_C = 100mA, V_{CE} = 5V$)
  $V_{BE(sat)} = 0.7V$ (@$I_C = 100mA, V_{CE} = 5V$)

- $R, R_B$?
  $U_R = Vcc - V_{CE(sat)} - V_F$
  $R = U_R / I_F$
  $I_C = h_{FE} I_B$
Behavior of Transistors (active region)

NPN (e.g. BC548)

\[ I_C = h_{FE} I_B = \beta I_B \approx I_E \]
\[ V_C = ? \]
\[ V_E = V_B - 0.6V \]
\[ I_E = (h_{FE} + 1) I_B \approx I_C \]

PNP (e.g. BC558)

\[ I_C = h_{FE} I_B = \beta I_B \approx I_E \]
\[ V_C = ? \]
\[ V_E = V_B + 0.6V \]
\[ I_E = I_C + I_B \approx I_C \]
Typical Characteristics of BC548

- $I_C = h_{FE} I_B = \beta I_B$
- $I_E = I_C + I_B$
- $I_E \approx I_C$

Source: Vishay Datasheet

Figure 2. DC Current Gain vs. Collector Current

Figure 7. Collector Saturation Voltage vs. Collector Current
EXAMPLE 1  Given $V_{CC} = +20\, \text{V}$, $V_B = 5.6\, \text{V}$, $R_1 = 4.7\, \text{k}\Omega$, $R_2 = 3.3\, \text{k}\Omega$, and $h_{FE} = 100$, find $V_E$, $I_E$, $I_B$, $I_C$, and $V_C$.

\[ V_{CC} = 20\, \text{V} \]

\[ V_B = 5.6\, \text{V} \]

\[ R_1 = 4.7\, \text{k}\Omega \]

\[ R_2 = 3.3\, \text{k}\Omega \]

\[ I_E = V_B - 0.6 \, \text{V} \]

\[ V_E = 5.6\, \text{V} - 0.6 \, \text{V} = 5.0 \, \text{V} \]

\[ I_E = \frac{V_E - 0 \, \text{V}}{R_2} = \frac{5.0 \, \text{V}}{3300 \, \Omega} = 1.5 \, \text{mA} \]

\[ I_B = \frac{I_E}{(1 + h_{FE})} = \frac{1.5 \, \text{mA}}{(1 + 100)} = 0.015 \, \text{mA} \]

\[ I_C = I_E - I_B \approx I_E = 1.5 \, \text{mA} \]

\[ V_C = V_{CC} - I_C R_1 \]

\[ V_C = 20 \, \text{V} - (1.5 \, \text{mA})(4700 \, \Omega) \]

\[ V_C = 13 \, \text{V} \]

**Example 2** Given $V_{CC} = +10\,\text{V}$, $V_B = 8.2\,\text{V}$, $R_1 = 560\,\text{Ω}$, $R_2 = 2.8\,\text{kΩ}$, and $h_{FE} = 100$, find $V_E$, $I_E$, $I_B$, $I_C$, and $V_C$.

\[ V_{CC} = +10\,\text{V} \]

\[ V_B = 8.2\,\text{V} \]

\[ I_E, R_1 = 560\,\text{Ω} \]

\[ I_B \]

\[ I_C, R_2 = 2.8\,\text{kΩ} \]

\[ V_E = V_B + 0.6\,\text{V} \]

\[ V_E = 8.2\,\text{V} + 0.6\,\text{V} = 8.8\,\text{V} \]

\[ I_E = \frac{V_{CC} - V_E}{R_1} = \frac{10\,\text{V} - 8.8\,\text{V}}{560\,\text{Ω}} = 2.1\,\text{mA} \]

\[ I_B = \frac{I_E}{(1 + h_{FE})} = \frac{2.1\,\text{mA}}{(1 + 100)} = 0.02\,\text{mA} \]

\[ I_C = I_E - I_B = I_E = 2.1\,\text{mA} \]

\[ V_C = 0\,\text{V} + I_C R_2 \]

\[ V_C = 0\,\text{V} + (2.1\,\text{mA})(2800\,\text{Ω}) \]

\[ V_C = 5.9\,\text{V} \]

Transistors

• BD139 – NPN
  – maximum ratings:
    \( I_C = 1.5\text{A}, I_B = 0.5\text{A} \)
  – \( V_{CE(sat)} = 0.5\text{V}, V_{BE} = 1\text{V} \)
  – \( h_{FE} = 63..160 \) @ \( I_C = 150\text{mA}, V_{CE} = 2\text{V} \)

• BD140 – PNP
  – maximum ratings:
    \( I_C = -1.5\text{A}, I_B = -0.5\text{A} \)
  – \( V_{CE(sat)} = -0.5\text{V}, V_{BE} = -1\text{V} \)
  – \( h_{FE} = 40..250 \) @ \( I_C = -150\text{mA}, V_{CE} = -2\text{V} \)
Multiplexing LEDs

Multiplexing LEDs

Charlieplexing LEDs

- Enables one LED at a time
  - N LEDs, each only on 1/N<sup>th</sup> of the time
- Z = tri-state (high impedance state, “no” current)

<table>
<thead>
<tr>
<th>LED</th>
<th>Pin1</th>
<th>Pin2</th>
<th>Pin3</th>
</tr>
</thead>
<tbody>
<tr>
<td>D1</td>
<td>1</td>
<td>0</td>
<td>Z</td>
</tr>
<tr>
<td>D3</td>
<td>Z</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>D6</td>
<td>1</td>
<td>Z</td>
<td>0</td>
</tr>
<tr>
<td>D4</td>
<td>Z</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>D2</td>
<td>0</td>
<td>1</td>
<td>Z</td>
</tr>
<tr>
<td>D5</td>
<td>0</td>
<td>Z</td>
<td>1</td>
</tr>
</tbody>
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Source: Wikipedia, Author: Dan Kouba, public domain
Exercise: Controlling LEDs

• Control brightness of two LEDs with PWM
  – Attach 2 LEDs to an ATtiny13
  – Periodically
    • Over 2s: increase brightness of LED\textsubscript{1} from dark to maximum, decrease brightness LED\textsubscript{2} from maximum to dark
    • Over 2s: increase brightness of LED\textsubscript{2} from dark to maximum, decrease brightness LED\textsubscript{1} from maximum to dark
    • Over 2s: no change in LED brightness
  – Use timers and interrupts as needed

• Control brightness of an LED using PWM and two buttons
  – Attach LED to an ATtiny13
  – While button\textsubscript{1} is pressed, slowly increase brightness
  – While button\textsubscript{2} is pressed, slowly decrease brightness
Button De-Bouncing

- Activate pull-up resistor on pin
  - Pull-up puts pin into defined state
  - (see previous slides on pin configurations)

- Connect button to GND
  - Pin will be high until button pressed

- De-Bouncing
  - Button contacts bounce, which generates many spikes
  - Hardware solutions: SR latch, capacitor
  - Software solution:
    - wait for 10-20ms after first event

Source: Wikipedia, Author: Tomoldbury, public domain
74HC138: 3-to-8 Line Decoder/Demultiplexer

- Input $x = \text{not}(E1) \text{ and not}(E2) \text{ and } E3$
- Address lines $A0,A1,A2$ to select output $Y_{A0,A1,A2}$
- Output $Y_{A0,A1,A2} = \text{not}(x)$
- other outputs: $Y_i = 1$
- $V_{cc} = 5V$
- $I_{\text{OUT}} = \pm25mA$

Source: Philips Datasheet
74HC154: 4-to-16 Line Decoder/Demultiplexer

- Input $x = (E1 \text{ or } E2)$
- Address lines $A0, A1, A2$ to select output $Y_{A0, A1, A2}$
- Output $Y_{A0, A1, A2} = x$
- Other outputs: $Y_i = 1$
- $V_{cc} = 5V$
- $I_{OUT} = \pm 50mA$

Source: Harris Semiconductor Datasheet