AN5755

Application note

Qvar sensing

Introduction

Qvar is an **electrostatic sensor** from STMicroelectronics that can be used for human presence and motion detection, touch detection, and user interface (UI) applications.

This application note provides guidelines about the Qvar sensing channel in terms of configuration and operation.

When you walk over a plastic floor and then touch a metallic doorknob, you experience a tiny electric shock. Sometimes when you take off your woolen sweater, you may have also experienced a tiny electric spark. Children often rub a balloon on their clothes to make it stick. We can conclude from such common phenomena that static electricity, or electric charge, originates from friction between two different objects. In fact, any close physical contact between two objects through rubbing generates static electricity. Sometimes close contact between two different objects and then separation without physical friction can also make both objects electrostatically charged.

All materials are comprised of atoms, each of which has a positive nucleus with a number of electrons surrounding it. When two different materials are brought together in close physical contact such as rubbing, one of the materials may attract electrons more than the other, so some electrons are pulled from one material to the other. When the materials are separated, one of them has gained some more electrons (negatively charged) while the other has lost some (positively charged), depending on the working function of each material. Such a phenomenon is often known as **triboelectricity** or **triboelectric effect**, where the prefix ‘tribo’ means friction. Since the triboelectric phenomenon exists widely in our daily lives, **electrostatic sensors** can be used to detect or sense a diverse range of human activities, mechanical systems, or industrial processes.

In comparison with more established sensing techniques such as those based on acoustic, resistive, capacitive, piezoelectric, optical, and electromagnetic principles, **electrostatic sensors** are relatively uncommon and less understood. However, electrostatic sensors have clear advantages over other sensors, including cost-effectiveness and high sensitivity.

1 Electrostatic charge sensing principle

An electrostatic charge is expected on a material whenever it comes into contact with another material or a solid or liquid surface. The level of charge is usually unpredictable, but it can be detected by means of an **electrode** and an **electronic signal conditioning circuit.**

A signal is derived from the electronic circuit due to the fluctuations in the electric field resulting from the passage of the charged particles. If the electrode is embedded in an insulator or there is no direct contact between the electrode and the particles, the sensing process is achieved through electrostatic induction. On the contrary, if the electrode is exposed to the electric charges, charge transfer due to physical contact between the electrode and the particles occurs.

In cases where an exposed electrode is used, both electrostatic induction and charge transfer take place, although the former is often the dominant interaction. If the insulated electrode is connected to a signal conditioning circuit with an input resistance Ri, the latter measures the flow of electrons and produces a measurable output.

An electrostatic sensor is based on the sensing principle of electrostatic induction or through charge transfer and has certainly no correlation with an electromagnetic effect. When a sensor works by electrostatic induction, the sensing principle may be explained in terms of an equivalent capacitive sensor. This is because the charged object can be modeled as a plate of a capacitor while the electrode itself is modeled as the other plate. The movement of the charged object with reference to the electrode changes the distance between the two plates and hence the value of the capacitance. Similarly, the quantity of charge on the object may change with time and hence the voltage across the plates.

Qvar stands for electric charge (= Q) variation (= var). It is an electrical potential sensing channel able to measure the quasi-electrostatic potential changes, enabling applications such as:

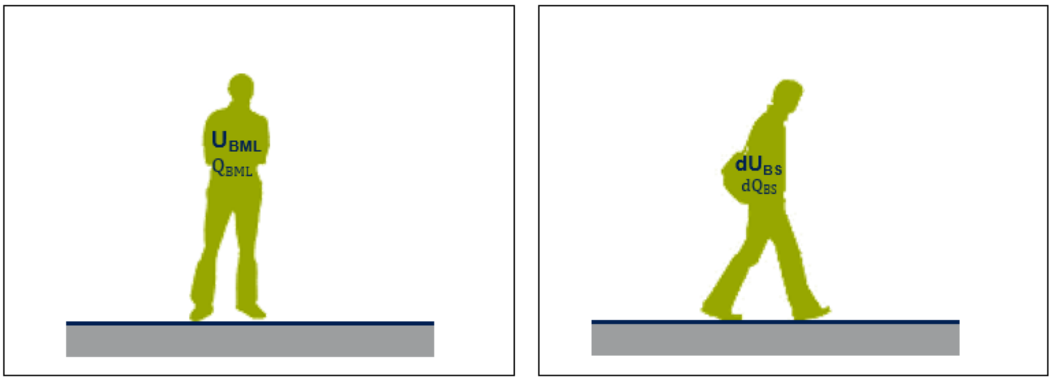
- contact and no-contact human motion detection and human motion gait analysis
- human presence detection
- user interface (UI)
- water detection

Let’s take as an example human movement. When a person walks, steps, jumps or, more in general, interacts with the environment, static electricity is produced as a result of these actions, and an electric potential (U) is charged within the human body itself.

This static potential change ends within several milliseconds because the human body is capacitively coupled to the ground through the air (C_x) or shoe soles (C_s) and floor (C_F).

We have depicted in the following figure a man that is standing and another that is walking, labeled with terms for electric potential and charges that are introduced hereafter.

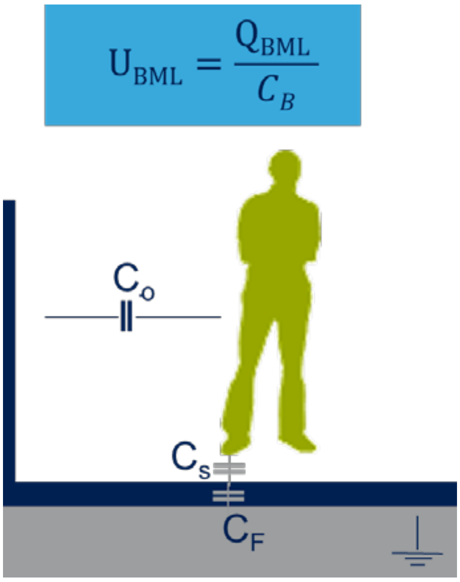
Figure 1. Standing vs. walking



- U_{BML} = motionless human body potential
- Q_{BML} = motionless human body charge
- dU_{BS} = human body step potential
- dQ_{BS} = human body step charge

Focusing on the case of a motionless human body, we can consider the capacitive coupling of the human body itself with the environment according to the model represented in the following figure.

Figure 2. **Human body model**



U_{BS} (human potential) variation over time due to human step is computed as:

$$grad\, U_{BS} = \frac{dU_{BS}}{dt} = Q_{BS} = \left(\frac{1}{\varepsilon a S} \frac{dx}{dt} - \frac{x}{\varepsilon a S^2} \frac{dS}{dt} \right)$$

where:

x = distance from foot to floor

S = actual floor surface in contact with foot

εa = permittivity of air gap between the sole and the floor

There are two important terms that deserve to be explained.

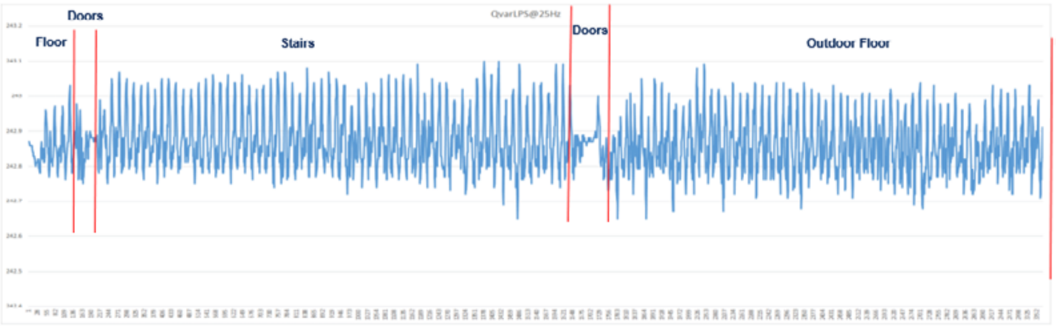
The first term is dS/dt. This term represents the contribution to the electric potential variation due to the sole movement where S is the actual surface where the foot is touching the ground.

The second term is dx/dt proportional. This term represents the contribution to the electric potential variation due to the x variation where x represents the distance between the ground and the foot.

A step is a combination of two movements that are in the opposite direction. The increase of one contribution corresponds to a reduction of the other.

The following figure shows the Qvar sensing signal for continuous walking with electrodes on the body (no skin contact).

Figure 3. **Qvar signal during indoor and outdoor walking**



Specifically, the Qvar sensing channel is able to detect the differential electric potential variation induced on the electrodes connected.

Electrodes can be placed in different ways:

1. on the body but not in contact with human skin
2. on the body and in contact with human skin
3. no contact

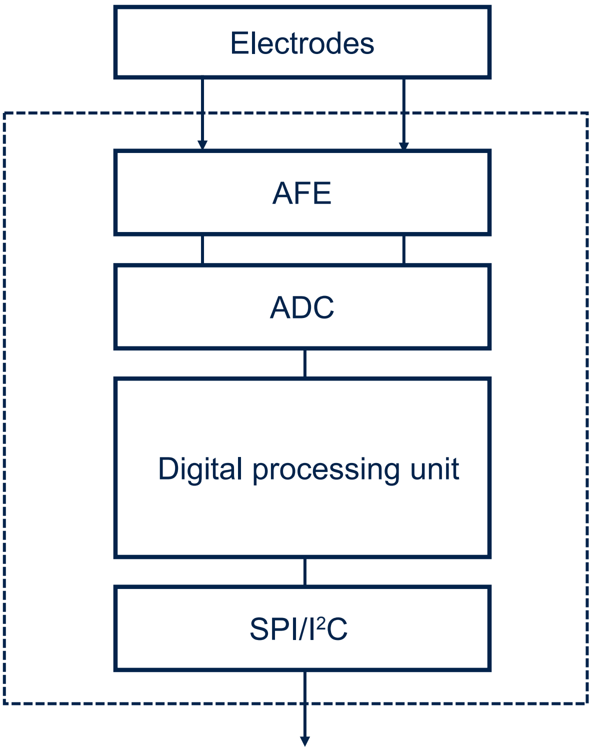
We refer to cases 1 and 2 as **Qvar on-body** functions and case 3 as **Qvar radar** function.

For UI and water-leak detection applications, dedicated electrodes have to be considered (see Section 5.1 Qvar for user interface applications).

2 Qvar sensing channel architecture

The following figure shows the high-level block diagram of the device including external electrodes.

Figure 4. **Qvar sensing channel architecture**



The main blocks of the architecture include:

- External electrodes: one or two electrodes must be connected to the appropriate pins in order to enable sensing data acquisition by Qvar. The number of electrodes as well as the size is based on the specific application
- Qvar analog front end (AFE)
- Analog-to-digital converter (ADC)
- Digital processing unit
- Communication interface as SPI or I²C

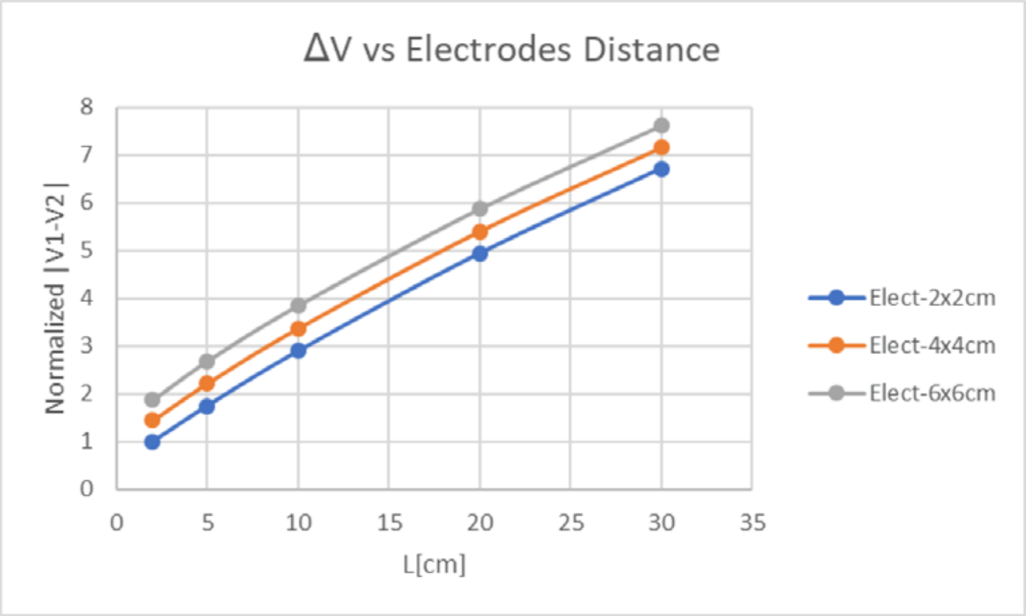
3 Electrodes

It is well known that electrode features such as size, shape, and material are important factors that may produce different Qvar channel results.

For instance, it exists a linear relationship between sensitivity and the electrode area. The sensitivity of the sensor is asymptotically increased with the area of the electrode.

Such linearity is confirmed from simulation results too. The following figure shows the linear relationship between the electrode area and electric potential difference by varying the distance among the electrodes in the range of 2 cm to 30 cm.

Figure 5. Qvar sensing channel simulation results



The materials that are commonly used for the electrodes are copper, silver, tin, or ITO (indium tin oxide), and so forth. The material of the electrode plays an important role in sensor sensitivity.

In general, electrode materials have to be electrically conductive and have a low electrical resistance. Copper offers low resistivity compared to other materials (see Table 1) and thus it has good electrical conductivity. As the resistivity of the conductor decreases, the ability to move electric charges in the electrode increases. For this reason, most applications use copper as electrodes on a PCB. Since the electrodes are built as a metal surface on a PCB, in general they are protected by solder resistance to prevent electrical shorting and limit any corrosion.

Table 1. Resistivity of materials

Material	Resistivity (ohm x cm)
Copper	1.68×10^{-6}
Silver	1.59×10^{-6}
Tin	1.09×10^{-5}
Indium tin oxide	1.05×10^{-3}

If high resistivity material is used, note that sensor sensitivity may be reduced. In this case, the recommendation is to increase the electrode area in order to reduce the resistance.

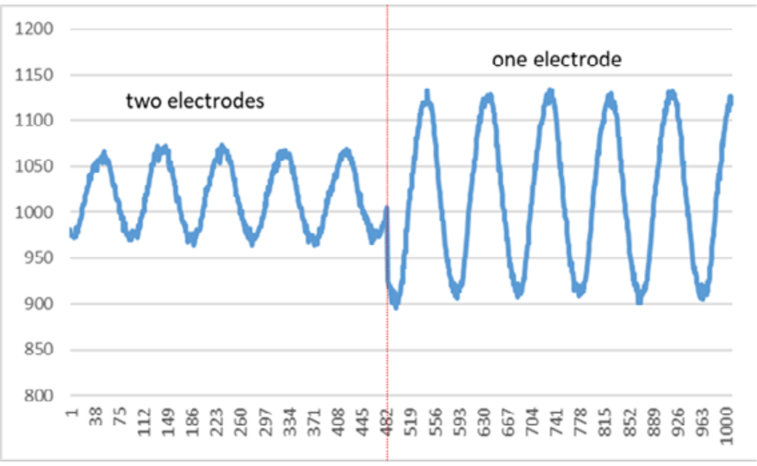
The last point is related to the number of electrodes and their placement. The Qvar sensing channel can be connected with one or two electrodes based on the specific application.

The following figure shows different amplitudes of the external noise signal in both electrode configurations (one vs. two electrodes). The common mode coupling AC power is attenuated when the two electrodes are placed close to each other (within 30 cm).

Increasing the distance (electrode to electrode) above 30 cm, the amplitude of external noise increases proportionally and this parameter should be compensated by using an algorithm.

In general, by choosing the right electrode size and distance it is possible to achieve an optimum signal-to-noise ratio (SNR) corresponding to the target application.

Figure 6. External 50 Hz noise signal for different electrode configurations



The Qvar sensing channel can work with one or two electrodes.

These electrodes have to be connected to the QVAR1 and QVAR2 pins (refer to the datasheet for the pin description and connections). In both cases, Qvar works in differential mode but with a single electrode configuration, the sensitivity to the electrostatic field variation is enhanced since common modes are not well canceled. This configuration is recommended for presence detection.

A configuration with two electrodes is recommended when the powerline noise is strong, which is a way to attenuate it. Another reason for using two electrodes is in order to detect the direction of arrival. If you place one electrode far from the other, you have two points of sensing, and based on the sign of the Qvar signal, you can detect the direction of arrival.

If the second electrode is not used, you can leave its pin floating.

4 Register configuration for data sampling

Configuration parameters to enable and use Qvar vary in relation to the specific sensors. The following sections provide details for the sensors embedding Qvar, with the instructions to turn it on and read data. Each sensor has the possibility to route the Qvar data-ready interrupt to an interrupt pin of the sensor.

If supported, the equivalent input impedance of the Qvar buffers can be selected. Further information on this topic can be found in the datasheets.

The pseudo-instruction used to write and read data have the following structure:

Write(register_to_write, data_to_write); MultiRead(register_to_read, pointer_to_data_buffer, data_bytes_to_read);

4.1 ILPS22QS

In order to enable Qvar:

- ***Write(0x10, 0x08); // ODR set to 1 Hz***
- ***Write(0x12, 0x80); // QVAR_enable***

The ODR is shared with the pressure sensor, for further information on its values refer to the datasheet or the appropriate application note.

Then, to read the output data, registers 28h, 29h, and 2Ah must be read:

- ***MultiRead(0x28, (uint8_t*)&qvar_out, 3)***

Qvar data is stored in the variable qvar_out, expressed in LSB. To convert this value to mV, the value of Qvar_Gain of this sensor (438000) is used in the following formula:

- value[mV] = value[LSB] / Qvar_Gain

It is to be noted that the output registers are the same as the pressure sensor registers. For this reason, if Qvar is enabled, the pressure output cannot be read.

Be sure to implement the network of recommended external connections and electrodes to the Qvar pins, as shown in the datasheet.

4.2 LSM6DSV16X

In order to enable Qvar and route the data-ready interrupt to INT2:

- ***Write(0x10, 0x07); // accelerometer turned ON in high-performance mode***
- ***Write(0x11, 0x07); // gyroscope turned ON in high-performance mode***
- ***Write(0x16, 0xC0); // QVAR_enable, QVAR_DRDY_INT2 active***

Then, to read the output data, registers 3Ah and 3Bh must be read:

- ***MultiRead(0x3A, (uint8_t*)&qvar_out, 2)***

Qvar data is stored in the variable qvar_out at a fixed 240 Hz ODR, expressed in LSB. To convert this value to mV, the value of Qvar_Gain of this sensor (78) should be used in the following formula:

- value[mV] = value[LSB] / Qvar_Gain

Moreover, Qvar data can be stored in FIFO (by setting the QVAR_BATCH_EN bit to 1 in the COUNTER_BDR_REG1 (0Bh) register) and can also be processed by MLC/FSM logic. The equivalent input impedance of the Qvar buffers can be selected by properly setting the QVAR_C_ZIN_[1:0] bits in the CTRL7 (16h) register. Finally, the QVAR_SW bit in the CTRL10 (19h) register allows internally swapping the input electrodes connected to the QVAR1 and QVAR2 pins.

Be sure to implement the network of recommended external connections and electrodes to the Qvar pins, as shown in the datasheet.

4.3 LSM6DSV16BX

In order to enable Qvar and route the data-ready interrupt to INT2:

- ***Write(0x10, 0x07); // accelerometer turned ON in high-performance mode***
- ***Write(0x11, 0x07); // gyroscope turned ON in high-performance mode***
- ***Write(0x16, 0xCC); // QVAR_enable, QVAR_DRDY_INT2 active, both pins active***

Then, to read the output data, registers 3Ah and 3Bh must be read:

- ***MultiRead(0x3A, (uint8_t*)&qvar_out, 2)***

Qvar data is stored in the variable qvar_out at a fixed 240 Hz ODR, expressed in LSB. To convert this value to mV, the value of Qvar_Gain of this sensor (78) should be used in the following formula:

- value[mV] = value[LSB] / Qvar_Gain

The Qvar pins can be enabled separately to work in both single-ended or differential mode with bits AH_QVAR1 _EN and AH_QVAR2 _EN in register CTRL7 (16h).

Moreover, Qvar data can be stored in FIFO (by setting the AH_QVAR_BATCH_EN bit to 1 in the COUNTER_BDR_REG1 (0Bh) register) and can also be processed by MLC/FSM logic. The equivalent input impedance of the Qvar buffers can be selected by properly setting the AH_QVAR_C_ZIN_[1:0] bits in the CTRL7 (16h) register. Finally, the AH_QVAR_SW bit in the CTRL10 (19h) register allows internally swapping the input electrodes connected to the QVAR1 and QVAR2 pins.

Be sure to implement the network of recommended external connections and electrodes to the Qvar pins, as shown in the datasheet.

5 Application examples

Qvar can be used to improve and simplify the user interface (UI) by sensing charge variations with high precision when the electrodes are in contact with the user.

The UI can be enabled by turning on the Qvar sensor, as described in Section 4 Register configuration for data sampling, then the sensor data can be processed using dedicated firmware functions, or directly fed to the finite state machine to save resources and power consumption, using one of the configurations shown in Section 5.3 Register configuration for FSM usage.

5.1 Qvar for user interface applications

In a scenario where the user touches the device to interact with it, a button is the usually most common solution, but a touch sensitive interface would be much cleaner and cost effective.

Qvar can be used as a sensitive touch interface by connecting a simple electrode to the sensor in order to detect a touch, a press, or even a swipe.

All possible actions performed on the electrodes can be detected through an algorithm running on the microcontroller, or directly on the sensors where the machine learning core (MLC) and finite state machine (FSM) functions are available.

In Section 5.3 Register configuration for FSM usage, two examples of FSM are presented, one that shows the in-ear detection algorithm, and one that shows touch, double touch, triple touch, long press, and swipe, all in one configuration.

5.1.1 Electrodes for touch sensing

Detecting a touch or a long press can be done by using two signals: Q+ or Q- (referred to as QVAR1/QVAR2 in the datasheet) and GND.

The goal of the design is to let the user touch both the Q+ and GND area at the same time. For this reason, many different designs are possible.

An electrode like the one shown in the figure below has been used in internal tests, where 4 pins (GND, Q+, GND, and GND in that order) are considered just for configuration with a 4-pin connector. It is possible to use only 2 pins to acquire the signal.

These are printed on a flex board with the contact surfaces (in copper) exposed. In this way, in order to detect a touch gesture, it can be put in the area of the device that should be touched by the user.

The exposed copper areas at the tip of the board are the actual electrodes.

When both of these electrodes are pressed, the sensor measures a high charge variation and the output signal is saturated. The level at which the signal saturates depends on the connected pin: Q+ and Q- have the opposite effect on it.

In this way, the saturated signal is comparable to the press of a button.

Figure 7. Example of a flex electrode

The dimensions used for this example are 10 x 10 mm, but the size of the electrodes in UI applications is not as important as when used for presence detection, so they should be selected in order to consider the effort in touching the area.

This layout is particularly useful for a touch sensitive interface because it is easy to touch both electrodes with a small fingertip surface pressing the area.

Another example of an electrode is the one shown below, printed on a PCB board, where the Q+ and GND signals are interleaved in another pattern. The difference lies only in the pattern, and the size can be adjusted to fit the application.

Figure 8. **Example of a PCB electrode for touch detection**

Keep in mind that is possible to use two different UI interfaces at the same time, having one “button” that uses interleaved Q+ and GND, while the other uses Q- and GND.

In this case, the output signal saturates high or low depending on the button pressed. If both buttons are pressed at the same time, usually the signal saturates low, but depending on the different path impedances, the situation can change and Q+ can dominate.

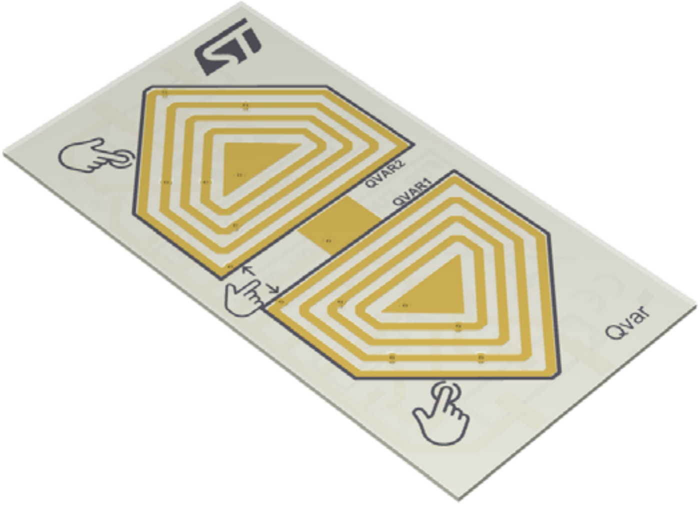
5.1.2 Electrodes for swipe sensing

Two “buttons”, as described in Section 5.1.1 Electrodes for touch sensing, can be used to sense a swipe interaction in the area of the electrode.

The idea behind the swipe detection application is the fact that when the user touches in rapid succession one button and the other (short-circuiting first one Qvar output with GND and then the other output with GND), the signal goes from one saturation end to the other.

The electrode design used for our tests is the one shown below.

Figure 9. Example of a PCB electrode for swipe detection



On the sides, the arrows are made of concentric layers of Q+ on one side, Q- on the other, and GND, while the central square is connected to GND.

As for the touch interface, the size can be adjusted to fit the application. The important rule to keep in mind is that Q and GND should be easy to touch at the same time.

It is important to note that in order to detect a swipe, an algorithm has to be implemented. A typical approach involves setting one threshold for Q+ and one for Q-, to detect if one of the electrodes is short circuited (that is, if the corresponding button is pressed). If the signal output goes over these thresholds one after the other, the algorithm should detect a swipe in one direction, if the order is inversed, the swipe is on the other direction.

It is to be noted that the two electrodes can still be used as buttons, the firmware/software should take care of analyzing the signal and provide detection of the interaction.

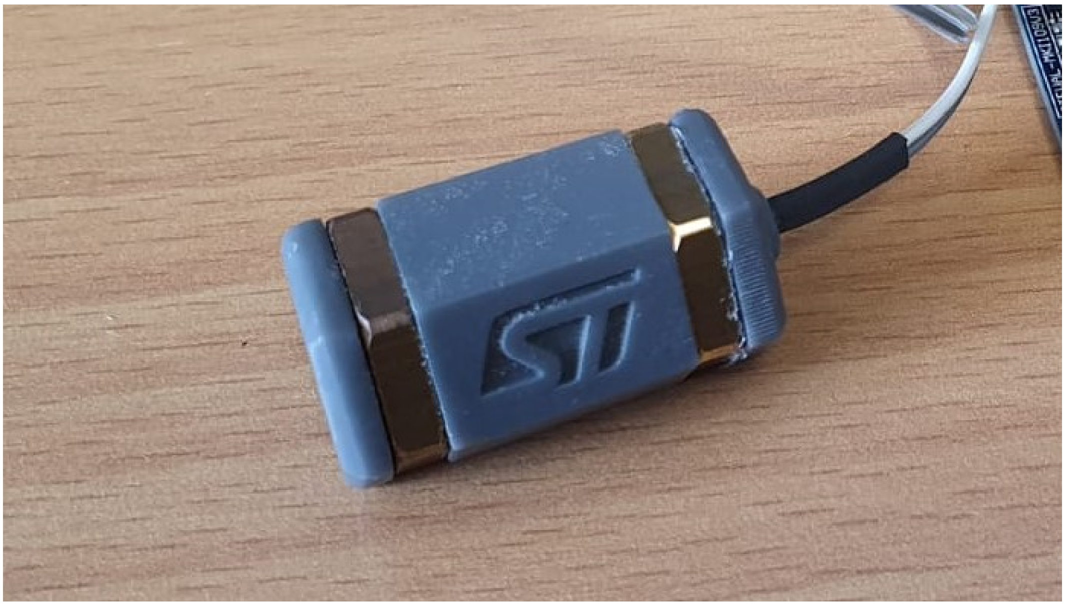
5.1.3 Electrodes for water-leak detection

Water-leak detection is based on the assumption that water is a conductor and is able to transfer charge just as the human finger.

The same principle of the touch electrodes is used, so the two electrodes Q+ (or Q-) and GND must be easily short circuited by the water.

After trying different morphologies, the final electrode structure for water-leak detection is shown in the figure below, but keep in mind that, as always, the structure can be modified to adjust to the application in which it is used.

Figure 10. Example of an electrode for water-leak detection



Inside this structure, the wires that come from the outside are linked to the two metal rings fixed in the slots in the plastic section. The main body was printed with 3D printing technology.

If the water-detection device is placed horizontally on a surface, as in the figure above, a very thin layer of water can be detected.

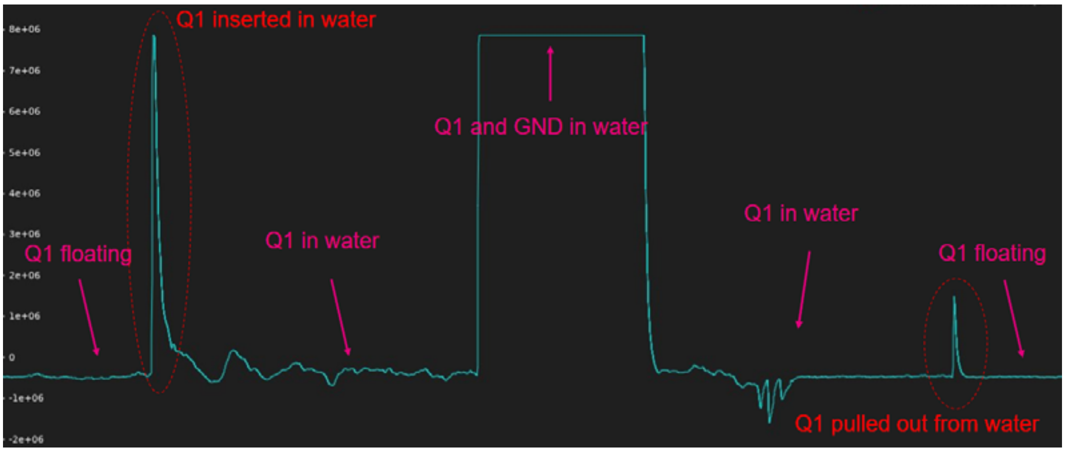
When there is water that envelopes both electrodes, a short circuit occurs between the Qvar sensing channel and GND.

This triggers the saturation of the signal, just as it happens with the touch sensing electrode.

If it is placed vertically inside a container, the water is able to trigger the Qvar response only when it reaches the higher metal surface, so an application where the water level to be detected is fixed can be developed with a custom distance between the two electrodes.

Note that the Qvar signal is noisier when one of the electrodes is in water while the other is floating, but, with a little computation, the water can be detected touching both electrodes clearly, as can be seen in the graph below.

Figure 11. **Example of water-leak detection**



When working on a water-detection application, it is important to take into consideration the layer of residual water that can remain on the surface of the structure that holds the metal rings when the water level returns below the level detected.

If this layer is thick enough, it can trigger a short circuit and the saturation of the signal.

For this reason, the vertical configuration is more robust in this respect.

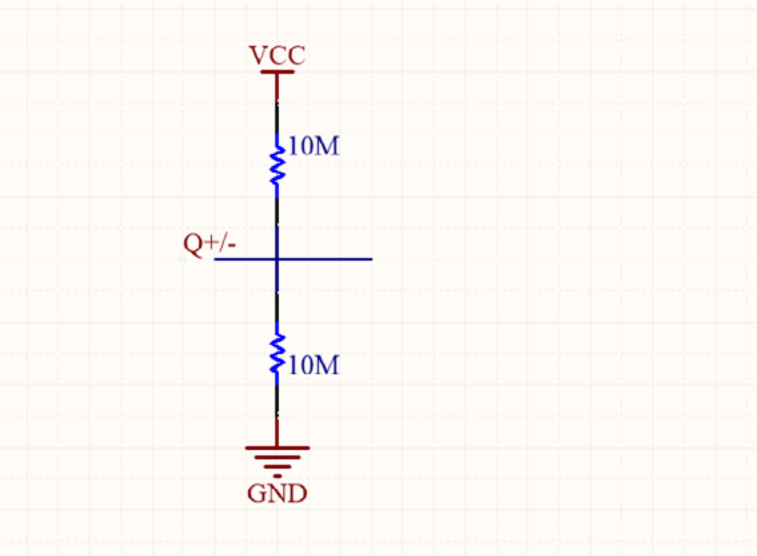
5.1.4 Polarization circuit for UI

The signal can be close to or exactly at saturation level depending on the polarization of the signal provided by the adapter, due to the offset value of the signal at default state (when both pins are floating).

Without a polarization circuit, the offset cannot be controlled and is dependent on mismatches in vias and wires. By using a polarization circuit like the one shown in the figure below, this mismatch is stransferred to the big resistors of the voltage divider.

In this way, if the resistors have a precision of ±1%, the greater offset obtainable is around ±1300 LSB.

Figure 12. **Polarization circuit**

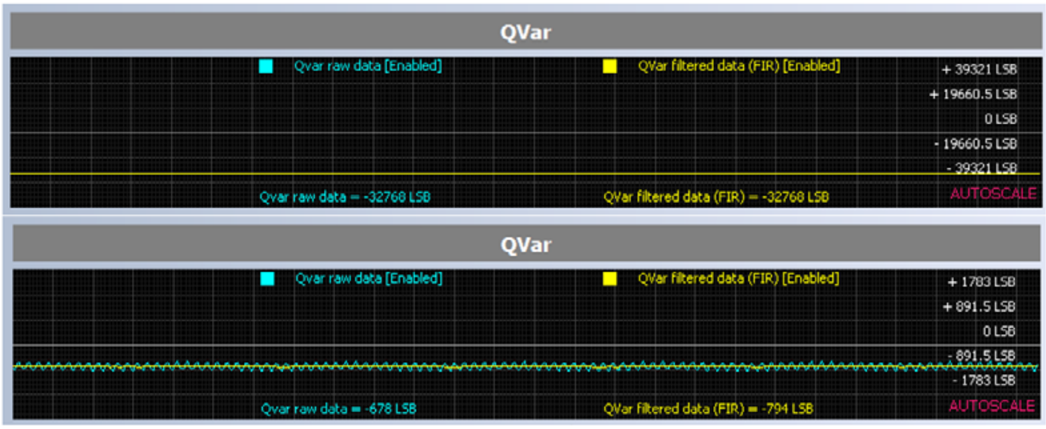


Moreover, the signal has a range of both positive and negative values to explore, and the two electrodes can be used to provide separate functions. For example, when used in conjunction with a grounded electrode, they can provide two “buttons” that can be managed by a single sensor.

When touching Q+ and GND, the signal saturates on the positive side. When touching Q- (referred to as QVAR2 in the datasheet) and GND, the signal saturates the negative side.

In the following figure there is an example with a pretty bad mismatch that generates a high offset pretty close to the low saturation level (-32000 LSB), and the same adapter with the polarization circuit where the offset drops to -700 LSB.

Figure 13. **Example of Qvar signal on high offset adapter without (upper plot) and with (bottom plot) polarization circuit**



Qvar raw data = -32768 LSB
QVar filtered data (FIR) = -32768 LSB

Qvar raw data = -678 LSB
QVar filtered data (FIR) = -794 LSB

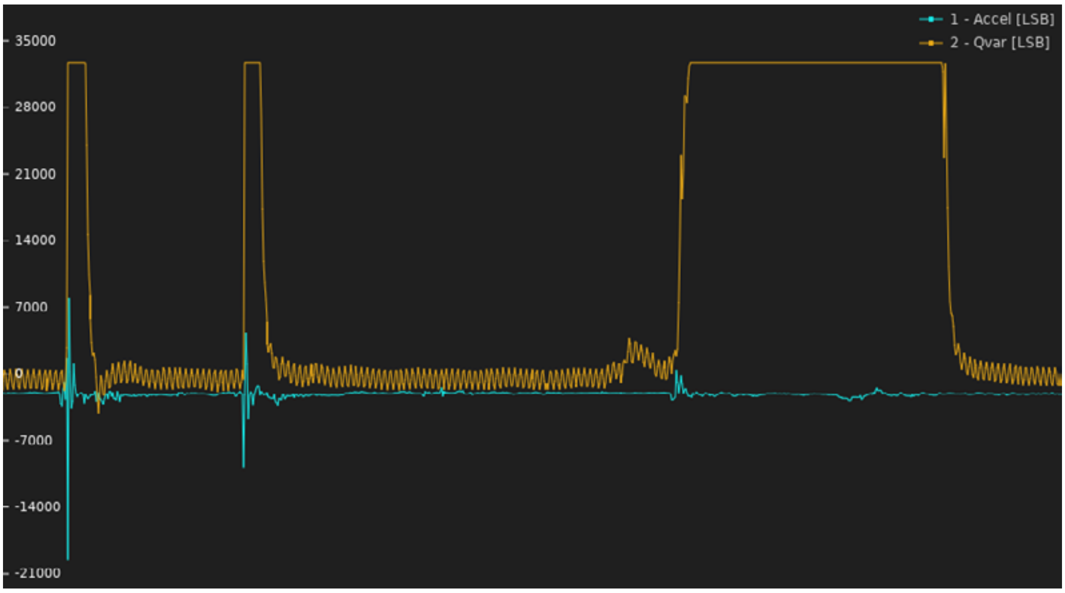
5.1.5 Example of touch sensing in UI

An accelerometer is often utilized in user interface applications to detect single or double tap, because by touching a device, the accelerometer can detect the small shock applied. By adding Qvar it is possible to distinguish whether the user is tapping or touching the device and also to distinguish a long touch, which is not possible with an accelerometer sensor.

The figure below shows a sequence of two taps and a long press of the device, touching the electrode area.

The electrode and polarization circuit used are the ones shown in the previous section.

Figure 14. **Comparison of tap and long touch for Qvar (yellow) and accelerometer (light blue)**



The two tap events are seen for both the accelerometer and Qvar, but during the long press event only Qvar is able to show a signal that can be associated with the expected event.

The signal detected by Qvar is strongly dependent on the electrode design.

For UI applications the electrode (it can be either Q+ or Q-) should be close enough to the GND electrode so that both can be touched together.

5.1.6 50 Hz signal processing

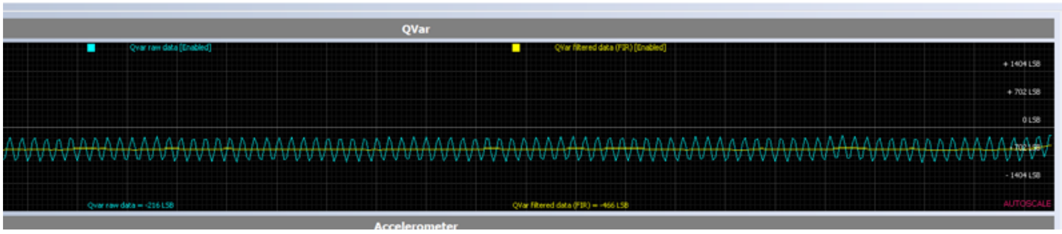
Qvar detects 50/60 Hz external noise which comes from the power supply.

This noise can be filtered with a digital band-pass FIR filter.

The filter should be designed to consider the desired response time and the reduction level of the noise signal needed for the application.

In the following figure the raw signal can be seen in light blue, while the filtered signal can be seen in yellow.

Figure 15. **Qvar signal raw (light blue) and filtered (yellow)**



5.2 Qvar for radar applications

Qvar charge sensing capabilities make it useful in many different situations where there is no contact with the source to sense.

The principle upon which Qvar functions has already been described in depth in this application note in Section 1 Electrostatic charge sensing principle. This section presents ideas and indications that can be used as guidelines to develop certain applications when using Qvar charge sensing capabilities.

Keep in mind that the single electrode configuration was the best suited, in internal tests, for radar applications.

5.2.1 Presence detection

As already stated, the human body is electrically charged, so, when a person is moving around a Qvar electrode, a difference in the charge is detected by the electrode.

It is not easy to discern between different situations (for example, a human or an animal passing by, or the direction in which the person is moving), but with a precise characterization of the application, presence detection is feasible.

Different electrodes were used during internal tests, and different sizes and shapes were tested. In the end, the layout shown below resulted in the best approach.

Figure 16. **Qvar electrode for radar applications**

Be aware that the surrounding environment influences the detected signal in many ways.

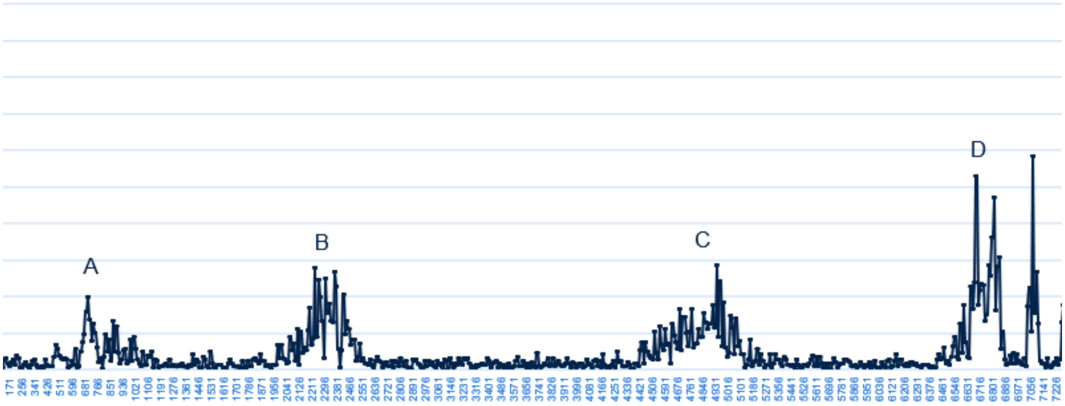
For example, there is a significant difference in noise intensity (mainly for the 50/60 Hz signal) between indoor and outdoor measurements.

The same difference can be seen when the sensor is powered by a wire connected to a power source or to a small battery.

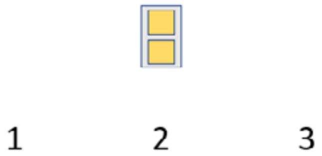
Even the material of the surface on which the electrode is placed influences how much the signal increases.

An example of data collected with this electrode is shown below (with 50/60 Hz filtered).

Figure 17. **Qvar data collection (the 4 points indicate the movements of a person walking by)**



The different points refer to different ways of moving in proximity to the sensor. In particular, see the figure below for reference, where the positions were located at 1 meter from the electrode indicated in yellow.



A. Movement of 1 person from point 2 to point 1

B. Movement of 1 person from point 1 to point 3

C. Movement of 2 people from point 3 to point 2

D. Movement of 1 person from point 1 to point 2

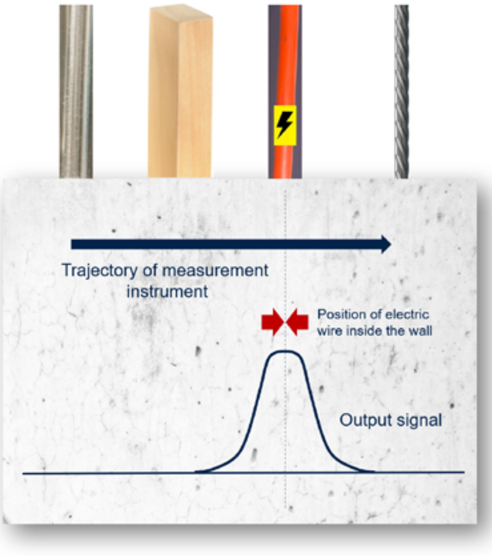
It can be seen that 2 people passing by the electrode have a wider signal, but it is hard to differentiate between a single person passing with a slower walk.

5.2.2 Wire detection

The 50/60 Hz noise can be a problem for different applications, but it can be used to detect a wire in the vicinity of the electrode.

The main idea is shown in the figure below.

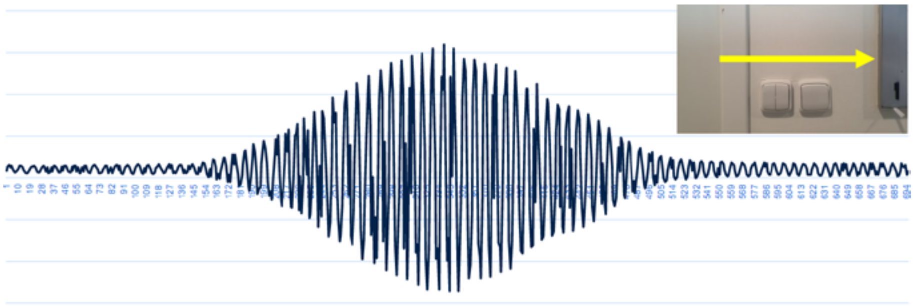
Figure 18. **Wire detection**



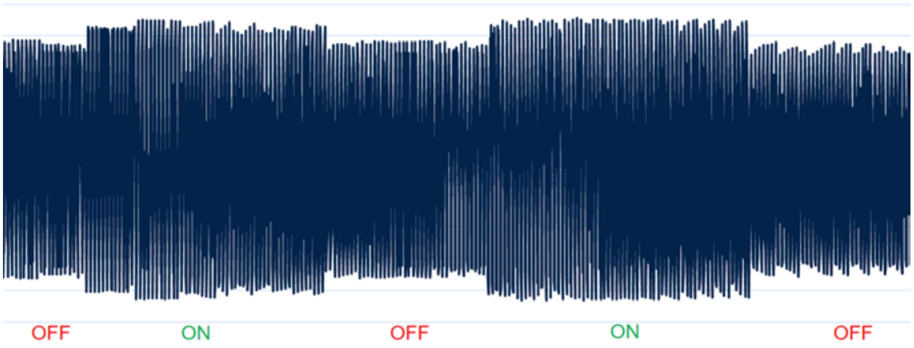
Using the same electrode used for the presence detection application, it is possible to detect the wire when moving the electrode near a wall, even if the wire is not conducting in that moment.

As an example, a test with a wire from light switches were conducted, the results are shown in the plots below.

When moving the electrode sideways above the switches, the signal is clearly higher at the point where the wires pass beneath the wall.



It is also possible to sense if the switches are on or off. In this case, the signal difference is not much, so the reference should be detected before deciding which state is which.



5.3 Register configuration for FSM usage

To recognize the different patterns of the UI applications, both an algorithm running on a microcontroller or a finite state machine running directly on the sensor (when available) can be used.

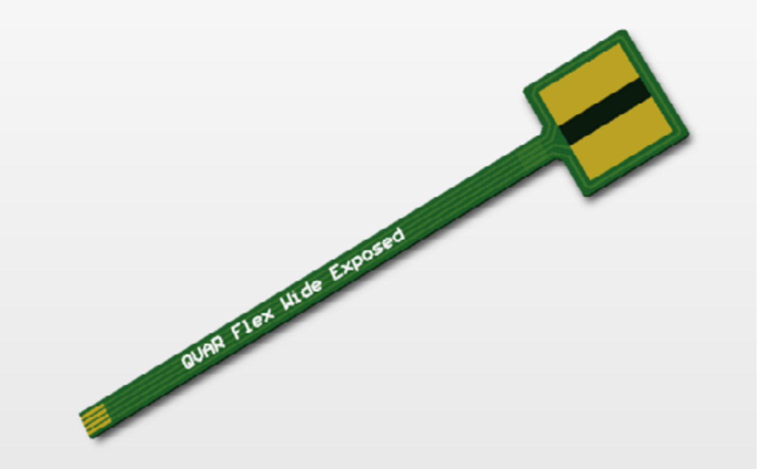
The following section gives some configuration examples for using the FSM.

For further information about the finite state machine, refer to the FSM application note of the corresponding device.

5.3.1 In-ear detection

In-ear detection can be considered as a long touch gesture where the device touches the inside of the ear and the Qvar is able to detect it.

Figure 19. Electrode used for FSM in-ear detection



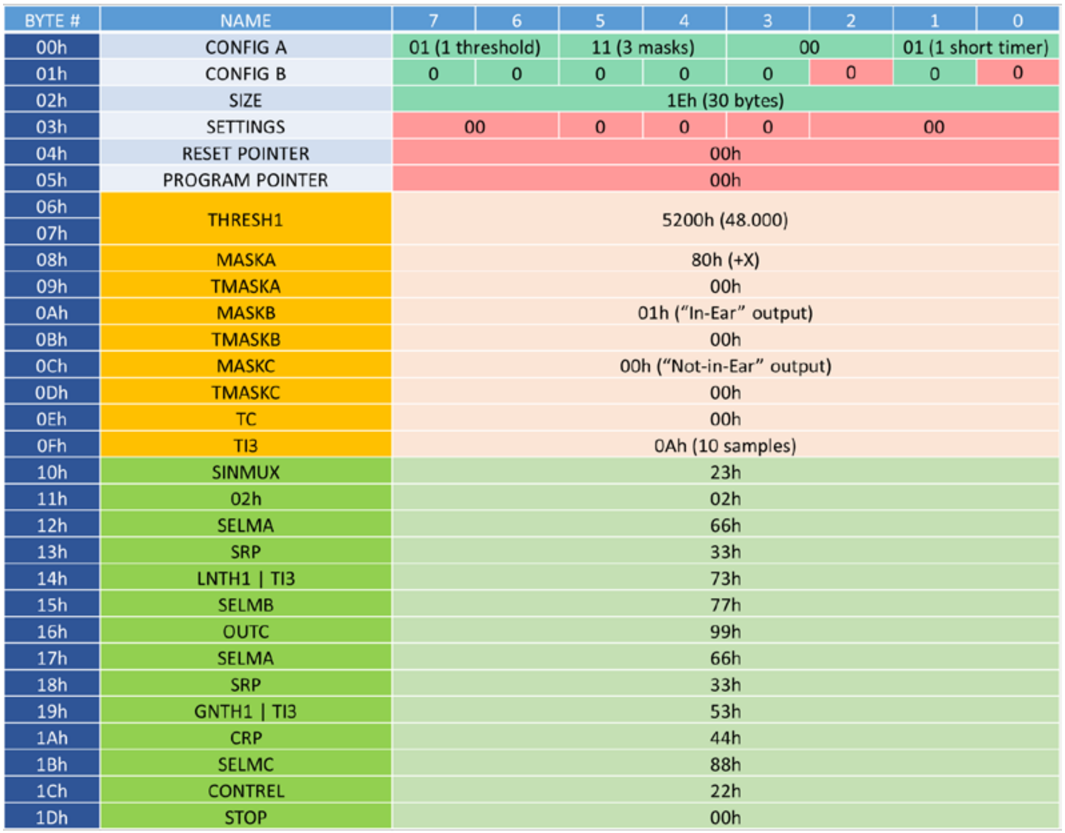
The electrode used is shown in Figure 19, it uses Q+ and GND pins to detect the charge variation and enables the INT2 interrupt to rise when Qvar detects the presence of the human body in contact with the electrode.

For the in-ear detection application, the LSM6DSV16X was used, with the configuration shown in Figure 20.

In this configuration the accelerometer ODR is 30 Hz, the Qvar ODR is 240 Hz, while the current consumption is 195 µA for the accelerometer, 15 µA for the Qvar and 4 µA for the FSM, for a total of 214 µA. The threshold applied to the Qvar data is set to 32000 LSB. Since the sensitivity of the external sensor (in this case Qvar) is kept to its default value (which is 0.0015, equal to 1624h in half floating-point, HFP for short), the FSM THRESH1 value is set to 48.000.

The in-ear detection state machine is described in the following paragraphs.

Figure 20. In-ear detection configuration



BYTE #	NAME	7	6	5	4	3	2	1	0
00h	CONFIG A	01 (1 threshold)		11 (3 masks)		00		01 (1 short timer)	
01h	CONFIG B	0	0	0	0	0	0	0	0
02h	SIZE	1Eh (30 bytes)							
03h	SETTINGS	00		0	0	0	00		
04h	RESET POINTER	00h							
05h	PROGRAM POINTER	00h							
06h	THRESH1	5200h (48.000)							
07h									
08h	MASKA	80h (+X)							
09h	TMASKA	00h							
0Ah	MASKB	01h (“In-Ear” output)							
0Bh	TMASKB	00h							
0Ch	MASKC	00h (“Not-in-Ear” output)							
0Dh	TMASKC	00h							
0Eh	TC	00h							
0Fh	TI3	0Ah (10 samples)							
10h	SINMUX	23h							
11h	02h	02h							
12h	SELMA	66h							
13h	SRP	33h							
14h	LNTH1 | TI3	73h							
15h	SELMB	77h							
16h	OUTC	99h							
17h	SELMA	66h							
18h	SRP	33h							
19h	GNTH1 | TI3	53h							
1Ah	CRP	44h							
1Bh	SELMC	88h							
1Ch	CONTREL	22h							
1Dh	STOP	00h							

Instructions section description

- **PP = 10h**

  SINMUX command with argument 02h is performed without needing a sample set. It is used to select the “external sensor” as input of the state machine. Since the QVAR_EN bit of the CTRL7 (16h) register is set to 1, the Qvar sensor is selected. In this case, the Qvar data is available as +X axis of the external sensor. PP = PP + 2.
- **PP = 12h**

  SELMA command is performed without needing a sample set. The MASKA (80h) is selected. PP = PP + 1.
- **PP = 13h**

  SRP command is performed without needing a sample set. The RESET POINTER is set to the next state, 14h. PP = PP + 1.
- **PP = 14h**

  LNTH1 | TI3 condition is performed with the need for a sample set. If Qvar data is lower than or equal to THRESH1, then PP = RP. If Qvar data is greater than THRESH1 for 10 consecutive samples, then the PP is increased (PP = PP + 1).
- **PP = 15h**

  SELMB command is performed without needing a sample set. MASKB (01h) is selected. PP = PP + 1.
- **PP = 16h**

  OUTC command is performed without needing a sample set. An interrupt is generated, and the OUTS register is updated according to the selected temporary mask (01h). PP = PP + 1.
- **PP = 17h**

  SELMA command is performed without needing a sample set. MASKA (80h) is selected. PP = PP + 1.
- **PP = 18h**

  SRP command is performed without needing a sample set. The RESET POINTER is set to the next state, 19h. PP = PP + 1.

- **PP = 19h**
  GNTH1 | TI3 condition is performed with the need for a sample set. If Qvar data is greater than THRESH1, then PP = RP. If Qvar data is lower than or equal to THRESH1 for 10 consecutive samples, then the PP is increased (PP = PP + 1).
- **PP = 1Ah**
  CRP command is performed without needing a sample set. The RESET POINTER is cleared to its default value, 10h. PP = PP + 1.
- **PP = 1Bh**
  SELMC command is performed without needing a sample set. MASKC (00h) is selected. PP = PP + 1.
- **PP = 1Ch**
  CONTREL command is performed without needing a sample set. An interrupt is generated, and the OUTS register is updated according to the selected temporary mask (00h). PP = RP.

The FSM configuration has to be performed with both accelerometer and gyroscope sensors in power-down mode. Refer to the following script for the complete device configuration:

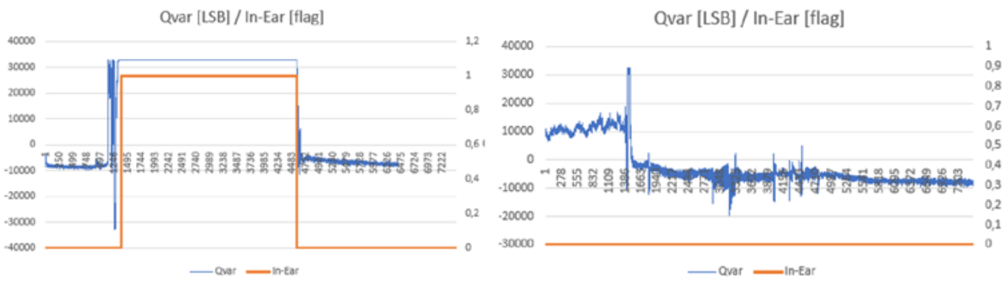
1. Write 00h to register 10h // Set accelerometer sensor in power-down mode
2. Write 00h to register 11h // Set gyroscope sensor in power-down mode
3. Write 80h to register 01h // Enable access to embedded function registers
4. Write 01h to register 05h // EMB_FUNC_EN_B (FSM_EN) = ‘1’
5. Write 4Bh to register 5Fh // EMB_FUNC_ODR_CFG_B (FSM_ODR) = '01' (26 Hz)
6. Write 01h to register 46h // FSM_ENABLE = '01h'
7. Write 01h to register 0Fh // FSM_INT2 = '01h'
8. Write 40h to register 17h // PAGE_RW: enable write operation
9. Write 11h to register 02h // Enable access to embedded advanced features registers, PAGE_SEL = 1
10. Write 7Ah to register 08h // PAGE_ADDRESS = 7Ah
11. Write 00h to register 09h // Write 00h to register FSM_LONG_COUNTER_L
12. Write 00h to register 09h // Write 00h to register FSM_LONG_COUNTER_H
13. Write 01h to register 09h // Write 01h to register FSM_PROGRAMS
14. Write 01h to register 09h // Dummy write in order to increment the write address
15. Write 00h to register 09h // Write 00h to register FSM_START_ADDRESS_L
16. Write 04h to register 09h // Write 04h to register FSM_START_ADDRESS_H
17. Write 41h to register 02h // PAGE_SEL = 4
18. Write 00h to register 08h // PAGE_ADDRESS = 00h
19. Write 71h to register 09h // CONFIG_A
20. Write 00h to register 09h // CONFIG_B
21. Write 1Eh to register 09h // SIZE
22. Write 00h to register 09h // SETTINGS
23. Write 10h to register 09h // RESET POINTER
24. Write 00h to register 09h // PROGRAM POINTER
25. Write 00h to register 09h // THRESH1 LSB
26. Write 52h to register 09h // THRESH1 MSB
27. Write 80h to register 09h // MASKA
28. Write 00h to register 09h // TMASKA
29. Write 01h to register 09h // MASKB
30. Write 00h to register 09h // TMASKB
31. Write 00h to register 09h // MASKC
32. Write 00h to register 09h // TMASKC
33. Write 00h to register 09h // TC
34. Write 0Ah to register 09h // TIMER3
35. Write 23h to register 09h // SINMUX
36. Write 02h to register 09h // 02h
37. Write 66h to register 09h // SELMA

38. Write 33h to register 09h // SRP
39. Write 73h to register 09h // LNTH1 | TI3
40. Write 77h to register 09h // SELMB
41. Write 99h to register 09h // OUTC
42. Write 66h to register 09h // SELMA
43. Write 33h to register 09h // SRP
44. Write 53h to register 09h // GNTH1 | TI3
45. Write 44h to register 09h // CRP
46. Write 88h to register 09h // SELMC
47. Write 22h to register 09h // CONTREL
48. Write 00h to register 09h // STOP
49. Write 01h to register 02h // Disable access to embedded advanced features registers, PAGE_SEL = 0
50. Write 00h to register 17h // PAGE_RW: disable write operation
51. Write 00h to register 01h // Disable access to embedded function registers
52. Write 02h to register 5Fh // MD2_CFG (INT2_EMB_FUNC) = '1'
53. Write 74h to register 10h // CTRL1_XL = '74h' (normal mode, 30 Hz)
54. Write B0h to register 16h // CTRL7 = ‘B0h’ (Qvar enabled, Zin = 235 MΩ)

The following plots are examples of a signal response when the device is plugged in and removed from the ear (on the left) and when the device is just picked up from a desk (on the right).

On the left side, the signal saturates when the device is in contact with the skin inside the ear, and the FSM returns 1 until the electrodes are removed from the ear. On the right side, the signal fluctuates when the device is handled, but it does not saturate, so the FSM output does not rise.

Figure 21. Signal response of the FSM



Appendix A

References

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- Chen Xi, Zheng Wei, Cui Zhanzhong and Li Pengfei ,"Research on the detection method based on human body quasi-electrostatic field," IEEE 2011 10th International Conference on Electronic Measurement & Instruments, 2011, pp. 357-359, doi: 10.1109/ICEMI.2011.6037834

Revision history

Table 2. **Document revision history**

Date	Version	Changes
11-Jan-2022	1	Initial release
23-Feb-2022	2	Updated Section 4.1 ILPS22QS
15-Jul-2022	3	Updated Section 1 Electrostatic charge sensing principle Updated Section 4.2 LSM6DSV16X Added Section 4.3 LSM6DSV16BX Updated Section 5.1 Qvar for user interface applications Updated Section 5.1.1 Electrodes for touch sensing Added Section 5.1.2 Electrodes for swipe sensing, Section 5.1.3 Electrodes for water-leak detection, and Section 5.2 Qvar for radar applications
11-Aug-2022	4	Updated Figure 18. Wire detection Minor textual updates

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