Introduction

The Wearable Electrocardiogram (ECG) Reference Design (also referred to as the ECG Demo Board) is a hardware platform to evaluate the Microchip ATSAML22N18A ARM-based microcontroller, and other solutions, such as the BTL1000-MR110CA and ATECC508A in a Wearable Electrocardiogram environment.

Supported by the Atmel Studio integrated development platform, the kit provides easy access to the features of the ATSAML22N18A and demonstrates how to integrate the device in an Electrocardiogram environment.

The following figure shows the front view and rear view of the board.

Figure 1. Board Front view and Rear view
# Table of Contents

- **Introduction** ...................................................................................................................... 1

1. **Board Features** .................................................................................................................. 4

2. **Getting Started** ................................................................................................................... 5
   2.1. Quick Start .................................................................................................................. 5
   2.2. Power Supply ............................................................................................................... 5
   2.3. Jumper Configurations .............................................................................................. 6
   2.4. Board Power-up .......................................................................................................... 6
   2.5. Operational Modes ...................................................................................................... 6
      2.5.1. Normal Mode ...................................................................................................... 7
      2.5.2. Low-Power Mode ............................................................................................ 8
   2.6. How to Use ECG Demo Board .................................................................................. 8

3. **Hardware Overview** .......................................................................................................... 11
   3.1. Board Overview .......................................................................................................... 11
   3.2. Functional Blocks ....................................................................................................... 12
   3.3. Power Distribution ...................................................................................................... 12
   3.4. Power Supplies .......................................................................................................... 12
      3.4.1. VSYS_COIN Generation: Step-Up DC-DC Converter ........................................ 12
      3.4.2. VSYS_USB Generation: Low Drop Out Regulator ............................................. 13
      3.4.3. Automatic Power Switch .................................................................................. 13
   3.5. Microcontroller ............................................................................................................ 13
   3.6. Serial Flash Memory ................................................................................................... 14
   3.7. Crypto Authentication ................................................................................................ 15
   3.8. Custom Segment LCD with Touch Buttons ............................................................ 15
   3.9. Bluetooth Module ...................................................................................................... 16
   3.10. Sensor-Hub with Accelerometer .............................................................................. 16
   3.11. Bio-Sensor ................................................................................................................ 17
   3.12. Tri-Color RGB LED ................................................................................................ 17
   3.13. Vibrator Interface ..................................................................................................... 17
   3.14. Reset Button ............................................................................................................ 17
   3.15. MCU SWD Debug Interface .................................................................................... 17
   3.16. Bluetooth SWD Debug Interface ............................................................................ 18

4. **Software Overview** ............................................................................................................ 19
   4.1. User Interface (SLCD, Touch) ................................................................................ 20
   4.2. BLE Interface ............................................................................................................ 20
   4.3. Storage Interface ....................................................................................................... 21
   4.4. ECG Interface ............................................................................................................ 22
   4.5. Activity Interface ...................................................................................................... 22
   4.6. USB Interface ............................................................................................................ 22
   4.7. Low-Power Interface ............................................................................................... 24
   4.8. Memory Usage .......................................................................................................... 24
1. **Board Features**

The following table provides the ECG Demo Board specifications.

**Table 1-1. Board Specifications**

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCB characteristics (System Section)</td>
<td>60.00 × 60.00 × 16mm (6 layers)</td>
</tr>
<tr>
<td>Processor</td>
<td>SAML22N18A (100-lead LQFP package) ARM Cortex-M0 Processor.</td>
</tr>
<tr>
<td>Processor clock sources</td>
<td>• 24 MHz crystal oscillator</td>
</tr>
<tr>
<td></td>
<td>• 32.768 kHz crystal oscillator</td>
</tr>
<tr>
<td>Memory</td>
<td>64Mb Serial Flash Memory (SST26VF064B)</td>
</tr>
<tr>
<td>Crypto Authentication</td>
<td>Crypto Authentication Device (ATECC508A) for Bluetooth Secure Authentication.</td>
</tr>
<tr>
<td></td>
<td><em>Note:</em> The firmware does not have support for ATECC508A.</td>
</tr>
<tr>
<td>Sensors</td>
<td>• Bio-Sensor : High Performance Cardio Chip for Heart Rate measurement (BMD101)</td>
</tr>
<tr>
<td></td>
<td>• Sensor-Hub : Autonomous sensor hub equipped with 3-axis accelerometer (BHA250)</td>
</tr>
<tr>
<td>Segment LCD Module</td>
<td>Custom 38-segment Display with 3 Touch Buttons on Glass.</td>
</tr>
<tr>
<td>Communication</td>
<td>Bluetooth module (BTLC1000) for Smart phone communication (BTLC1000-MR110CA)</td>
</tr>
<tr>
<td>Luminotherapy</td>
<td>Tri-Color RGB LED for Luminotherapy and for System Status</td>
</tr>
<tr>
<td></td>
<td><em>Note:</em> The firmware does not have support for tri-color RGB LED.</td>
</tr>
<tr>
<td>Board supply voltage</td>
<td>Powered by AAA Alkaline Battery or Powered by Target USB Connector</td>
</tr>
<tr>
<td>User interface</td>
<td>1 User Reset Button (SW701), 1 Power Switch(SW101)</td>
</tr>
<tr>
<td>Debug</td>
<td>SAML22 SWD (J701) and BTLC SWD (J704) interface for program and debug.</td>
</tr>
<tr>
<td>Expansion connectors, for debug purpose</td>
<td>• 1x4 pin header (J703) for additional device connection under I²C interface.</td>
</tr>
<tr>
<td></td>
<td>• 1x4 pin header (J702) for L22 UART interface for debugging</td>
</tr>
<tr>
<td></td>
<td>• Jumper for Power Consumption Measurement of the system under battery powered (J103)</td>
</tr>
</tbody>
</table>
2. Getting Started

2.1 Quick Start
The following hardware and software are required to enable the ECG Demo Board to explore and debug various features:

- Atmel Studio 7.0.1186 or later
- ASF 3.32.0 or later
- Micro-B USB cable to connect the USB port and PC
- Atmel ICE or SAM-ICE kit for programming and debugging
- SAM-BA 2.16 or later for programming

2.2 Power Supply
The following two options are available to power-up the ECG Demo Board. Power to the board can be:

- Supplied by a AAA battery
- Supplied by a USB cable connected on the USB Target Connector (J101)

Important:
1. ESD-Sensitive Electronic Equipment. The Evaluation Kit is shipped in a protective anti-static package. The board system must not be subject to high electrostatic potentials. It is recommended to use a grounding strap or similar ESD protective device when handling the board in hostile ESD environments (for example, offices with synthetic carpet).
2. When powering up the board with USB, the user must connect the ground header pin J403 of the board to the body of the user.
3. Avoid touching the component pins or any other metallic element on the board.

Table 2-1. Specification

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating Temperature</td>
<td>0°C to +60°C</td>
</tr>
<tr>
<td>Storage Temperature</td>
<td>• -40°C to +85°C (Without AAA Battery connected)</td>
</tr>
<tr>
<td></td>
<td>• -40°C to +60°C (With AAA Battery connected)</td>
</tr>
<tr>
<td>Relative Humidity</td>
<td>0 to 90% (non-condensing)</td>
</tr>
<tr>
<td>RoHS status</td>
<td>Compliant</td>
</tr>
</tbody>
</table>
Table 2-2. Electrical Parameters

<table>
<thead>
<tr>
<th>Electrical Parameter</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Input voltage on Battery Holder</td>
<td>1.8 VCC</td>
</tr>
<tr>
<td>Maximum input voltage on USB Connectors</td>
<td>5.5 VCC</td>
</tr>
<tr>
<td>I/O Voltage</td>
<td></td>
</tr>
<tr>
<td>• 3.1V (when supplied by battery)</td>
<td></td>
</tr>
<tr>
<td>• 3.3V (when supplied by USB)</td>
<td></td>
</tr>
</tbody>
</table>

2.3 Jumper Configurations

The following table provides Jumper Configurations details on the board.

Table 2-3. Jumper Configurations

<table>
<thead>
<tr>
<th>Jumper</th>
<th>Description</th>
<th>Default Position</th>
</tr>
</thead>
<tbody>
<tr>
<td>J402, J403, J404</td>
<td>Connector for external electrodes connections</td>
<td>Open</td>
</tr>
<tr>
<td>J602</td>
<td>Connector for PWM Vibrator connection</td>
<td>Open</td>
</tr>
</tbody>
</table>

2.4 Board Power-up

Use the following steps to power the board:
1. Unpack the board, taking care to avoid electrostatic discharge.
2. Verify the jumper configurations as described in the section Jumper Configurations.
3. Insert a AAA Battery into the battery holder (S101).
4. Change the slide button position to ON.

2.5 Operational Modes

The ECG Demo Board has the following modes of operation:

- Normal mode:
  - ECG mode (Default mode)
  - Standalone (DEMO) mode
  - USB (DATA) mode
- Low-Power mode

The following diagram illustrates the modes and transition events between them.
2.5.1 Normal Mode

This is default functional mode on system Reset. During this mode, all of the blocks are enabled and ready to function. In Normal mode, users can perform these actions:

- Measure ECG parameters and Step Count
- Read/write serial Flash
- Operate in USB or Demo mode
- Interface with the mobile app

The following sections provide functional details about the individual modes.

2.5.1.1 ECG Mode

**ECG Monitoring (ECG-EM) Mode**

This is the primary mode of this reference design, where the Bio sensor and Motion sensor can be read to measure parameters. In ECG mode, the MCU monitors ECG data while connected to the body through sensor pads or external electrodes. ECG algorithms are executed to determine Heart Rate (HR), Heart Rate Variability (HRV), and Heart Age (HA) from the incoming ECG signal. After detecting a valid ECG signal, and on completion of algorithm execution, the current HR, HRV, HA, and Signal Strength (SQ level bar) are display on the SLCD.

**ECG Recording and Streaming (ECG-ERS) Mode**

This mode is activated upon having valid time stamp with system. The time stamp will be provided by the app upon setting the user profile. Once the time stamp is available, ECG sample data and Step count information will be recorded to the on-board serial Flash with the time stamp. Also, on requests from the app, the ECG Demo Board begins streaming ECG samples to the app for real-time graphs and to execute additional algorithms on the app.

Refer to the following steps for smoother connectivity with the app.

1. Touch the BT button for two seconds and release. Control will begin advertising BLE packets.
   1.1. BT Icon blinks at 1Hz rate and few seconds; before termination blinks at 4Hz rate.
   1.2. On establishing a connection and while connected, the BT Icon remains ON.
2. Start the Mobile App and try connecting to the ECG Demo Board. Refer to Mobile App Overview for available features and interactions.
3. The connection can be terminated from the device by a gentle BT button touch and release while connected/advertising.

2.5.1.2 Standalone (DEMO) Mode
This mode is provided to demonstrate a few functionalities without user interaction. In this mode, ECG algorithms will be executed on a predefined ECG samples and the same samples will be repeated while in this mode. It also displays current HR, HRV, HA, and Signal Quality values on the SLCD. On connecting to the Mobile App, the ECG Demo Board begins streaming ECG samples to the app for real-time graphs and to execute additional algorithms.

Demo mode has all of the functionality that is available in ECG mode with these exceptions:
- During Demo mode no data will be recorded to serial Flash
- The ECG Demo Board contains hard-coded ECG samples, which will be used instead of samples from the Bio sensor

Perform the following to enter Demo mode:
1. Touch the MODE button for two seconds and then release when in ECG Mode.
   1.1. The HEART Icon should be ON indicating simulated ECG sampling.

2.5.1.3 USB (DATA) Mode
USB mode is provided to enable storage data retrieval through the USB interface. Upon entering this mode, the ECG Demo Board will be enumerated as a USB-CDC device. This mode helps to read ECG, Pedo, and Diagnostics records stored in the serial Flash, and also helps to erase serial Flash records.

To enter in this mode, while control is in ECG mode, follow these steps:
1. Connect the USB host on the ECG Demo Board USB port.
2. Touch the DATA button for two seconds and release.
   2.1. The SLCD should display “USB” and should enumerate as a USB-CDC device.

2.5.2 Low-Power Mode
Low-Power mode is provided to minimize power consumption while the ECG Demo Board is not in use. This mode can be entered only from ECG-EM mode. When there is no interaction for five seconds in ECG-EM mode, this mode will be entered automatically.

During Low-Power mode, the SLCD will be OFF, all of the unused peripherals, clocks, and external components are disabled to reduce power consumption. PTC Monitoring and RTC are enabled with the SleepWalking feature.

To help wake up, perform these actions:
1. Touch the On MODE button for two seconds and release.
2. Periodically, (i.e., once in every minute) read Pedo activities while in Sleep mode.

The Low-Power mode entry is not allowed while in DEMO or USB mode, as these modes are meant for specific functionalities and they need to be active at all times.

2.6 How to Use ECG Demo Board
The following steps provide preliminary use of the ECG Demo Board:
1. Power up the ECG Demo Board, as described in Board Power-up.
2. While the system is booting, you should see 'PUP', 'Sxx', and '0', with the HR Icon ON.
   2.1. PUP indicates powerup, and Sxx indicates the software version as 'xx'.

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3. ECG mode has two internal modes: ECG Monitoring Mode and ECG Recording and Streaming Mode.

3.1. ECG Monitoring (EM) Mode. This is default mode after the power up sequence. To measure the Bio and Motion parameters in this mode, perform these actions:

3.1.1. Touch the positive and negative PCB electrodes with your index fingers. You need to ensure your body is not in contact with any other parts of the board.
   - The “HEART” Icon will be ON and the HR, HRV, HA, and MODE Icons will start sequencing with a three-second interval
   - 3-digit indicates:
     • Heart Rate while HR Icon is ON
     • Heart Rate Variability while HRV Icon is ON
     • Heart Age while HA Icon is ON
     • Current Step counts while MODE Icon is ON

3.1.2. Hold in the same position until the SQ (ECG signal quality) bar indicate four or five points.

3.1.3. A valid HR value should be displayed on 3-digit after approximately 10 seconds. For valid HRV and HA values, it is required to touch the electrodes for about 30 seconds.

3.1.4. Once HR, HRV, and HA values are monitored, remove both fingers from the electrodes.
   - The “HEART” Icon will be OFF; however, the HR, HRV, HA, and SQ values will be retained.
   - Using the MODE button, you can navigate through these parameters

3.1.5. To check the Motion sensor, gently touch and release the MODE button to navigate to “MODE” Icon ON, and then take a few steps. The Current Step count should be changing on 3-digits.
   - This count will be rolled over after 999 steps due to 3-digit limitation

3.2. ECG Recording and Streaming (ERS) Mode

3.2.1. Touch the BT button for two seconds and release to start ECG Demo Board advertisement.

3.2.2. Connect to the Mobile App on BLE connection. Once it is connected, the BT Icon will remain ON.

3.2.3. Refer to Mobile App Overview for the available features and interactions.

3.2.4. Upon receiving the User Profile from the Mobile App, the ECG Demo Board’s RTC will be synced with the app time and the “SET” Icon turns ON if it is OFF. If the SET Icon is already ON, this indicates that the ECG Demo Board Time is already synced with the Mobile App.
   **Note:** The SET icon should be ON for serial Flash recording.

3.2.5. After syncing with the Mobile App, the ECG waveform, parameters, and Motion sensor values can be monitored on the Mobile App in real-time, as well as syncing ECG Demo Board storage with the Mobile App.

4. Standalone (DEMO) Mode

4.1. Touch the MODE button for two seconds and release in ECG Mode.

4.1.1. The “HEART” Icon will be ON and the HR, HRV, HA, and MODE Icons will start sequencing with a three-second interval.
4.1.2. After approximately 10 seconds, the HR value should be displayed, and after approximately 30 seconds, the HRA and HA values should be displayed on the SLCD.

4.1.3. While “MODE” Icon, SLCD value indicates current step count.

4.2. With the exception that ECG samples are hard-coded and no recording to storage device, the remaining functionality is same as ECG Mode.

4.3. Press the Mode button to exit from this mode.

5. **USB (DATA) Mode**

5.1. Connect a USB cable between the USB Host and the ECG Demo Board, and then touch the DATA button for two seconds in ECG Mode.

5.1.1. 3-digit will display USB and all other Icons will be off.

5.2. To exit this mode, gently touch the DATA button or disconnect the USB cable.

6. **Bootloader Mode**

When connecting a USB cable between the ECG Demo Board and the USB Host, if there is no application programmed into the Flash memory, the device will boot in Bootloader mode.

When the application is running, the following steps are required to switch the ECG Demo Board to Bootloader mode.

6.1. Connect a USB cable between the ECG Demo Board and the USB Host.

6.2. Touch the DATA button for two seconds in ECG Mode. This will enable the USB (DATA) mode.

6.3. Touch the MODE button for less than two seconds to enable the Bootloader mode.

6.4. Reset the ECG Demo Board using the on-board reset button (SW701).

3. **Hardware Overview**

The ECG Demo Board is an evaluation platform for SAM L22 series ARM-based Microcontrollers, which allows users to extensively evaluate these devices in an Electrocardiogram environment.

3.1 **Board Overview**

The ECG Demo Board integrates several peripherals and interface connectors, as shown in the following images.

**Note:** SLCD is removed in the "TOP Overview" image to enable PCB view under SLCD.

**Figure 3-1. ECG Demo Board (Top view)**

![ECG Demo Board (Top view)](image1)

**Figure 3-2. ECG Demo Board (Bottom View)**

![ECG Demo Board (Bottom View)](image2)

The ECG Demo Board is equipped with the following connectors/jumpers.

**Table 3-1. Connectors And Jumpers**

<table>
<thead>
<tr>
<th>Connector/Jumpers</th>
<th>Interfaces to/Allow to</th>
</tr>
</thead>
<tbody>
<tr>
<td>J101</td>
<td>USB device connector. Connect to USB Host</td>
</tr>
<tr>
<td>J103</td>
<td>Allow power consumption measurement on the AAA Battery.</td>
</tr>
<tr>
<td>J402, J403, J404</td>
<td>Connector for external electrodes connections</td>
</tr>
<tr>
<td>J602</td>
<td>Vibrator external connection</td>
</tr>
<tr>
<td>J701</td>
<td>SWD Interface connector for ATSAML22N18A device</td>
</tr>
<tr>
<td>J704</td>
<td>SWD Interface connector for Bluetooth Module</td>
</tr>
</tbody>
</table>
3.2 Functional Blocks

The following figure shows interfaces between various modules and the SAM L22 Microcontroller.

Figure 3-3. ECG Demo Board Architecture

3.3 Power Distribution

The ECG Demo Board has the following two power sources as shown in the figure below.

- Supplied by a AAA battery
- Supplied by external USB power connected to the USB Target Connector

Figure 3-4. Power Sources

3.4 Power Supplies

3.4.1 VSYS_COIN Generation: Step-Up DC-DC Converter

The MCP16251 is a compact, high-efficiency, fixed frequency, synchronous step-up DC-DC converter. This family of devices provides an easy-to-use power supply solution for applications powered by one-cell alkaline battery.

A low-voltage technology allows the regulator to start up without high inrush current or output voltage overshoot from a low-voltage input. High efficiency is accomplished by integrating the low-resistance N-Channel boost switch and synchronous P-Channel switch. All compensation and protection circuitry are integrated to minimize external components.
The MCP16251 operates and consumes less than 14 µA from battery, while operating at no load (VOUT = 3.3V, VIN = 1.5V). The devices provide a true disconnect from input to output, while in shutdown (EN = GND).

Both options consume less than 0.6 µA from battery. Output voltage is set by a small external resistor divider. For more information refer to the MCP16251 product page on the Microchip Website.

A button (SW101) is present between alkaline battery holder and Step-Up DC-DC converter to completely disconnect battery from the system. This will help to increase the battery life time when the system is not used.

3.4.2 VSYS_USB Generation: Low Drop Out Regulator

The MIC5365 is an advanced, general purpose, linear regulator offering high-power rejection ratio in an ultra-small 1mm x 1mm package. It includes an auto-discharge feature that is activated when the enable pin is low.

The MIC5365 is capable of sourcing 150mA output current and offers high PSRR making it an ideal solution for any portable electronic application. For more information, refer to the MI5365 product page on the Microchip Website.

3.4.3 Automatic Power Switch

The automatic switch is managed by two MIC94062 devices and is controlled by a transistor. It manages the power switch between the supply from the USB Target (Vsys_USB = 3.3V) and the supply from the AAA battery (Vsys_coin = 3.0V). For more information, refer to the MIC94062 product page on the Microchip Website.

Priority is given to Vsys_USB node when its voltage is present.

3.5 Microcontroller

The ECG Demo Board is built around the SAM L22 microcontroller in a 100-lead LQFP package. It is a low-power, 32-bit, ARM® Cortex®-M0+ application microcontroller achieving high-performance computing at low-power consumption and embeds a wide range of communication peripherals, such as SERCOM (USART, SPI, and I²C), USB, SLCD, and PTC.

The ARM Cortex-M0+ processor can run at up to 32 MHz with a maximum power consumption of 39 µA/MHz. For more information, refer to the SAM L MCUs page on the Microchip Website.
3.6 Serial Flash Memory

The SST26VF064B is a Serial Quad I/O™ (SQI™) family of Flash memory devices, which feature a six-wire, 4-bit I/O interface that allows for low-power, high-performance operation in a low pin-count package. The SST26VF064B supports full command-set compatibility to the traditional Serial Peripheral Interface (SPI) protocol. The SST26VF064B/064BA significantly improve performance and reliability, while lowering power consumption.

These devices write (Program or Erase) with a single power supply of 2.3-3.6V. The total energy consumed is a function of the applied voltage, current, and time of application. The signal lines are SCK (serial clock), SI, SO (for command/response and data input/output), and control signals CS, HOLD, WP.

This hardware interface creates a low pin-count device with a standard pin out that remains the same from one density to another, supporting future upgrades to higher densities without board redesign.

The SST26VF064B memory array is organized in uniform, 4 KByte erasable sectors with the following erasable blocks: eight 8 KByte parameter, two 32 KByte overlay, and one-hundred twenty-six 64 KByte overlay blocks. For more information, refer to the SST26VF064B product page on the Microchip Website.

The Serial Peripheral Interface (SPI) provides interface to serial Flash with a cost-effective non-volatile memory storage solution in systems where pin count is kept to a minimum.
3.7 Crypto Authentication

The ATECC508A is a member of the CryptoAuthentication family of crypto engine authentication devices with highly secure hardware-based key storage. The ATECC508A has a flexible command set that can be used in many applications, for example, among many others: Network/IoT Node Protection, Anti-Counterfeiting, Protecting Firmware or Media, Storing Secure Data and Checking User Password. The ECG Demo Board design only provides hardware support to the ATECC508A chip.

This device is available in a 8-lead UDFN package. For more information, refer to the ATECC508A product page on the Microchip website: http://www.microchip.com/wwwproducts/en/ATECC508A.

3.8 Custom Segment LCD with Touch Buttons

The ECG Demo Board embeds a Custom Segment LCD which includes 3 Touch Buttons (mutual capacitance configuration) for application control.

It is especially designed for ECG application and allows displaying the following information:

- **3-Digits**: Displays numeric data of the measurements performed on bio-sensor data
- **HR Icon**: Indicates the “Heart Rate” in Bit Per Minutes
- **HRV Icon**: Indicates the "Heart Rate Variability"
- **HA Icon**: Indicates the "Heart Age"
- **MODE Icon**: This Icon will be ON while displaying current step count on 3-Digits
- **SET Icon**: This Icon will be ON after RTC syncs with app, otherwise OFF
- **SQ Icons**: 5-level are available and reflects the “Signal Quality” of the measurement. Higher the SQ is better the signal is.
- **DAT Icons**: 5-level are available and reflects the space used on serial Flash. Higher the DAT is more data in Flash.
- **BT Icon**: This icon indicates Bluetooth connection status
- **Heart Icon**: This icon is ON when a Heart Measurement is performing

**Figure 3-6. Display Layout and Mechanical Structure**

Fixed silk screen is present on the glass and the three icons on the bottom of the screen are dedicated to touch buttons and allows activating the following features:

- **“BT” Button**: Allows enabling and disabling Bluetooth connection
- **“DATA” Button**: Allows the system transferring data to PC
- **“MODE” Button**: Allows changing different modes of the system
3.9 Bluetooth Module

The BTLC1000-MR110CA is an ultra low-power Bluetooth® Smart (BLE 4.1) module with Integrated Transceiver, Modem, MAC, PA, TR Switch, and Power Management Unit (PMU). It can be used as a Bluetooth Low Energy link controller or data pump with external host MCU. The qualified Bluetooth Smart protocol stack is stored in dedicated ROM, the firmware includes L2CAP service layer protocols, Security Manager, Attribute protocol (ATT), Generic Attribute Profile (GATT) and the Generic Access Profile (GAP). Additionally, application profiles, such as Heart Rate is supported and included in the protocol stack. The module contains all circuitry required including a ceramic high-gain antenna, 26 MHz crystal and PMU circuitry. The user must place the module on the board and provide power, as well as a 32 kHz Real-Time Clock or crystal.

The BTLC1000 is connected to the SAM L22 device through 4-wire interface. It is required to set fuse on the BTLC1000 module to be able to operate in 4-wire mode. For more information, refer to the BTLC1000-MR10CA product page on the microchip website: http://www.microchip.com/wwwproducts/en/ATBTLC1000.

3.10 Sensor-Hub with Accelerometer

The BHA250 is a small, low-power Sensor Hub with an integrated acceleration sensor designed for mobile applications, such as augmented reality or indoor navigation which require highly accurate, real time sensor data at very low power consumption. It is specifically designed for applications in Android smart phones, implementing the full Android Lollipop sensor stack inside the device and provides a flexible, low-power solution for motion sensing and sensor data processing. The device integrates a 14 Bit acceleration sensor with the new Bosch Sensortec Fuser core.

The BHA250 is connected to the SAM L22 device through the I2C interface, and is available in a 2.2 x 2.2 x 0.95 mm LGA package.
3.11 Bio-Sensor
The BMD101 bio-sensor is designed with an advanced analog front-end circuitry and it has a flexible, powerful digital signal processing structure. The BMD101 can process bio signal inputs ranging from µV to mV levels and is supported by NeuroSky proprietary SDK and algorithms to provide a complete solution. The low-noise amplifier and ADC are the main components of the BMD101 analog front end. Because of the BMD101’s extremely low-system noise and programmable gain, it can detect and process bio signals and convert them into digital words using a 16-bit high resolution ADC. The AFE also contains a sensor-off detection circuit.

The heart of the BMD101 digital circuit is a powerful system management unit that is in charge of overall system configuration, operation management, internal/external communication, proprietary algorithm computation, and power management. The BMD101 digital section also includes DSP blocks to accelerate calculations, such as various digital filtering, controlled by the configuration of the system management unit.

The J401 is the positive electrode and the J405 is the negative electrode. These electrodes are PCB electrodes and can be removed from the main PCB if external electrode’s connection is needed.

If external electrodes connection is required, the following connectors must be mounted and can be used as:
- J402- Pin 1: Positive Electrode Signal net
- J402- Pin 2: Positive Electrode Shield
- J404 - Pin 1: Negative Electrode Signal net
- J404 - Pin 2: Negative Electrode Shield
- J403 - Pin 1: Ground Electrode Signal net
- J403 - Pin 2: Ground Electrode Shield

3.12 Tri-Color RGB LED
The ECG Demo Board embeds tiny RGB LED’s that can be used for Lunimotherapy and/or system status. The ECG Demo Board design only provides hardware support for the Tri-Color RGB LED.

3.13 Vibrator Interface
It is possible to control an external vibrator through the J602 2-pin connector. This vibrator is controlled by a PWM output pin of the SAM L22 device.

3.14 Reset Button
One reset button is placed on the ECG Demo Board to reset the microcontroller and their by its functionality.

3.15 MCU SWD Debug Interface
A SWIO connector (J701) is available to program the SAM L22 microcontroller.
3.16 Bluetooth SWD Debug Interface

A SWIO connector (J704) for the Bluetooth module is available to program and debug the module when necessary.
4. Software Overview

This section provides software functional blocks and interface details. The ECG Demo Board is built around the SAM L22 device, which is a low-power 32-bit ARM Cortex-M0+ microcontroller achieving high-performance computing at lower power consumption and embeds a wide range of communication peripherals, such as SERCOM (USART, SPI, I\(^2\)C), USB, SLCD, and PTC.

The following diagram shows various peripherals and libraries used in ECG Demo Board software.

**Figure 4-1. Peripherals and Libraries**

ECG Demo Board functionality can be divided into the following interfaces:

- User Interface (SLCD, Touch)
- BLE Interface
- Storage Interface
- ECG Interface
- Activity Interface
- USB Interface
- Low Power Interface

The SAM L22 obtains ECG samples from the BMD101 and activity data from the BHA250. The data from the BMD101 is processed using the NeuroSky library for Heart Rate, Heart Age, and Heart Rate Variability, and transfers the ECG samples to the tablet/phone through the BTLC1000. The SAM L22 device also drives Icons and Touch on the SLCD. It interfaces to the serial Flash storage to store ECG parameters, Pedo, and diagnostics information and provides access to the same through an USB interface.

The following diagram illustrates the data flow from the Bio and Activity sensors to the BLE and Storage.
During Normal mode, the GCLK is configured to operate at 24 MHz, which is required to have smoother functionality of all of the interfaces. This requires that the SAM L22 be set to run in Performance Level2.

The following sections provide an overview of the various interfaces and configuration details. For complete configuration settings and other information, refer to the project and source files provided with ECG Demo Board kit.

### 4.1 User Interface (SLCD, Touch)

The user interface is provided by the SLCD, PTC, EVSYS, and TC peripherals and the QTouch Library. This interface takes care of SLCD navigation, Touch Inputs, and waking the system from Low-Power mode.

The SLCD is configured to use internal VLCD, with a 2 kHz refresh rate.

The PTC is configured to operate in mutual Capacitance mode. Four Mutual-Cap channels are used for three touch buttons, and one LUMP button for EVSYS is configured. The PTC uses GEN_CLK2, which is configured to run at 4 MHz.

### 4.2 BLE Interface

The BLE interface is provided by the BTLC1000 module and the BluSDK 6.1 Library. This interface enables interaction with apps that have been custom developed for the given protocol. In this ECG Demo Board it is configured to meet apps provided by NeuroSky. SAML22 and BTLC1000 are interfaced using 4-wire mode of BTLC1000 where UART with Flow Control is enabled. SERCOM3 plus GCLK0 are used to provide this interface.

This interface supports Device Information Service (0x180A) and ECG Demo Board-specific characteristics.

The following table provides the Read/Write/Notify characteristics for the same. Refer to the Seagull FW Spec Sheet provided by NeuroSky for further details.

<table>
<thead>
<tr>
<th>Characteristic Name</th>
<th>Characteristics Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>User Profile and Settings</td>
<td>Read/Write Characteristic</td>
</tr>
<tr>
<td>Current Count</td>
<td>Read/Notify Characteristic</td>
</tr>
<tr>
<td>Handshake / Command</td>
<td>Write Characteristic</td>
</tr>
<tr>
<td>Characteristic Name</td>
<td>Characteristics Type</td>
</tr>
<tr>
<td>---------------------------------------------------------</td>
<td>-------------------------------</td>
</tr>
<tr>
<td>• Start Real Time ECG</td>
<td></td>
</tr>
<tr>
<td>• Stop Real Time ECG</td>
<td></td>
</tr>
<tr>
<td>• Start Data Sync</td>
<td></td>
</tr>
<tr>
<td>• Erase Flash Memory</td>
<td></td>
</tr>
<tr>
<td>• Update and Send Flash Header</td>
<td></td>
</tr>
<tr>
<td>• Update and Send Current Pedo Counts</td>
<td></td>
</tr>
<tr>
<td>• Abort Sync Transfer</td>
<td></td>
</tr>
<tr>
<td>Flash Memory Data Transmission</td>
<td>Notify Characteristic</td>
</tr>
<tr>
<td>Real-time ECG</td>
<td>Notify Characteristic</td>
</tr>
<tr>
<td>Flash Memory Header</td>
<td>Notify Characteristic</td>
</tr>
<tr>
<td>Security Token</td>
<td>Read/Write Characteristic</td>
</tr>
</tbody>
</table>

The BT Icon is provided on the SLCD to indicate the connection status and has the following states:

- **ON** – BTLC1000 is connected to app
- **OFF** – BTLC1000 is disabled
- **1Hz blink** – BTLC1000 is advertising
- **4Hz blink** – BTLC1000 is advertising and going to stop soon

The Bluetooth connection can be established by touching the BT button for two seconds. On this event, the ECG Demo Board starts advertising its presence. The Bluetooth connection can be terminated by the Mobile App or from the board by a gentle BT button touch while it is advertising or in connected state.

### 4.3 Storage Interface

SPI-based Serial Flash (8 MB) is used as the storage device to store ECG parameters, Pedo, and Diagnostics information. This interface takes care of reading and writing various records to Flash. SERCOM3 and GCLK0 are used for this SPI Interface. In this interface, the SAM L22 acts as the Master and serial Flash as the Slave, and is configured to use 10 MHz as the SPI Clock.

Complete memory is divided into three blocks: one for ECG parameters, one for Pedo records, and one for diagnostics. This approach helps to navigate to records quickly while responding to read requests from the BLE app or from the USB Host.

Storage of ECG, Pedo, and diagnostics records are allowed only after having a valid time stamp with the ECG Demo Board and during ECG mode. No recording will occur during Demo and USB modes.

The SST26VF064B/064BA SQI memory array is organized in uniform, 4 KByte erasable sectors with the following erasable blocks: eight 8 KByte parameter, two 32 KByte overlay, and one-hundred twenty-six 64 KByte overlay blocks. This translates to 32,768 pages with each page containing 256 bytes.

In the current software it is set to utilize 32,136 pages for ECG, 600 pages for Pedo, and 32 pages for diagnostics data. This enables storage of 216 minutes of ECG data, 4,320 minutes of Pedo data, and 200 diagnostic records.
4.4 ECG Interface
The ECG interface is provided by the UART and NeuroSky Library. This interface takes care of reading packets from BMD101 sensor and process it using library. In this reference design, the BMD101 interface is only configured to read data from the sensor on the UART (57600-8-N-1). SERCOM5 and GCLK0 are used for this UART interface.

The supported packet codes for the BMD101 interface are as follows:
- 0x02 – Signal Quality
- 0x80 – 16-bit Raw Data (2’s complement)

The BMD101 sends 512 samples per second while it is enabled. The SAM L22 devices read the packets and parses them to read signal quality and 16-bit raw data receiving from the sensor.

The SAM L22 resets the NSK algorithm on the first transition from no signal to valid signal and feeds the received raw samples in the order received to the algorithm. While connected to the app, the same raw samples will be transmitted to the app upon enabling real-time ECG notification. Also, upon detection of a valid time stamp (should be more than 00:00:00 on 2016-11-01), the SAM L22 starts recording this ECG data to storage along with the current time stamp.

The NSK algorithm provides HR, HRV, and HA values in addition to the received Signal Quality.

4.5 Activity Interface
The Activity interface is provided by interfacing the BHA250 sensor on the I2C. This interface takes care of configuring and reading packets from the BHA250 and processing them to detect the step count. In this I2C interface, the SAM L22 acts as a Master and the BHA250 as a Slave. They are configured to communicate a baud rate of 100 kHz. The address 0x29 is the Slave address assigned for the BHA250. SERCOM1 and GCLK0 are used for this I2C interface.

The BHA250 is configured for Activity Recognition and Step Counter detection.

During Normal mode, the BHA250 will be read on every one second to receive Activity status and Step Counter, whereas in Low-Power mode it will be read on every one minute.

Upon reading Activity status and the Step Counter, SAM L22 processes for activity detection and for current and cumulative step counts. While connected to the app, the same Pedo data will be transmitted to the app upon enabling current count notification. When a valid time stamp is detected (should be more than 00:00:00 on 2016-11-01), the SAM L22 starts recording it to storage along with the current time stamp.

4.6 USB Interface
The USB Interface is provided to read storage data and to erase it when needed. The USB-CDC device functionality is provided on the ECG Demo Board for interfacing with the USB Host. This also supports Full-Speed and Low-Speed communication as per the USB 2.1 specification supporting device modes. GCLK3 is used for this USB interface.

Upon entering into USB mode, the ECG Demo Board enumerates as a USB-CDC Virtual COM port for further communications with the Host. It also disables ECG, DEMO modes, and BLE features while in this mode.
Table 4-2. USB Command Message Format and Supported Commands

<table>
<thead>
<tr>
<th>Command</th>
<th>HDR (1 byte)</th>
<th>Message Index (2 bytes)</th>
<th>Message (16 bytes)</th>
<th>Checksum (1 byte)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Erase Flash</td>
<td>0x77</td>
<td>0x0105</td>
<td>00 00 .... 00 00</td>
<td>0xF9</td>
</tr>
<tr>
<td>Start Data Sync</td>
<td>0x77</td>
<td>0x0103</td>
<td>00 00 .... 00 00</td>
<td>0xFB</td>
</tr>
<tr>
<td>Flash Header</td>
<td>0x77</td>
<td>0x0207</td>
<td>SID* 00 .... 00 00</td>
<td>(2+7+SID)^0xFF</td>
</tr>
<tr>
<td>Abort Sync</td>
<td>0x77</td>
<td>0x010A</td>
<td>00 00 .... 00 00</td>
<td>0xF4</td>
</tr>
<tr>
<td>Pedo Count</td>
<td>0x77</td>
<td>0x0108</td>
<td>00 00 .... 00 00</td>
<td>0xF6</td>
</tr>
</tbody>
</table>

**Note:** SID (Session ID) is a rolling sequence number. The firmware will return the SID in the Flash Header. Valid SIDs are 1 to 255, if SID of zero appears in byte 19 of a Flash Header it indicates old firmware.

Table 4-3. USB Response Message Format and Supported Responses

<table>
<thead>
<tr>
<th>HDR (1 byte – 0x77)</th>
<th>Message Index (2 bytes)</th>
<th>Response Status (1 byte)</th>
<th>Response Data Length (2 bytes)</th>
<th>Response Data (Optional)</th>
</tr>
</thead>
</table>

Table 4-4. Supported USB Responses

<table>
<thead>
<tr>
<th>Response Status</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x00</td>
<td>Message request started</td>
</tr>
<tr>
<td>0x01</td>
<td>Message request is in progress and the device yet to complete the response</td>
</tr>
<tr>
<td>0x02</td>
<td>Success/completion of message</td>
</tr>
<tr>
<td>0x03</td>
<td>System error message (When an existing message is currently in progress)</td>
</tr>
<tr>
<td>0x04 – 0xFF</td>
<td>Application-specific error code</td>
</tr>
</tbody>
</table>

Table 4-5. USB Error Response Message Format and Supported Responses

<table>
<thead>
<tr>
<th>HDR (1 byte – 0x77)</th>
<th>Message Index (2 bytes – 0xFFFF)</th>
<th>Error Code (1 byte)</th>
<th>Error Data Length (2 bytes)</th>
<th>Data (optional)</th>
</tr>
</thead>
</table>

**Note:** Message Index 0xFFFF is fixed for Error Response Messages.

Table 4-6. Supported USB Error Responses

<table>
<thead>
<tr>
<th>Error Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x00</td>
<td>Incorrect Message Format – Header</td>
</tr>
<tr>
<td>0x01</td>
<td>Incorrect Message Format – Checksum</td>
</tr>
<tr>
<td>0x02</td>
<td>Incorrect Message Format – Frame Length</td>
</tr>
<tr>
<td>0x03</td>
<td>Unsupported Message received.</td>
</tr>
</tbody>
</table>
Note: Any PC application which can scan/detect the presence of a virtual com port should be able to send the functional commands as shown in the previous Tables. The PC should have Atmel USB drivers pre-installed to detect the ECG Demo Boards.

USB-CDC interface is also used by the USB host to communicate with the device in Bootloader mode. In this mode, the user can program the application firmware or upgrade the existing application firmware.

4.7 Low-Power Interface

The low-power interface enables the ECG Demo Board to consume low power while it is not in use. The SAM L22 device offers four Sleep modes: Idle, Standby, Backup, and Off Modes. The ECG Demo Board is enabled to enter into Standby mode, which helps in faster recovery from Sleep mode.

The PDTOP can be disabled only when operating in Backup mode. PDTOP cannot be disabled on the ECG Demo Board, as it is required to keep checking for user activity on touch buttons, as well as record changes on Activity Interface. Therefore, both the PDTOP and PDBACKUP domains are active at all times.

Low-Power mode will be entered on the request from different interfaces. Interfaces that control Low-Power mode entry are User Interface, ECG Interface, and BLE Interface. On confirmation from all three interfaces, the system waits for five seconds and then transits to Low-Power mode.

During Low-Power mode, PTC, TC, EVSYS, and RTC are configured to run to wake up on touch activity and to check the Activity interface for any changes in Step Count.

The RTC is configured to generate an alarm on every minute. This event is used to record Activity interface changes.

The EVSYS is enabled to connect TC output to PTC start conversion. This enables the PTC to check for touch sensing without CPU intervention, thereby allowing the SAM L22 to remain in Low power mode.

The SAM L22 is configured to wake up from Low-Power mode in the following two scenarios:

- Periodic wake up on RTC alarm
- User activity on Touch buttons

When the SAM L22 wakes up on a RTC alarm, it records the Activity interface and checks for pending touch activity. If no pending activity is detected, the SAM L22 re-enters Low-Power mode.

When the SAM L22 wakes up on touch detection, it brings up all interfaces and starts checking for ECG, BLE, and Activity interfaces. If no activity is detected on these interfaces, the SAM L22 re-enters Low-Power mode after five seconds. This cycle repeats on every touch detection in Low-Power mode.

The SAM L22 is not configured to check sensor pads or electrodes while it is in Low-Power mode.

4.8 Memory Usage

This section provides memory utilization in SAM-BA and user application projects.

Table 4-7. Memory Footprint

<table>
<thead>
<tr>
<th>Application Type</th>
<th>Program Memory in Bytes</th>
<th>Data Memory in Bytes</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAM-BA Application</td>
<td>~20K</td>
<td>~4K</td>
</tr>
<tr>
<td>ECG Demo Application</td>
<td>~130K</td>
<td>~25K</td>
</tr>
</tbody>
</table>

Note:
• Optimization level (-O1) enabled for both bootloader and user application
• ARM/GNU C Compiler version: 5.3.1, Atmel Studio 7.0.1186, and ASF 3.32.0
5. **Supporting Applications**

5.1 **Mobile App Overview**

CardioStik is the app provided by NeuroSky for the BLE interface with the ECG Demo Board. This app has features to measure HR, R-R Interval, HRV, heart age, stress, and mood parameters based on ECG samples received from the ECG Demo Board. It also provides user profile and time stamp information to the board. The ECG Demo Board uses the user profile information while measuring HR, HRV, and HA locally on the SAM L22 device. Time Stamp information is used to provide the time stamp in the storage device.

The User Profile can be set on this app by navigating to *Menu>Settings> Profile*. After updating the profile, click **Apply**.

To connect the ECG Demo Board to the CardioStik app on mobile, click the **Connect** Icon on the app while the ECG Demo Board is advertising. Refer to the section *How to Use ECG Demo Board* for the steps to start BLE advertising.

**Figure 5-1. App Connect Screen**

![App Connect Screen](image)

**Note:** Use “123456” as pair key when app is prompted for this.

On connection to app, the “Sync” and “Start” Icons will be displayed. Click on the **Start** Icon to receive ECG samples from the ECG Demo Board. The following screen will be displayed on receiving the sample from the ECG Demo Board.
Figure 5-2. App ECG Screen

Note: The mobile app shown in this user guide is provided “as is” and is to be used for reference and demonstration purposes only. Neither Microchip nor Neurosky will provide support for this Mobile App or for any issues that users might encounter. This Mobile App has been tested with several versions of the Android OS and on several different brands and types of mobile devices. However, neither Microchip nor Neurosky guarantees that this Mobile App will work on all versions of the Android OS or on all brands or types of mobile devices.
6. Appendix

6.1 ECG Demo Board Schematics

Figure 6-1. Power Supply Interface

Figure 6-2. MCU Connection
Figure 6-3. Memory and Crypto Interface

Figure 6-4. Sensor Interface
Figure 6-5. Display Interface

Figure 6-6. BTLC Interface
6.2 Power Consumption Numbers

Table 6-1. Power Consumption Numbers

<table>
<thead>
<tr>
<th>Device</th>
<th>Active Mode (Typical)</th>
<th>Stand-by Mode (Typical)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAML22</td>
<td>39 μA/MHz</td>
<td>1.8 μA</td>
</tr>
<tr>
<td>BTLC1000</td>
<td>4512 μA (Rx)</td>
<td>3012 μA (Tx)</td>
</tr>
<tr>
<td>SST26VF064B</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>BMD101</td>
<td>800 μA</td>
<td>-</td>
</tr>
<tr>
<td>BHA250</td>
<td>800 μA</td>
<td></td>
</tr>
</tbody>
</table>

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Table 7-1. Revision A - 10/2017

<table>
<thead>
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<th>Comments</th>
</tr>
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<tbody>
<tr>
<td>Initial released version of this user's guide.</td>
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<th>ASIA/PACIFIC</th>
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<tr>
<td>Corporate Office</td>
<td>Asia Pacific Office</td>
<td>China - Xiamen</td>
<td>Austria - Wels</td>
</tr>
<tr>
<td>2355 West Chandler Blvd.</td>
<td>Suites 3707-14, 37th Floor</td>
<td>Tel: 86-592-2388138</td>
<td>Tel: 43-7242-2244-39</td>
</tr>
<tr>
<td>Chandler, AZ 85224-6199</td>
<td>Tower 6, The Gateway</td>
<td>Fax: 86-592-2388130</td>
<td>Fax: 43-7242-2244-393</td>
</tr>
<tr>
<td>Tel: 480-792-7200</td>
<td>Harbour City, Kowloon</td>
<td>China - Zhuhai</td>
<td>Denmark - Copenhagen</td>
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<td>Fax: 480-792-7277</td>
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<td></td>
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