Using biosensors for ECG monitoring: guidelines for setting up the adapter boards and MEMS Studio

Introduction

This application note describes the context-aware analysis of the ST1VAFE6X and ST1VAFE3BX biosensors in electrocardiogram (ECG) signal detection and monitoring. The configuration of the sensors for biopotential and motion data in the MEMS Studio software is provided as well as the setup of the STEVAL-MKI109V3 or STEVAL-MKI109D professional MEMS tools with the following adapter boards for each device:

- **ST1VAFE6AX**: STEVAL-MKI242A adapter board along with the STEVAL-MKI249A adapter board and STEVAL-MKE005A electrode board
- **ST1VAFE3BX**: STEVAL-MKI250A adapter board along with the STEVAL-MKE006A and STEVAL-MKE007A electrode boards

1 Human biopotentials and ECG

Human biopotentials are electrical signals generated by the body's cells and tissues. They are used in a variety of medical tests and procedures, including electrocardiogram (ECG), electroencephalogram (EEG), and electromyogram (EMG). For instance, the electrocardiogram is a noninvasive medical test that measures the electrical activity of the heart. It is a valuable tool for diagnosing and monitoring heart conditions. Single-lead ECGs are a simplified version of traditional 12-lead ECGs (10 electrodes), using only two electrodes to capture electrical signals. This makes them more portable and convenient for certain applications, such as home monitoring and activity tracking. Single-lead ECGs have a wide range of applications, including:

- Home monitoring: Single-lead ECGs can be used by individuals to monitor their heart health at home. This can help them to identify potential problems early on and seek medical attention if necessary.
- Activity tracking: Single-lead ECGs can be used to track heart rate variability (HRV), which is a measure of how well the heart responds to stress. HRV can be used to assess overall health and fitness, and to detect early signs of stress and anxiety.
- Athletic training: Single-lead ECGs can be used to monitor the heart health of athletes during training and competition. This can help to prevent overtraining and to identify potential cardiovascular problems.
- Telehealth: Single-lead ECGs can be used for telehealth appointments, allowing patients to have their ECGs taken remotely by a healthcare provider.

Single-lead ECGs offer several advantages over traditional 12-lead ECGs, including:

- Portability: Single-lead ECGs are more portable and can be used in a variety of settings, including home and athletic training facilities.
- Convenience: Single-lead ECGs are easier to use and require fewer electrodes than traditional 12-lead ECGs.
- Cost-effectiveness: Single-lead ECGs are less expensive to purchase and operate than traditional 12-lead ECGs.

The ECG signal is an AC signal with bandwidth of 0.05 Hz to 100 Hz, sometimes up to 1 kHz. It is in the order of amplitude of a few mV affected by several sources of noise like:

- High-frequency noise:
  - Motion artifacts
  - Electromagnetic interference (EMI)
  - Electromyographic (EMG) signals
- Low-frequency noise:
  - Body movement
  - Muscle contraction
  - Breathing and respiration
- Common-mode noise:
  - 50/60 Hz powerline noise
  - DC electrode offset potential

1.1 ECG filtering with ST1VAFE6AX

The STEVAL-MKI242A and the STEVAL-MKI249A adapter boards host the ST1VAFE6AX system-in-package inertial measurement unit (IMU) featuring electric potential sensing to read human biopotentials.

The following table indicates the configuration (AH_BIO_LPF bit in the CTRL9 (18h) register and the AH_BIO_HPF bit in the CTRL8 (17h) register) for filtering the ECG signal. Refer to the datasheet for detailed information.

Table 1. Analog hub / vAFE channel ODR and bandwidth configuration

AH_BIO_LPF	AH_BIO_HPF	AH / vAFE ODR (typ.)(1)	AH / vAFE bandwidth (typ.) [low, high]
0	0	240 Hz	[0 Hz, 318 Hz]
0	1	240 Hz	[0.15 Hz, 318 Hz]
1	0	120 Hz	[0 Hz, 14.8 Hz](2)
1	1	120 Hz	[0.08 Hz, 14.8 Hz](2)

1. *The analog hub / vAFE channel ODR is equal to 240 Hz if the notch filter is disabled, otherwise the ODR is equal to 120 Hz.*
2. *First -3 dB crossing point*

2 Compensating motion artifacts

Motion artifacts are unwanted electrical signals that can be introduced into a biopotential measurement such as the electrocardiogram (ECG) recording due to user movement. These artifacts can obscure the normal ECG waveform that is in the range of 0.5 mV to 5 mV, making it difficult to interpret and potentially leading to misdiagnosis. Motion artifacts can be caused by a variety of factors, for example in an ECG recording they include the following:

- Breathing: The expansion and contraction of the chest during breathing can generate electrical signals that mimic the ECG waveform.
- Muscle movement: Muscle contractions, such as those caused by walking, talking, or coughing, can also generate electrical signals that interfere with the ECG recording.
- Body movements: Any movement of the patient, such as fidgeting or rolling over, can introduce motion artifacts into the ECG recording.

There are two main types of motion artifacts:

- High-frequency artifacts: These artifacts are caused by rapid movement and appear as spikes or sawtooth waves on the ECG recording.
- Low-frequency artifacts: These artifacts are caused by slow movement or tremors and appear as a wavy or blurred baseline on the ECG recording.

There are several techniques that can be used to detect and reduce motion artifacts in ECG recordings. These include:

- Filtering: Electronic filters can be used to remove high-frequency noise from the ECG signal.
- Adaptive filtering: Adaptive filters can adjust their filtering parameters in real time to minimize the effects of motion artifacts.
- Artifact-removal algorithms: Artifact-removal algorithms can identify and remove motion artifacts from the ECG signal.

Correction or compensation algorithms can use the motion data provided by the accelerometer in the ST1VAFE6AX or ST1VAFE3BX or the ST1VAFE6AX's inertial measurement unit (IMU) to detect and reduce the effects of motion artifacts in the ECG signal.

3 Synchronization of ECG

Both the ST1VAFE6AX system-in-package inertial measurement unit (IMU) and the ST1VAFE3BX feature an electric potential sensing channel for reading human biopotentials such as ECG and a motion sensor channel for activity recognition. The ST1VAFE3BX includes an accelerometer, while the ST1VAFE6AX includes both an accelerometer and a gyroscope, enabling adaptive filtering on biopotential signals.

In the ST1VAFE6AX, acquisitions from both channels can be run in parallel, while for the ST1VAFE3BX they run as complementary signals. This means that the signals are intrinsically synchronous, enabling the computation of healthy status indicators on a single channel, or heart conditions based on features extracted by using both channels.

The synchronized acquisition from both channels using the same device enables:

- Recording human biopotential signals from a single-lead ECG
- Deriving heart condition parameters by analyzing the ECG signal
- Using motion information for compensation and correction
- Using motion sensors for context detection in reading vital signs.

3.1 Context-aware vital signs monitoring (VSM)

ST1VAFE6AX

Regarding the context-aware measurements of vital signs, refer to the following application notes available on www.st.coom:

- **AN6120** ST1VAFE6AX: biosensor with vAFE (vertical analog front-end) for biopotential signals and 6-axis IMU (inertial measurement unit) with AI and sensor fusion
- **AN6155** ST1VAFE6AX: finite state machine
- **AN6161** ST1VAFE6AX: machine learning core

ST1VAFE3BX

- **AN6160** ST1VAFE3BX: biosensor with vAFE (vertical analog front-end) for biopotential signals and ultralow-power accelerometer with AI and antialiasing
- **AN6207** ST1VAFE3BX: finite state machine
- **AN6208** ST1VAFE3BX: machine learning core

Some examples of context-aware measurements include:

- Interpretation of ECG, heart rate, and heart rate variability based on user activity
- ECG healthy or status indicators used for triggering other kinds of measurements (for example, an increasing heart rate triggers detection of user activity)
- Event-based measurements:
  - ECG acquisition and analysis at a periodic number of human steps
  - Increase the frequency of ECG analysis depending on the detected user activity (for example, bicycle activity)
  - Free-fall detection triggers continuous ECG recording and analysis.

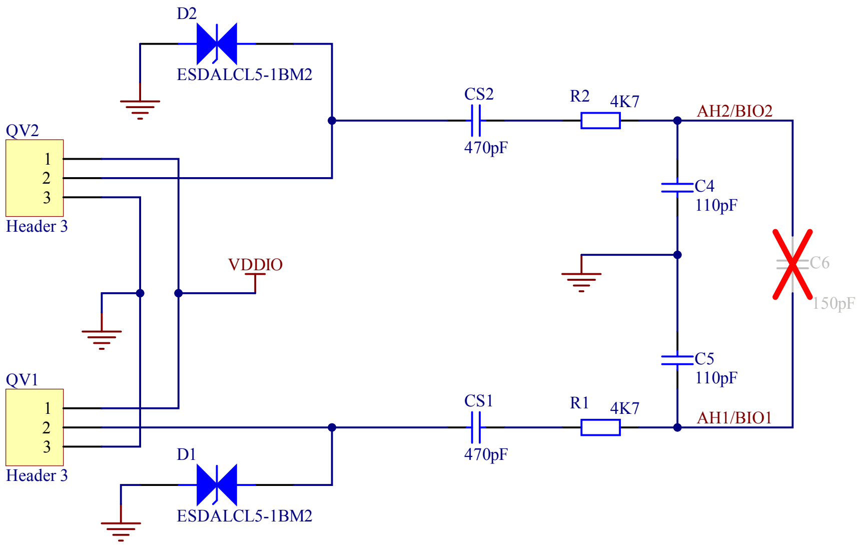
4 Front-end stage and reference voltage

4.1 ST1VAFE3BX input stage

The STEVAL-MKI250A provides the ST1VAFE3BX with an input stage composed of a passive network.

The ECG signals, entering through headers QV1 and QV2, pass through AC coupling capacitors CS1 and CS2 (470 pF), to decouple any DC voltage . Subsequently, the signals are filtered and conditioned by a network comprising resistors R1 and R2 (4.7 kΩ) and capacitors C4 and C5 (110 pF), which removes high-frequency noise and ensures impedance matching.

Figure 1. **ST1VAFE3BX input stage**

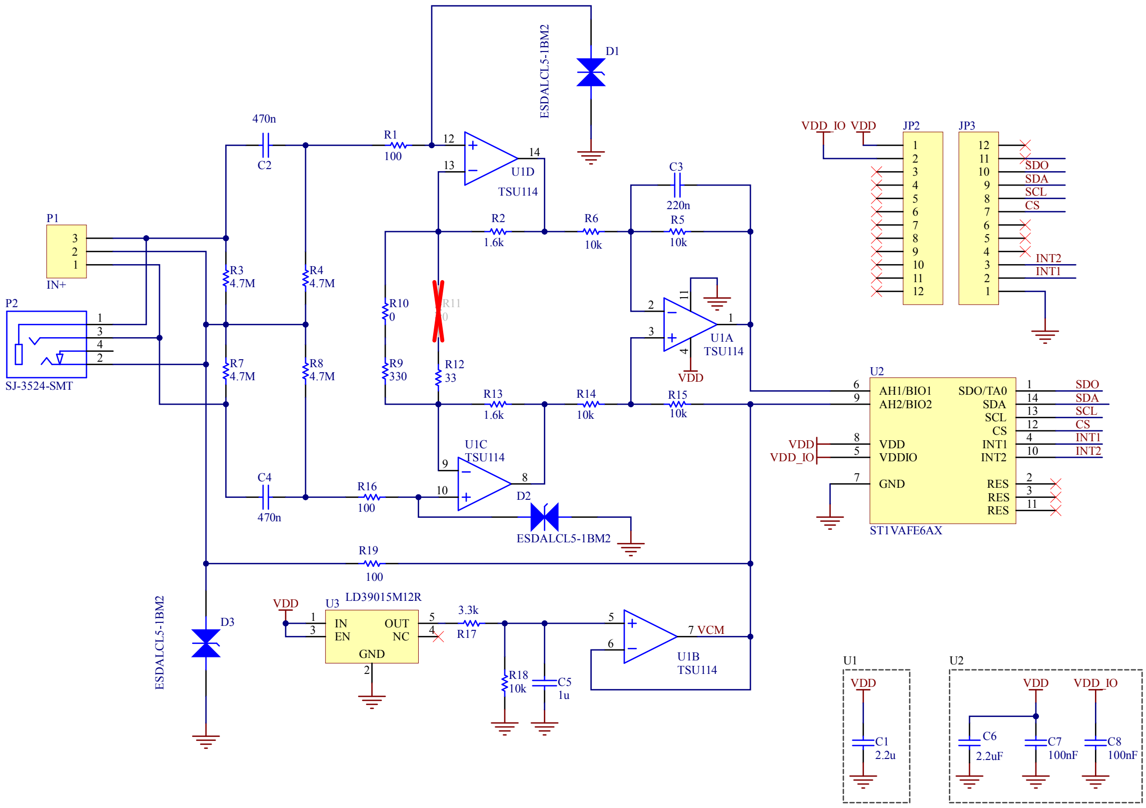


4.2 ST1VAFE6AX preamplification stage

Biopotential signals can be weak. For this reason, a preamplification stage is an important part of any ECG, or for reading other human biopotentials. It is responsible for amplifying the weak biopotential signal from the body to a level that can be processed and recorded. Part of this preamplification stage is the filtering block that removes noise and artifacts.

The STEVAL-MKI242A and STEVAL-MKI249A provide the ST1VAFE6AX with a preamplification stage with the intent of amplifying the human biopotential signals. It is a tiny analog front-end circuitry based on ST's TSU114 quad op-amp.

Figure 2. **Schematic of analog front-end for ECG signal**



The ECG signals, coming from P1 or P2, are brought to the preamplifier inputs by the passive network, composed of R3, R4, R7, R8, C2, and C4, which implements a 100 mHz high-pass first-order filter for decoupling any DC voltage.

The preamplification circuit is based on an instrumentation amplifier topology, which is implemented by means of $U1_A$, $U1_C$, and $U1_D$. The gain of this stage is configurable in the hardware on two levels by placing or removing the two 0 ohm resistors R10 and R11, as indicated in the following table.

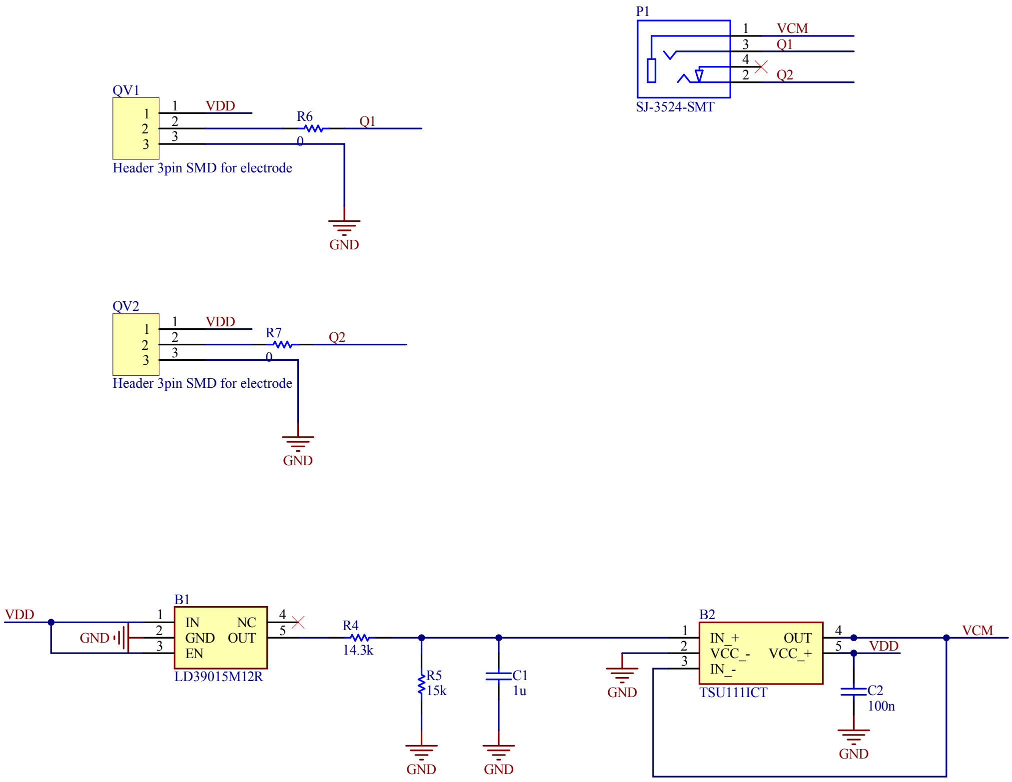
Table 2. **AFE gain configuration**

R10	R11	GAIN
Closed	Open	≈ 100 V/V
Open	Closed	≈ 10 V/V

The differential output of the amplifiers $U1_C – U1_D$ is converted to single-ended by $U1_A$.

4.3 Reference voltage

Figure 3. Schematic of STEVAL-MKE007A



- In the STEVAL-MKE006A and STEVAL-MKE007A electrode boards, a VCM is obtained by buffering the partition of the LDO B1 output voltage.
- In the STEVAL-MKI242A and STEVAL-MKI249A adapter boards, $U1_A$ adds an offset VCM = 0.9 V to the signal, for transferring to the U2 inputs a variable voltage centered on its optimal common-mode voltage. This VCM voltage is also obtained by buffering the partition of the LDO U3 output voltage and it is used for setting the common-mode voltage of $U1_C$ and $U1_D$ as well.

The quality of the ECG signal is commonly improved by placing this reference point close to the electrodes.

This feature is implemented by providing VCM as a third output channel in the STEVAL-MKI242A (through the header P1 and the connector P2) and in the STEVAL-MKE007A (through the connector P1).

This voltage can be used for biasing the skin area close to the electrodes to a fixed potential in order to attenuate any induced electromagnetic noise coming from the environment. Using an LDO potential instead of GND, takes advantage of a less noisy source than the GND itself, as it may be affected by noise caused by spike currents generated during digital transients.

5 Electrodes

Standard dry or gelled ECG electrodes are used to record biopotentials.

Gelled electrodes are made of a conductive material that is coated in a conductive gel. The gel helps to improve conductivity by providing a low-resistance path between the electrode and the skin.

Figure 4. Standard gelled electrodes for ECG

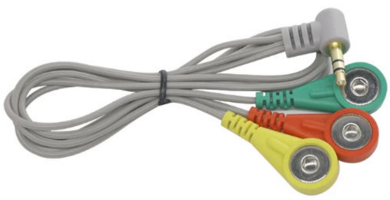
Dry electrodes are made of a conductive material, such as silver or silver-plated stainless steel, that is attached directly to the skin. They do not require any additional gel or paste to improve conductivity.

Table 3. Dry vs. gelled electrodes

Feature	Dry electrodes	Gelled electrodes
Requires gel	No	Yes
Skin impedance	Lower	Higher
Motion artifact susceptibility	Higher	Lower
Skin irritation	Lower	Higher
Comfort	More comfortable	Less comfortable

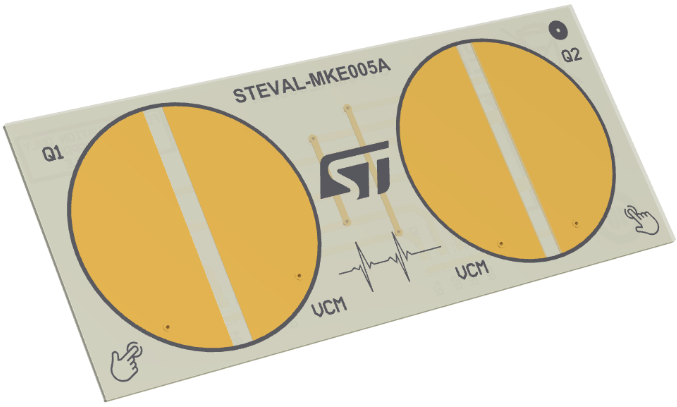
The STEVAL-MKI242A adapter board and the STEVAL-MKE007A electrode board provide a connector for a standard tripolar cable for connecting three electrodes, two as analog input for the differential input stage and one for the reference point.

Figure 5. Standard cable for ECG



The STEVAL-MKE005A and STEVAL-MKE006A provide a pair of exposed finger electrodes that connect directly to the vAFE inputs to collect the biopotential signals. Additionally, a third electrode, split into two parts, is connected to a reference voltage to reduce the noise contribution.

Figure 6. STEVAL-MKE005A



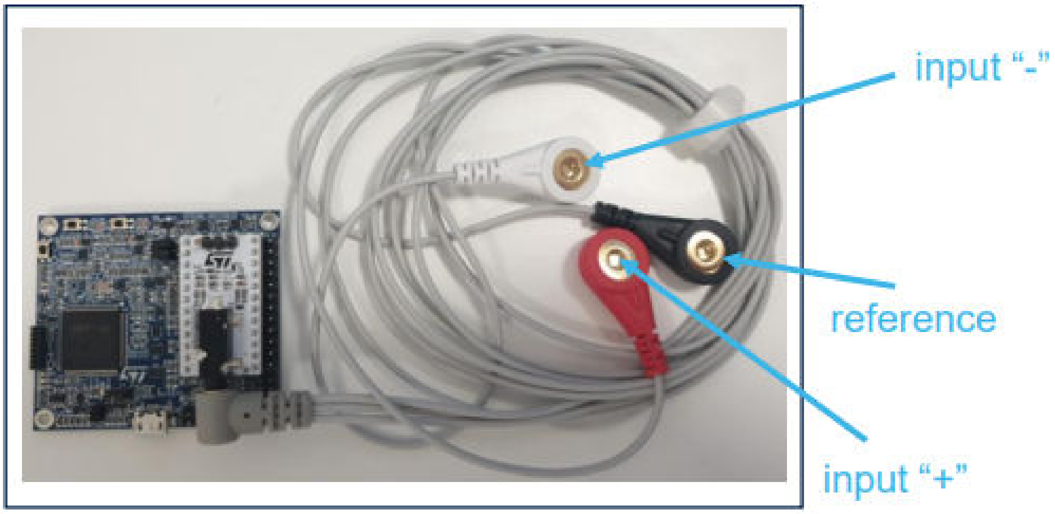
6 Setup for the ECG

The following sections provide instructions for the hardware setup, software configuration, and the initial human body measurements of single-lead electrocardiography.

6.1 Hardware setup for the STEVAL-MKI242A / STEVAL-MKI250A + STEVAL-MKE007A

1. Disconnect the power cord from the laptop.
2. Insert the DIL24 adapter in the ProfiMEMS tool socket, observing its orientation.
   a. For the **ST1VAFE6AX**, connect the STEVAL-MKI242A adapter board to the STEVAL-MKI109V3 or STEVAL-MKI109D (ProfiMEMS tools).
   b. For the **ST1VAFE3BX**, connect the STEVAL-MKI250A adapter board to the STEVAL-MKI109V3 or STEVAL-MKI109D (ProfiMEMS tools). Then, connect the STEVAL-MKE007A electrode board to the STEVAL-MKI250A matching with the header pins description: QV1/QV2.
3. Plug the ECG cable jack in the connector of the DIL24 adapter.

Figure 7. **Setup for ECG signal acquisition**



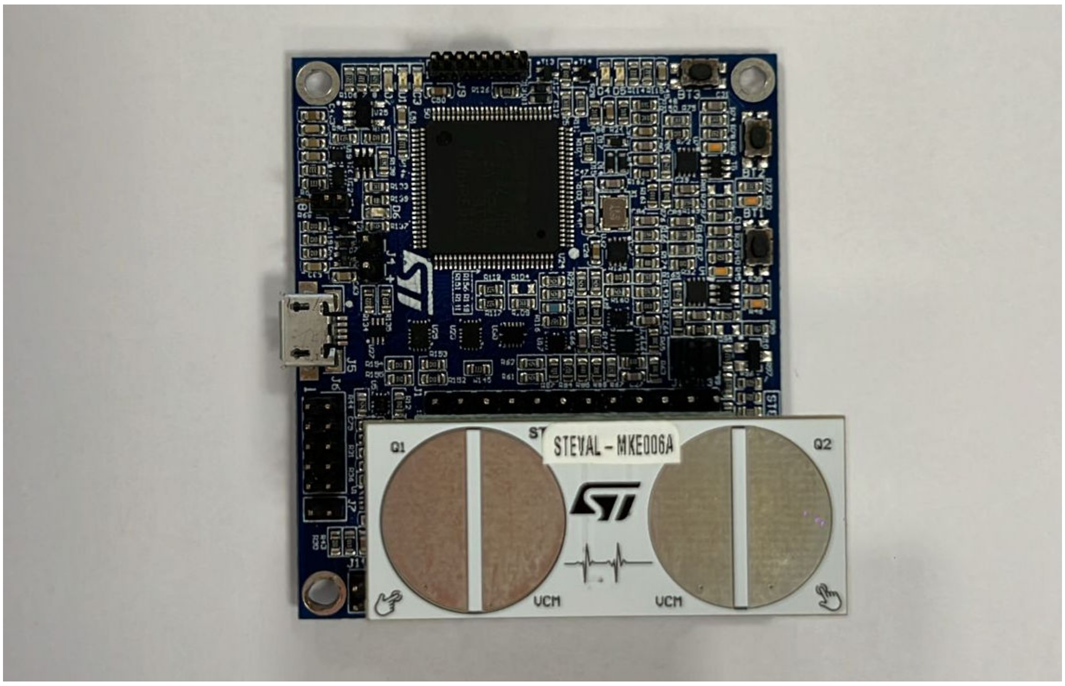
4. Connect the ProfiMEMS tool to the laptop using a USB cable (a blue LED turns on).
5. The laptop automatically recognizes and installs the STM32 VCP drivers. If not, they can be downloaded from: STSW-STM32102: STM32 Virtual COM Port Driver.

Note: Use the latest version of the firmware of the ProfiMEMS tool. Refer to user manual UM2116 of STEVAL-MKI109V3 on www.st.com to check the latest version of the firmware.

6.2 Hardware setup for the STEVAL-MKI249A + STEVAL-MKE005A / STEVAL-MKI250A + STEVAL-MKE006A

1. Disconnect the power cord from the laptop.
2. Insert the DIL24 adapter in the ProfiMEMS tool socket, observing its orientation.
   a. For the **ST1VAFE6AX**, connect the STEVAL-MKI249A adapter board to the STEVAL-MKI109V3 or STEVAL-MKI109D (ProfiMEMS tools). Then, connect the STEVAL-MKE005A electrode board to the STEVAL-MKI249A matching with the header pins description: P1/P2.
   b. For the **ST1VAFE3BX**, connect the STEVAL-MKI250A adapter board to the STEVAL-MKI109V3 or STEVAL-MKI109D (ProfiMEMS tool). Then, connect the STEVAL-MKE006A electrode board to the STEVAL-MKI250A matching with the header pins description: QV1/QV2.
3. Connect the ProfiMEMS tool to the laptop using a USB cable (a blue LED turns on).
4. The laptop automatically recognizes and installs the STM32 VCP drivers. If not, they can be downloaded from STSW-STM32102: STM32 Virtual COM Port Driver

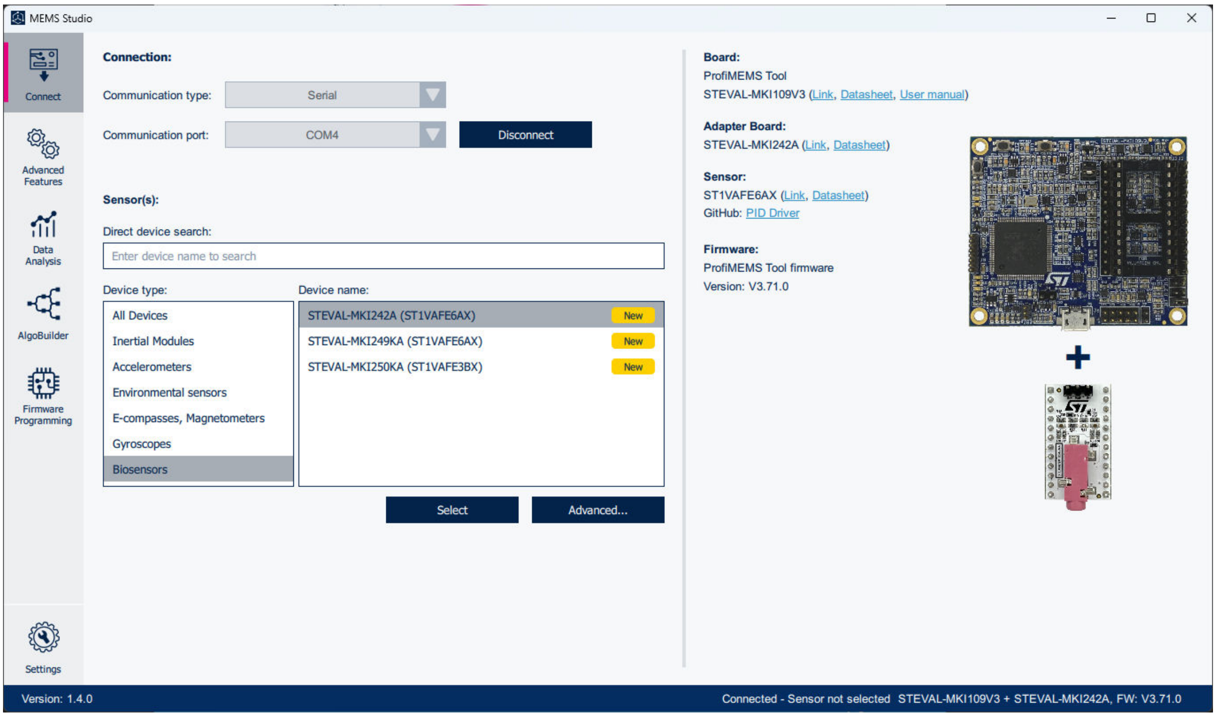
Figure 8. **Setup with STEVAL-MKE006A electrode board**



6.3 Software configuration and first run

1. Download and install the latest version of MEMS Studio from MEMS Studio.
2. Connect the ProfiMEMS tool to the laptop.
3. Launch MEMS Studio.
4. In the [**Connect**] tab, select [**Serial**], and choose the serial port.
5. Press the button [**Connect**] to connect the ProfiMEMS tool.
6. Select [**Biosensors**] from [**Device type**].
7. Select “**STEVAL-MKI242A (ST1VAFE6AX)**", “**STEVAL-MKI249A (ST1VAFE6AX)**”, or "**STEVAL-MKI250KA (ST1VAFE3BX)**" from [**Device name**].

Figure 9. **STEVAL board selection**

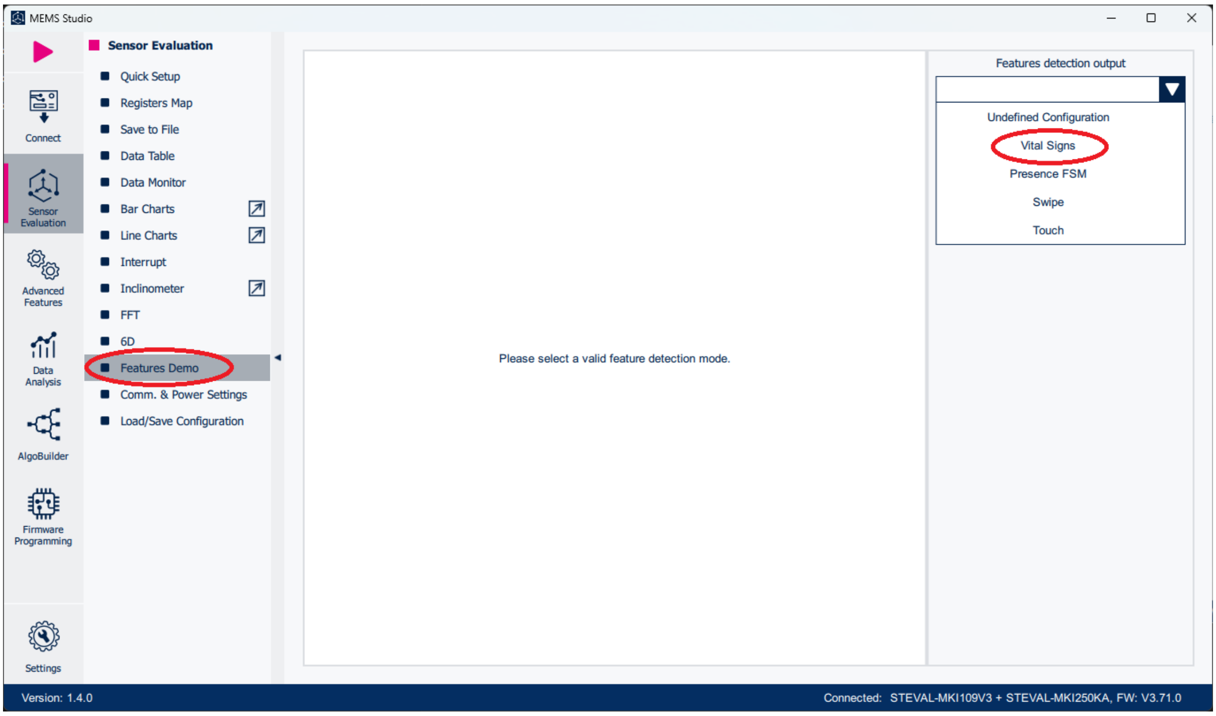


8. After a few seconds, on the ProfiMEMS tool, a red and a yellow LED turn on and the software automatically opens the [**Sensor Evaluation**] window (see figure below). This page shows all the parameters that can be set for the accelerometer, gyroscope, and vAFE.

Figure 10. Sensor Evaluation window

9. To open a predefined ECG demo, select [**Features Demo**] and, from the [**Features detection output**] list, select [**Vital Signs**] (see figure below).

Figure 11. Features Demo



10. Press the [**Start**] button present on the top left of the window to start streaming data.

Figure 12. Data streams with ECG options

In this window, there are three different real-time data streams:

– vAFE[LSB] stream: raw data plotted in LSB (least significant bit), an a-dimensional digital code that spans from -32768 up to 32768
– ECG[mV] stream: filtered vAFE data and converted from LSB to mV
– Parameters stream: extrapolated medical parameters from the ECG stream. The parameters available are:
  ◦ SDNN (standard deviation of NN intervals)
  ◦ RMSSD (root mean square of successive differences)
  ◦ SDSD (standard deviation of successive differences)
  ◦ PNN50 (percentage of successive NN intervals differing by more than 50 ms)
  ◦ PNN20 (percentage of successive NN intervals differing by more than 20 ms)

Indicated on the right are the [**Heart Rate (BPM)**] (beats per minute) with maximum and minimum frequencies, an icon of a heart pulsing at the read frequency, a [**Lead Off**] detection, and an adjustable [**ECG Gain**] based on the front-end used before the vAFE sensor. The default value for STEVAL-MKI242A and STEVAL-MKI249A is set to 80 while the default value for the STEVAL-MKI250KA is set to 1.

The [**Lead Off**] flag alerts the user when one or more ECG electrodes are not properly attached or if the ECG voltage goes out of valid range, ensuring timely correction for accurate readings.

Refer to the MEMS Studio user manual (UM3233) on www.st.com for more information and features.

7 Human biopotential measurements

The configuration described has been submitted to standard tests for safety for professional use of the boards. For further information on safety and regulatory aspects, contact STMicroelectronics.

1. Use a battery-operated laptop, therefore disconnect the power supply cord if the laptop is connected to the power network.
2. Connect the STEVAL-MKI109V3 or STEVAL-MKI109D with the **STEVAL-MKI242A / STEVAL-MKI249A + STEVAL-MKE005A**, or the **STEVAL-MKI250A + STEVAL-MKE006A**, or the **STEVAL-MKI250A + STEVAL-MKE007A** plugged in the DIL24 connector to the laptop using the USB cable.
3. Ensure proper contact between the individual's body and the electrodes.
   a. STEVAL-MKI242A / STEVAL-MKI250A + STEVAL-MKE007A
      i. Attach the electrodes to the user's skin according to the manufacturer's instructions. The signal shape and features of the ECG depend on the placement of the electrodes.
      ii. Connect the electrodes to the end of the ECG cable.
      iii. Plug the ECG cable jack in the **STEVAL-MKI242A**/STEVAL-MKE007A port.
   b. STEVAL-MKI249A + STEVAL-MKE005A / STEVAL-MKI250A + STEVAL-MKE006A
      i. Place two fingers of different hands on the exposed electrodes.
4. Run the MEMS Studio software according to the steps in Section 6.3: Software configuration and first run to stream real-time data of human biopotential as well as accelerometer and gyroscope data.

Heartbeat detection and computational algorithm are run in the background and the computed heart rate is displayed on the right.

8 Pinouts of the adapter boards

The pinouts of the three adapter boards for controlling the sensor using customized boards are indicated in the following figures.

Figure 13. **STEVAL-MKI242A DIL24 adapter board pinout (ST1VAFE6AX)**

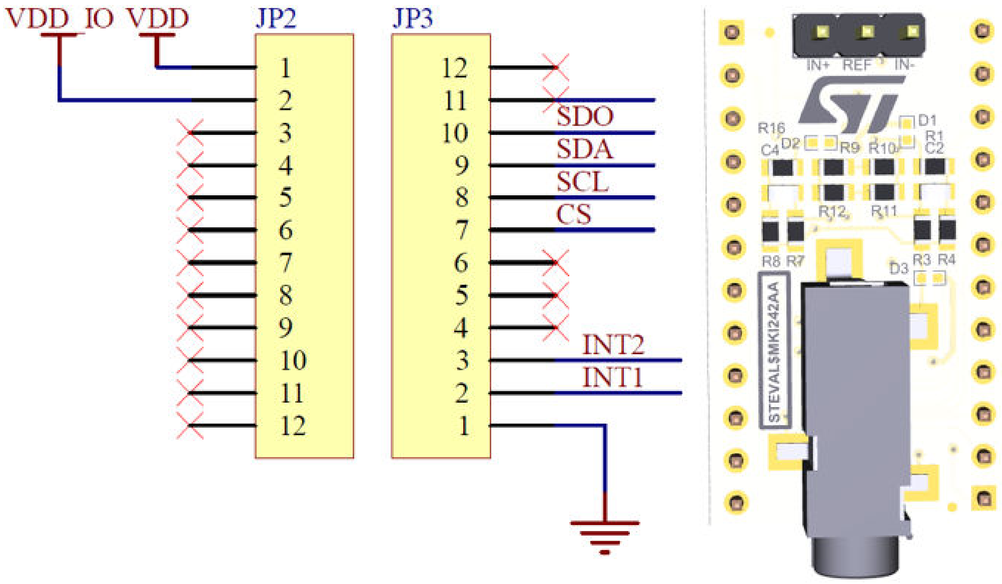


Figure 14. **STEVAL-MKI249A DIL24 adapter board pinout (ST1VAFE6AX)**

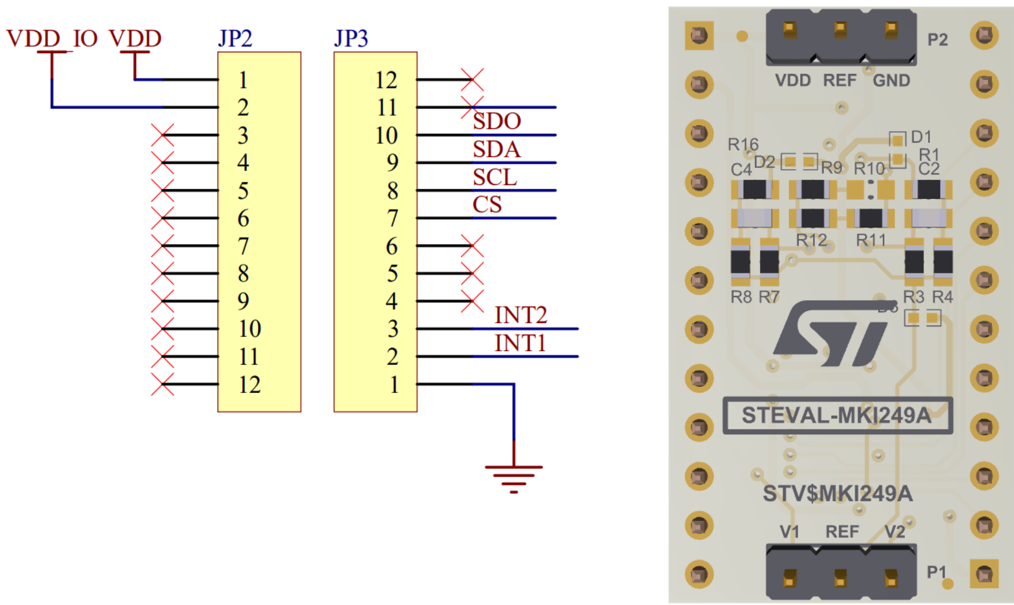
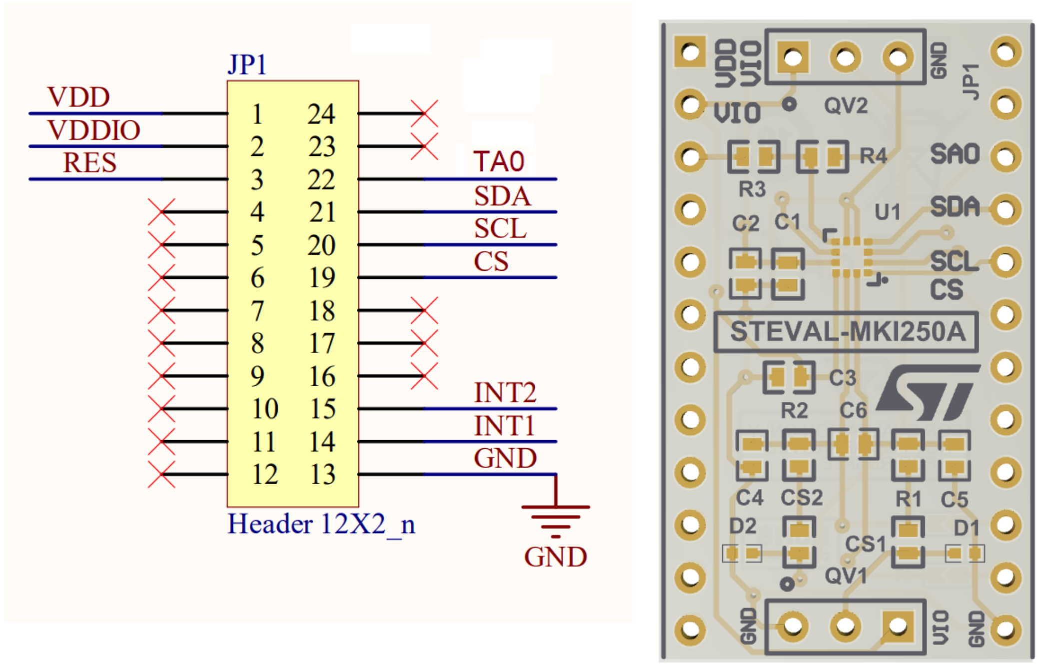


Figure 15. **STEVAL-MKI250A DIL24 adapter board pinout (ST1VAFE3BX)**



Appendix A Certifications

The STEVAL-MKI109V3 and STEVAL-MKI109D Professional MEMS tools as well as the **STEVAL-MKI242A, STEVAL-MKI249KA** (ST1VAFE6AX) and the **STEVAL-MKI250KA** (ST1VAFE3BX) adapter kits have been tested and are compliant with the following standards:

- EN 60601-1:2006
- CISPR 32:2015 +A1:2019 / EN 55032:2015 + A1:2020
- CISPR 35:2016 / EN 55035:2017+A11:2020
- CISPR 32:2015 +A1:2019 / EN 55032:2015 + A1:2020
- CISPR 35:2016 / EN 55035:2017+A11:2020
- IEC 61000-3-2:2018 +A1:2020
- EN IEC 61000-3-2:2019 +A1:2021
- IEC 61000-3-3:2013 + A1:2017 + A2: 2021
- EN 61000-3-3:2013 + A1:2019 + A2: 2021
- IEC 61000-6-1:2016 – IEC 61000-6-3:2020
- EN IEC 61000-6-1:2019 – EN IEC 61000-6-3:2021
- FCC CFR 47 Part 15 Subpart
- ICES-003 Issue 7 (2020)

Revision history

Table 4. **Document revision history**

Date	Version	Changes
13-Aug-2024	1	Initial release
24-Oct-2024	2	Added ST1VAFE3BX biosensor and specified the adapter boards for each biosensor Updated Section 3: Synchronization of ECG Updated Section 4: Front-end stage and reference voltage Updated Section 5: Electrodes Updated Section 6: Setup for the ECG Updated Section 7: Human biopotential measurements Added Section 8: Pinouts of the adapter boards Updated Appendix A: Certifications

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