Atmel AT03030: QMatrix Touchpad – 2D Position Tracking

Atmel QTouch

Features

- Two-dimensional position tracking using touch sensors
- Single tap detection
- Supports single finger operation
- Sensor design guidelines
- X-Y position reported in serial terminal
- 400dpi resolution
- Status LEDs

Introduction

This reference design demonstrates techniques to use QMatrix touch sensors for 2D position tracking application. ATxmega16D4 device is used in this touchpad design. X-Y position determined is displayed in PC HyperTerminal through USART interface. This design is suitable only for single-touch operation.

The firmware solution provided consists of QMatrix library, Touchpad library, USART driver and status LED control code. Firmware is written in C and supports GCC (Atmel® Studio) tool-chain.

This reference design can be used for low cost and low resolution touchpad applications, up to a maximum resolution of 400dpi. Applications that require higher resolution (more than 400dpi) and additional features like multi-touch can use the Atmel maXTouch® solution.

For this reference design, the hardware design files (schematic, BOM and PCB Gerber) and software source code can be downloaded from Atmel website. The provided hardware documentation can be used with no limitations to manufacture the reference hardware solution for the design.
**Table of Contents**

1. Abbreviations and Definitions .............................................................. 3

2. Hardware Design ..................................................................................... 4
   2.1 System Block Diagram ........................................................................ 4
   2.2 Sensor Design .................................................................................. 6
      2.2.1 Design Guidelines .................................................................... 7
      2.2.1.1 Sensor Arrangement .......................................................... 9
   2.3 LED Indication .................................................................................. 9
   2.4 Communication Interface ................................................................... 9
   2.5 Power Supply Considerations ........................................................... 11
      2.5.1 USB Supply ............................................................................. 11
      2.5.2 External Supply ....................................................................... 11
      2.5.3 On-board Regulator ................................................................. 11
   2.6 Programming and Debugging ............................................................. 11
      2.6.1 PDI Interface ........................................................................... 11
      2.6.2 Touch Data ............................................................................. 11

3. Firmware .................................................................................................. 12
   3.1 Touchpad Library ............................................................................. 12
      3.1.1 touchpad.h – header file .......................................................... 12
      3.1.2 Public functions ....................................................................... 12
         3.1.2.1 qt_init_touchpad ............................................................. 12
   3.2 QMatrix Library ................................................................................. 13
   3.3 USART Module .................................................................................. 14
   3.4 LED Interface ................................................................................... 14
   3.5 Application Code .............................................................................. 14
      3.5.1 Single Tap Detection ................................................................. 16

4. Schematic Design .................................................................................... 17

5. PCB Layout ............................................................................................ 19

6. Bill of Materials (BOM) ......................................................................... 21

7. References ............................................................................................. 22

Appendix A. Sensor Pattern for Flooded-X (Two-Layer) Design ........... 23

Appendix B. Revision History ................................................................. 24
1. Abbreviations and Definitions

Following is a list of terms which will be used throughout this document.

- **Acquisition**: A single capacitive measurement process.
- **QMatrix (Mutual Capacitance)**: A type of capacitive touch sensing technology that measures the mutual capacitance between two electrodes. Each channel has a drive electrode (X Electrode) and a receive electrode (Y Electrode).
- **X Line**: The Sense Line connected to the X Electrode used in QMatrix Technology.
- **Y Line**: The Sense Line connected to the Y Electrode used in QMatrix Technology.
- **SMP**: Sampling pin used in QMatrix Sensor Design.
- **AIN0**: Analog ground Reference pin used in QMatrix Design.
- **Sensor**: A channel or group of channels used to form a touch sensor. The three types of sensors are Buttons, Sliders and Wheels.
- **Button (zero-dimensional sensor)**: It is a zero dimensional sensor used to implement On/Off digital sensors, and is composed of a single channel. It is also known as a Key.
- **Coplanar (Single Layer) design**: Both X and Y electrodes fabricated on the same layer of the PCB in QMatrix sensor design.
- **Flooded-X (Two-Layer) design**: Both X and Y electrodes are distributed in two layers of the PCB in QMatrix sensor design.
- **Atmel QTouch® Library**: The set of libraries for the touch sensing technologies offered by Atmel (QTouch, QTouchADC and QMatrix).
- **Channel**: A channel is a logical group of pins used to perform the touch acquisition measurement. It can be composed of a single pin (QTouchADC), a pair of pins (QTouch) or a matrix of pins (QMatrix).
- **Sense Electrode**: Electrodes are typically areas of copper on a printed circuit board. An electrode or a pair of electrodes used to detect a finger touch.
- **Delta**: Difference between Reference and Signal value of sensors.
- **Detection threshold**: It defines how much the touch sensor’s signal value must drop below its reference level to qualify as a potential touch detect.
- **2D**: Indicates Two – Dimensional.

For more details refer to **BSW Touch Sensor Design Guide** and **Atmel QTouch Library User Guide**.
2. Hardware Design

2.1 System Block Diagram
The generic block diagram of this reference design is provided in Figure 2-1.

Figure 2-1. System Block Diagram
Touchpad design comprises of 56 touch sensors organized using 8 X lines and 7 Y lines. Table 2-1 provides pin configuration used in touchpad sensor design. QMatrix touch sensors require $X + 2Y + 2$ general-purpose I/O pins for realization, as shown in Figure 2-2.

Figure 2-2. Typical QMatrix Circuit

Table 2-1. Pin Configuration for Touchpad

<table>
<thead>
<tr>
<th>ATxmega16D4 GPIO Pin</th>
<th>Pin Description</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>PD4</td>
<td>X0</td>
<td>Configurable I/O Pin</td>
</tr>
<tr>
<td>PD5</td>
<td>X1</td>
<td>Configurable I/O Pin</td>
</tr>
<tr>
<td>PD6</td>
<td>X2</td>
<td>Configurable I/O Pin</td>
</tr>
<tr>
<td>PD7</td>
<td>X3</td>
<td>Configurable I/O Pin</td>
</tr>
<tr>
<td>PE0</td>
<td>X4</td>
<td>Configurable I/O Pin</td>
</tr>
<tr>
<td>PE1</td>
<td>X5</td>
<td>Configurable I/O Pin</td>
</tr>
<tr>
<td>PE2</td>
<td>X6</td>
<td>Configurable I/O Pin</td>
</tr>
<tr>
<td>PE3</td>
<td>X7</td>
<td>Configurable I/O Pin</td>
</tr>
<tr>
<td>PC0</td>
<td>Y0A</td>
<td>Configurable I/O Pin</td>
</tr>
<tr>
<td>PC1</td>
<td>Y1A</td>
<td>Configurable I/O Pin</td>
</tr>
<tr>
<td>PC2</td>
<td>Y2A</td>
<td>Configurable I/O Pin</td>
</tr>
<tr>
<td>PC3</td>
<td>Y3A</td>
<td>Configurable I/O Pin</td>
</tr>
<tr>
<td>PC4</td>
<td>Y4A</td>
<td>Configurable I/O Pin</td>
</tr>
<tr>
<td>PC5</td>
<td>Y5A</td>
<td>Configurable I/O Pin</td>
</tr>
<tr>
<td>PC6</td>
<td>Y6A</td>
<td>Configurable I/O Pin</td>
</tr>
<tr>
<td>PA0</td>
<td>Y0B</td>
<td>ADC Port Pin</td>
</tr>
</tbody>
</table>
2.2 Sensor Design

Sensor design is very important for designing touchpad using zero-dimensional touch sensors (buttons), which is used to determine 2D position. Accuracy and resolution of touch position is greatly dependent on Touch Sensor design.

The touchpad design consists of a set of sensors arranged in rows and columns to form a matrix. The reference design uses a sensor pattern of eight rows (X lines) and seven columns (Y lines) similar to 56 touch keys. Mutual capacitance (QMatrix) method is used in this design. Sensor Design uses Coplanar (Single Layer) method and 1mm thick front panel is used.

Coplanar design provides flexibility for controlling the sensitivity, by adjusting XY gap in sensor electrode. This allows usage of thicker front panel. This method can be easily implemented on a flex PCB.

Refer Figure 2-3 for sensor pattern used in this reference design.

**Figure 2-3. Coplanar (Single Layer) Sensor Design**

<table>
<thead>
<tr>
<th>PA1</th>
<th>Y1B</th>
<th>ADC Port Pin</th>
</tr>
</thead>
<tbody>
<tr>
<td>PA2</td>
<td>Y2B</td>
<td>ADC Port Pin</td>
</tr>
<tr>
<td>PA3</td>
<td>Y3B</td>
<td>ADC Port Pin</td>
</tr>
<tr>
<td>PA4</td>
<td>Y4B</td>
<td>ADC Port Pin</td>
</tr>
<tr>
<td>PA5</td>
<td>Y5B</td>
<td>ADC Port Pin</td>
</tr>
<tr>
<td>PA6</td>
<td>Y6B</td>
<td>ADC Port Pin</td>
</tr>
<tr>
<td>PC7</td>
<td>SMP</td>
<td>Sampling Pin</td>
</tr>
<tr>
<td>PA7</td>
<td>AIN0</td>
<td>Analog Ground Reference Pin</td>
</tr>
</tbody>
</table>
2.2.1 Design Guidelines

Sensor Design guidelines specific to touchpad design is listed below:

- Fundamental guideline is to place the sensors in close proximity as shown in Figure 2-4. To locate sensors closely follow the below recommendation.
  - Sensors that share same X line, the X regions can be merged. As shown in Figure 2-4, each row has seven sensors sharing same X line but uses different Y line and so there is no gap between the sensors horizontally.
  - Sensors using different X lines need to have minimal separation, which should be maintained between 0.1mm to 0.5mm gap. As shown in Figure 2-4, each column has eight sensors sharing same Y line but uses different X line. So minimal gap is maintained between the sensors vertically.

- Touchpad sensor pattern is formed using sensors arranged in rows and columns organized as a matrix. Touchpad library implementation puts restrictions on the number of rows / columns in the design.
  - Minimum number of rows / columns that can be used is limited to two.
  - Maximum number of rows / columns that can be used is limited to eight.

- Segment size of the sensor for a given X and Y line should be in the range 5mm to 8mm.
  - Segment size of sensor used beyond 8mm will not have proper linearity and have low resolution.

- Touchpad designs that use small segment size say 5mm x 5mm, Flooded-X (Two-Layer) design is preferred. Since it is difficult to realize Coplanar (Single layer) touchpad designs for small segment size. Refer Figure 2-5 for spacing recommendations for Flooded-X (Two-Layer) design.

- Shape of the touchpad sensor pattern should be rectangular or square. Other fancy shapes are not recommended, as they may not provide expected results.

- No additional touch sensor should be designed using same Atmel MCU used to design touchpad.
  - This is restricted by touchpad library implementation.

- Resolution is mainly dependent on sensor size and number of sensors used to form sensor pattern.
  - Better resolution can obtained using many sensors of small segment size.
  - Designs using few sensors which are bigger in size, the resolution achieved will be low.

For general Sensor Design Guidelines refer to “BSW Touch Sensor Design Guide”.
Figure 2-4. Recommended Spacing for Coplanar (Single Layer) Design

- 'T' refers to Front panel thickness used in design.

Figure 2-5. Recommended Spacing for Flooded-X (Two Layer) Design
2.2.1.1 Sensor Arrangement

Sensors in touchpad should be connected sequential as shown in Figure 2-6.

In this reference design, 56 sensors are arranged in the below order for 8 X lines and 7 Y lines.

**Figure 2-6. Sensor Arrangement**

<table>
<thead>
<tr>
<th>X0</th>
<th>X1</th>
<th>X2</th>
<th>X3</th>
<th>X4</th>
<th>X5</th>
<th>X6</th>
<th>X7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y0</td>
<td>S0</td>
<td>S1</td>
<td>S2</td>
<td>S3</td>
<td>S4</td>
<td>S5</td>
<td>S6</td>
</tr>
<tr>
<td>Y1</td>
<td>S8</td>
<td>S9</td>
<td>S10</td>
<td>S11</td>
<td>S12</td>
<td>S13</td>
<td>S14</td>
</tr>
<tr>
<td>Y2</td>
<td>S16</td>
<td>S17</td>
<td>S18</td>
<td>S19</td>
<td>S20</td>
<td>S21</td>
<td>S22</td>
</tr>
<tr>
<td>Y3</td>
<td>S24</td>
<td>S25</td>
<td>S26</td>
<td>S27</td>
<td>S28</td>
<td>S29</td>
<td>S30</td>
</tr>
<tr>
<td>Y4</td>
<td>S32</td>
<td>S33</td>
<td>S34</td>
<td>S35</td>
<td>S36</td>
<td>S37</td>
<td>S38</td>
</tr>
<tr>
<td>Y5</td>
<td>S40</td>
<td>S41</td>
<td>S42</td>
<td>S43</td>
<td>S44</td>
<td>S45</td>
<td>S46</td>
</tr>
<tr>
<td>Y6</td>
<td>S48</td>
<td>S49</td>
<td>S50</td>
<td>S51</td>
<td>S52</td>
<td>S53</td>
<td>S54</td>
</tr>
</tbody>
</table>

2.3 LED Indication

Two LEDs are used to indicate the single tap and touchpad state. These LEDs are driven by BC847B transistor. The state of the transistor is controlled by connected ATxmega16D4 GPIO pin.

LED1 is configured for single tap indication. This is set to operate in toggle mode. The LED1 turns ON when single tap event is detected first time and turns OFF in the subsequent single tap detection.

LED2 is configured to indicate touchpad active status. This LED will be in ON as long as there is a touch.

Table 2-2 details pin configuration used for LEDs.

**Table 2-2. Pin Configuration for LEDs**

<table>
<thead>
<tr>
<th>GPIO Pin</th>
<th>Pin Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>PD0</td>
<td>LED1</td>
</tr>
<tr>
<td>PD1</td>
<td>LED2</td>
</tr>
</tbody>
</table>

2.4 Communication Interface

Serial communication using USART interface is used to display the touchpad X-Y position on HyperTerminal of host PC. Figure 2-7 shows the communication header available on the PCB. Table 2-3 details pin configuration of USARTD0 used in touchpad.

**Table 2-3. Pin Configuration for USART**

<table>
<thead>
<tr>
<th>GPIO Pin</th>
<th>Pin Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>PD3</td>
<td>USART_TX</td>
</tr>
<tr>
<td>PD2</td>
<td>USART_RX</td>
</tr>
</tbody>
</table>
Figure 2-7. Communication Header

Figure 2-8. Communication Signals – USART

Figure 2-9 shows PC HyperTerminal screenshot, with X-Y Position display and Single tap indication.

Figure 2-9. X-Y Position Display
2.5 Power Supply Considerations

The reference design can be powered by using any of the following power supply sources.

2.5.1 USB Supply

The reference board can be powered with the Mini-B USB header available on the board. This supply acts as a source of power to the on-board voltage regulator and power indication LED.

2.5.2 External Supply

The reference board can be powered using +5V external supply. Power can be provided using J7 header available on board. This also acts as source of power to the on-board voltage regulator and power indication LED.

2.5.3 On-board Regulator

A linear drop-out regulator, which is mounted on the board acts as a regulated power supply source for the Atmel ATxmega16D4 device. This on-board regulator can be bypassed using zero Ohm resistor provision available. In such case, external supply provided should be +3.3V.

Using external supply, which is not regulated by the on-board regulator, should adhere to the power supply considerations mentioned in the application note Atmel AT02259: QTouch® Schematic and Layout Checklist.

2.6 Programming and Debugging

2.6.1 PDI Interface

The ATxmega16D4 device can be programmed using PDI interface. The on-board PDI header can be used for programming the device. This can also be used for On-Chip Debugging (OCD). Figure 2-10 shows the programming header available on the PCB.

Figure 2-10. Programming Header

![Programming Header Diagram]

2.6.2 Touch Data

Touch data is transmitted using QDebug protocol through Bit Bang SPI interface. QT600 USB Interface Bridge is used to transmit touch data to QTTouch Analyzer. The real time touch data can be used for debugging and analysis. Table 2-4 shows pins configured for QDebug in Touch Data Header available.

Table 2-4. Pin Configuration for Touch Data Debug

<table>
<thead>
<tr>
<th>ATxmega16D4 GPIO Pin</th>
<th>Pin Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>PB0</td>
<td>DBG_MISO</td>
</tr>
<tr>
<td>PB1</td>
<td>DBG_SS</td>
</tr>
<tr>
<td>PB2</td>
<td>DBG_MOSI</td>
</tr>
<tr>
<td>PB3</td>
<td>DBG_SCK</td>
</tr>
</tbody>
</table>
3. Firmware

Figure 3-1. Firmware Block Diagram

3.1 Touchpad Library

Touchpad library (*libtouchpad.a*) is a software library which calculates X-Y position of the touchpad sensor for the given resolution. This library is built for the Atmel ATxmega16D4 device and linked into application code to calculate the X-Y position.

This library is available as part of firmware that can be downloaded along with this document.

The below sections provides details of touchpad library APIs and its usage.

3.1.1 touchpad.h – Header File

The `touchpad.h` header file which needs to be included in user’s application and it has the type definitions and function prototypes of the API’s needs to be used for touchpad X-Y calculation.

3.1.2 Public Functions

This section provides details of touchpad library public functions and its usage.

3.1.2.1 qt_init_touchpad

Table 3-1. qt_init_touchpad

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>qt_init_touchpad</code>&lt;br&gt;<code>uint8_t num_x, uint8_t num_y, xy_resolution_t resolution, uint8_t position_hysteresis</code>&lt;br&gt;<code>uint8_t num_x, uint8_t num_y, xy_resolution_t resolution, uint8_t position_hysteresis)</code>&lt;br&gt;<code>uint8_t</code>&lt;br&gt;<code>uint8_t</code>&lt;br&gt;<code>uint8_t</code>&lt;br&gt;<code>uint8_t</code></td>
<td>Initializes touchpad library with the input parameters provided&lt;br&gt;Input: num_x: Number of X lines of the touchpad sensor&lt;br&gt;num_y: Number of Y lines of the touchpad sensor&lt;br&gt;resolution: Number of positions to be reported per sensor area&lt;br&gt;position_hysteresis: Hysteresis of reported X-Y position value&lt;br&gt;Output: None&lt;br&gt;Return: Returns TRUE if successful or FALSE otherwise</td>
</tr>
</tbody>
</table>
Resolution

Resolution is the number of positions to be reported for each sensor area. It can have values from four to seven bits (16 to 128 positions).

The total resolution for X-axis = no. of X lines * no. of positions for one sensor.

The total resolution for Y-axis = no. of Y lines * no. of positions for one sensor.

Touchpad resolution (dpi) = no. of sensors available in 1 inch area * no. of positions for one sensor.

Where, no. of sensors available in 1 inch area = 1 inch area in mm / 1 sensor area in mm.

In this reference design, one sensor area is 8mm x 8mm and firmware uses seven bit position resolution. Using above calculation, touchpad resolution for this design is 406 dpi.

Table 3-2, shows position and resolution possible with 8X x 7Y sensor configuration with one sensor area 8mm x 8mm for different resolution inputs.

Table 3-2. Touchpad Position Resolution

<table>
<thead>
<tr>
<th>Resolution [bits]</th>
<th>Positions Per Sensor</th>
<th>X-axis Positions</th>
<th>Y-axis Positions</th>
<th>Touchpad Resolution [dpi]</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>128</td>
<td>1024</td>
<td>896</td>
<td>406</td>
</tr>
<tr>
<td>6</td>
<td>64</td>
<td>512</td>
<td>448</td>
<td>203</td>
</tr>
<tr>
<td>5</td>
<td>32</td>
<td>256</td>
<td>224</td>
<td>102</td>
</tr>
<tr>
<td>4</td>
<td>16</td>
<td>128</td>
<td>112</td>
<td>51</td>
</tr>
</tbody>
</table>

Resolution Range: 4 to 7 bits.

Position Hysteresis

It is the number of positions the user has to move back, before the new X-Y touch position is reported when the direction of scrolling is changed. This is used to avoid jittering in the reported X-Y position.

Hysteresis can range from 0 (1 position) to 7 (8 positions). Hysteresis setting can be used when the reported position jitters due to noise effects.

Position Hysteresis Range: 0 to 7.

3.1.2.2 qt_get_xy

Table 3-3. qt_init_touchpad

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>touch_position_t qt_get_xy(void)</td>
<td>Calculates X-Y position and returns it</td>
</tr>
<tr>
<td>Input</td>
<td>None</td>
</tr>
<tr>
<td>Output</td>
<td>None</td>
</tr>
<tr>
<td>Return</td>
<td>Updates the X and Y values computed in structure ‘touch_position_t’</td>
</tr>
</tbody>
</table>

3.2 QMatrix Library

QMatrix library is a software library which performs touch acquisition and post-processing. This reference design uses ATxmega16D4 8X x 7Y sensor configuration library which supports up to 56 channels.

3.3 **USART Module**

USART Module consists of USART driver code and functions to convert integer to ASCII to display X-Y Position in HyperTerminal of host PC using RS232 interface. This module is sending data using polling method. ATxmega16D4 USARTD0 peripheral is used and it is configured as below.

- **Baud rate**: 115200
- **Start bits**: 1
- **Data bits**: 8
- **Parity**: Disabled
- **Stop bits**: 1

3.4 **LED Interface**

This module controls LED indication for the single tap and touchpad state.

3.5 **Application Code**

The application code implementation flow is provided in the Figure 3-2.
Measurement period depends on touch acquisition duration and USART transmission time. In this firmware solution, measurement period is set to 30ms.

Note: Things to be taken care while tuning the Touchpad sensor: QTouch Analyzer can be used for tuning purpose.
• The delta for each sensor in the touchpad should be peaking at the same amplitude. This gives improved linearity of reported X-Y position and also uniform sensitivity across the touchpad. Burst Length can be adjusted to compensate for imbalance.
• Make sure the delta for each sensor in the touchpad peak at around 25 counts and above. If touch delta is not enough to calculate position, the reported X-Y position can be jittery.
• Set the Detection Threshold for each sensor in the touchpad to report a touch when the finger lightly contacts the touchpad surface.

3.5.1 Single Tap Detection

Firmware solution provides demonstration of single tap detection feature. This single tap detection is indicated using LED and also indicated in PC HyperTerminal. The LED toggles for every single tap detection.

Note: Below listed features also can be implemented in user application code.

• Double-tap detection
• Horizontal Scroll detection
• Vertical Scroll detection
4. Schematic Design

Figure 4-1. Schematic – Part 1
Figure 4-2. Schematic – Part 2
5. PCB Layout

Figure 5-1. Top Layer
Figure 5-2. Bottom Layer
### 6. Bill of Materials (BOM)

**Table 6-1. BOM**

<table>
<thead>
<tr>
<th>Description</th>
<th>Designator</th>
<th>Qty.</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ceramic capacitor, SMD 0603, X7R, 50V, ±10%</td>
<td>C1, C2, C3, C4, C5, C6, C7</td>
<td>7</td>
<td>22nF</td>
</tr>
<tr>
<td>Ceramic capacitor, SMD 0603, X7R, 50V, ±10%</td>
<td>C8, C9, C10, C11, C24, C25, C26, C27, C28, C32</td>
<td>10</td>
<td>100nF</td>
</tr>
<tr>
<td>Ceramic capacitor, SMD 0603, NPO, 100V, ±1%</td>
<td>C13, C14</td>
<td>1</td>
<td>1nF</td>
</tr>
<tr>
<td>SMD tantalum capacitor, 35V</td>
<td>C23, C31, C33</td>
<td>3</td>
<td>47µF</td>
</tr>
<tr>
<td>Ceramic capacitor, SMD 0603, X7R, 16V, ±10%</td>
<td>C29, C30</td>
<td>1</td>
<td>4µ7</td>
</tr>
<tr>
<td>Yellow SMD LED</td>
<td>D1</td>
<td>1</td>
<td>Power indication</td>
</tr>
<tr>
<td>Yellow SMD LED</td>
<td>LED1, LED2</td>
<td>2</td>
<td>Single tap and touchpad state indication</td>
</tr>
<tr>
<td>BJT Transistor, NPN</td>
<td>Q3, Q4</td>
<td>2</td>
<td>BC847B</td>
</tr>
<tr>
<td>Thick film resistor, SMD 0603, 1/10W, 1%</td>
<td>R1, R2, R3, R4, R5, R6, R7, R8, R9, R10, R11, R12, R13, R14, R15, R24, R26, R46</td>
<td>18</td>
<td>1kΩ</td>
</tr>
<tr>
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<td>R16, R17, R18, R19, R20, R21, R22</td>
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7. References

[1]. Atmel QTouch Library User Guide

[2]. BSW Touch Sensor Design Guide

[3]. Atmel AT02259: QTouch Schematic and Layout Checklist

[4]. AVR XMEGA® D4 Devices Datasheet

[5]. Atmel AVR XMEGA D Manual
Appendix A.  Sensor Pattern for Flooded-X (Two-Layer) Design

Refer to Figure A-1 for Flooded-X sensor pattern that could be used in touchpad design.

Figure A-1.  8X x 7Y QMatrix Flooded-X (Two-Layer) Design
## Appendix B. Revision History

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