

REPORT ON DELIVERABLE 2.4.1 DAIAD@feel Prototypes for Trials

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Abstract

This report presents the design and implementation of the *Prototype Deliverable D2.4.1 "DAIAD@feel Prototypes for Trials"* which will be used throughout in the DAIAD project trials.

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Executive Summary

This report presents an overview of the prototype Deliverable D2.4.1 “DAIAD@feel Prototypes for Trials”. We discuss the features, the user experience and the tradeoffs we had to make. We highlight the state of the DAIAD@feel sensor prototypes and present a brief look into challenges presented by the successful assembly of the 300 sensors.

The first prototype versions have been tested in the field whereby bugs could be discovered and fixed. Moreover, 300 DAIAD@feel prototypes have been produced and successfully shipped to the trial households.

Abbreviations and Acronyms

BLE	Bluetooth low energy
ID	Identifier
kWh	Kilo-Watt-Hour
LCD	Liquid Cristal Display
PCB	Printed Circuit Board
RF	Radio Frequency

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1. Introduction

The DAIAD@feel sensor prototype is powered solely on harvested energy using a micro generator. The harvested energy is used to measure the water flow, the water temperature, compute the heat energy using configurable parameters such as heating efficiency, cold water inlet temperature, CO₂ per kWh and communicate via Bluetooth Low Energy (BLE). The rotational speed of the micro generator is used to measure the flow rate. Because of the relatively high (compared to the other modules) energy demand of the BLE-module, measures must be taken to achieve accurate measurements: the rotational frequency of the micro turbine is reduced stronger, if the load current is increased. This effect is well known in electrical grid supply where it is used to match the demand side. In our case, we have no control of the source, since the user might turn off running water at any time. Therefore, we had to compensate for the loss in rotational frequency due to high load currents algorithmically.

The DAIAD@feel sensor prototype by default displays the water and energy consumption for every individual shower taken. After a couple of minutes of interruption, a new measurement will start and the display will be reset to zero. Individual showers are locally stored to ensure lossless data generation during the Trials in case of a bridge failure. As soon as the bridge is working again (typically this means in range again), the stored data can be synchronized.

2. DAIAD@feel prototype

2.1. Electronics Design

The electronics of the DAIAD@feel prototype consists of six main components: MCU (Microcontroller Unit), BLE-Module (Dexatek), a display, Buffer-Capacity, Temperature Sensor (Thermistor), and the micro turbine used for energy harvesting and flow-rate measurement.

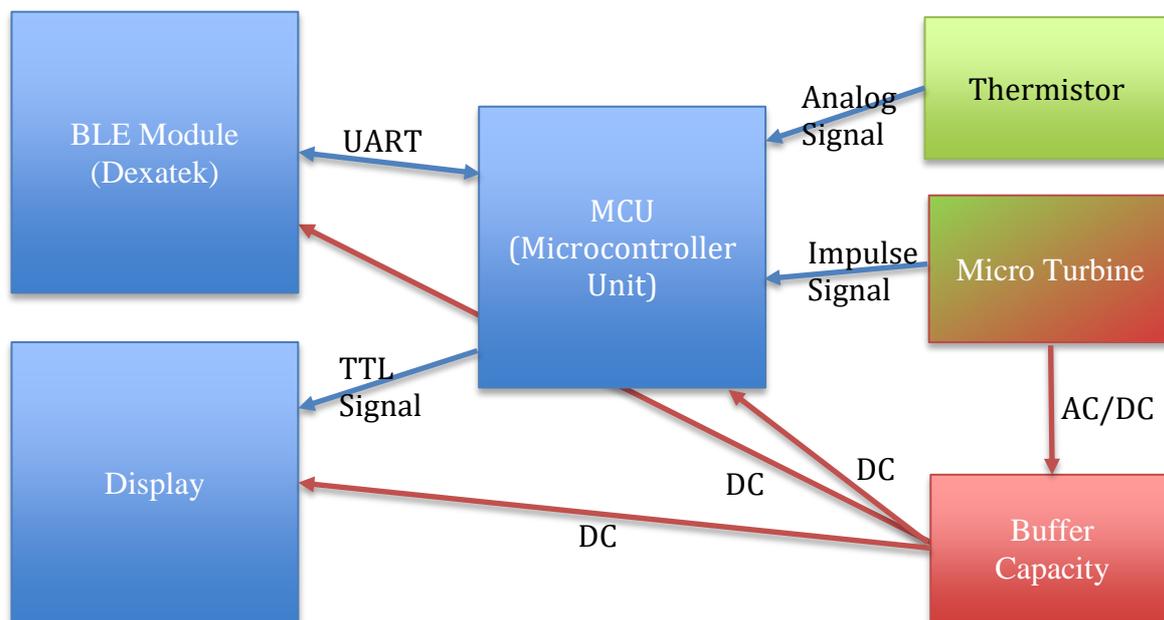


Figure 1: System Overview of the DAIAD@feel prototype. Green are Sensors, Red Power related components, and Blue are controllers and displays. The arrows indicate the direction of communication.

Figure 1 shows graphically the interconnection of these components and the communication strategies used. The main component is the MCU. Its main task is to collect analog signals from the sensors (Thermistor, Micro Turbine), process them and send it to the BLE-Module. The BLE-Module is connected by means of a two wire serial interface (UART, Universal Asynchronous Receiver and Transmitter), which allows bidirectional communication between the module and the MCU. The BLE-Module is produced by Dexatek and includes the RF-design as well as a dedicated microcontroller unit containing the BLE-Stack (Datasheet in Annex 6.4).

Further, the MCU is in charge of producing a TTL signal for the display. Dependent on this signal, the content of the display changes. The display is an LCD (Liquid Cristal Display) with 112 individual segments which can either be turned on (visible, positive TLL-signal) or turned off (not visible, zero TLL-signal). The customized display contains four 16-segment units for displaying text and numbers (ASCII-Symbols) and three 7-segments units for showing numbers. Further, there is the polar-bear symbol at the bottom for

providing an illustration of the shower efficiency. The display mask, where all segments are visible, is provided in Annex 6.6.

As for the sensors, a thermistor constantly provides water-temperature information by a changing resistance. This resistance can be measured using an ADC (Analog to Digital Converter) input of the MCU.

The micro-turbine is used both as a sensor and energy harvester. Used as a sensor, it provides an impulse-signal to the MCU. The time between two positive impulses provides a frequency measurement and therefore information about the rotational frequency of the turbine wheel. Used as energy-harvester, the micro-turbine delivers max. 150mW of AC-power. The AC-voltage is rectified and a buffer-capacity is charged. Voltage regulators connected to this buffer-capacity provide accurate voltage levels for all other system components.

Figure 2 shows the electronics of the DAIAD@feel prototype with all its components.



Figure 2: View of the electronics on the backside of the DAIAD@feel display. The golden framed area is the RF module and the can on the left is the energy storage capacitor (more than double the capacity of the offline solution).

2.2. Mechanical Design

2.2.1. Micro-Turbine

The micro-turbine is a complex structure that harvests energy from the water-flow and can be used to measure the flow-rate of the water flowing through the turbine. All parts of the turbine are designed such that they can be produced using injection molding.

2.2.2. Housing

The housing of the DAIAD@feel prototype is made out of two separate plastic parts. The front part is partly transparent in order to allow the user to see the display. The back part provides openings for the micro turbine and covers the whole electronics.

A DAIAD@feel prototype mounted to a shower-head is shown in Figure 3.



Figure 3: 3D model of the Micro-Turbine



Figure 4: DAIAD@feel prototype in a handheld showerhead installation. Showering data is stored locally and synchronized with the gateway when connection is established.

2.3. Installation

The outer physical dimensions of the DAIAD@feel prototype are the same as the ones of the amphiro a1 product and the installation in the shower is essentially the same and illustrated in Figure 5.

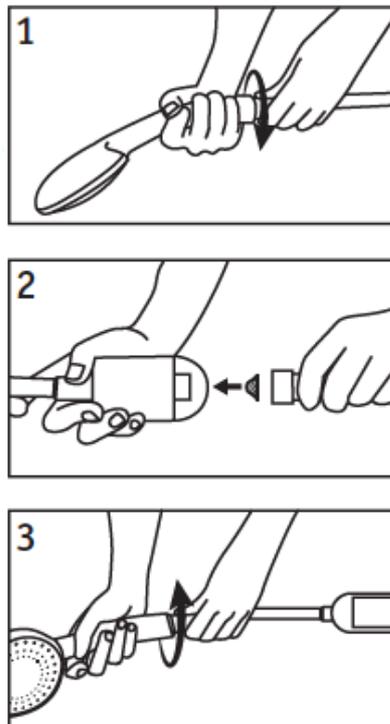


Figure 5: DAIAD@feel installation guide

Trial participants will be asked to first unscrew the showerhead from the hose.

Second, Trial participants are advised to remove the red adhesive tape at the bottom end of the DAIAD@feel sensor and ensure that the sieve (to keep small objects in the water away from the micro turbine) stays in place; the convex (curved) side must point towards the interior of the device. Screw the shower hose onto this connector with the sieve.

Last but not least, the showerhead has to be screwed into the short hose that comes with the DAIAD@feel sensor.

The only new step is the pairing of the DAIAD@feel sensor with the gateway by entering the connection key.

To do so, the Trial participants will have two options:

1. Turn on the water and stop it before 1.0 Liter is passed. The connection key is shown on the DAIAD@feel sensor display.
2. Run the DAIAD App and select the unpaired device. This will send a BLE packet in the background that causes the DAIAD@feel sensor to display the connection key.

The whole installation process can be carried out without any tools and can be performed by everyone.

3. Engineering Tradeoffs

Because we wanted a no-battery solution for safer, more cost-effective and maintenance-free operation, we had to accept the fact, that we will not have a guaranteed sense of time. Once the energy is used up (approximately 5min interruption of water flow), the electronics are completely powered down. Timestamps for extraction data are only available if the gateway is close enough to see the real-time event.

Choosing the Bluetooth Low Energy (V4) standard helped us with regards to the power requirements and guarantees a good acceptance among users (i.e., Trial participants) because of the wide spread of Bluetooth technology in mobile devices. However, the range is rather limited: approximately 10m open field and 5m with a wall in between. More details about the selection of BLE as RF-capability is provided in the report for Prototype deliverable D2.3.1 'RF-connectivity to data aggregator'.

We chose to increase the buffer capacitor in order to increase BLE performance, device operation stability, and the bridgeable shower or extraction breaks. Further, the manufacturing process of surface mounted aluminium can capacitors has made good progress, and a capacity of over *twice* the initially used one is available now with the same footprint and casing. Of course choosing the new capacitor increased the material costs.

Our BLE module comes preprogrammed directly from the manufacturer, which has the advantage of reduced production time and reduced development time, but comes at the cost of limited configurability and customization.

4. Production

For the Trials, 300 DAIAD@feel prototypes (i.e. amphiro b1) are required and – for that purpose – have been produced already.

The production of the 300 DAIAD@feel prototypes was successfully carried out in the EU and the sensors have been shipped to the Trial locations already. They are currently awaiting the start of the Trials.

4.1. Assembly

The assembly of the DAIAD@feel prototype includes 20 individual steps and is carried out by hand (no roboters). The main steps include:

- 1) Programming and testing of the electronics (see section 4.2)
- 2) Assembly of the micro-turbine (several sub-steps)
- 3) Assembly of the front-housing including the display
- 4) Assembly of the rear-housing including the micro-turbine

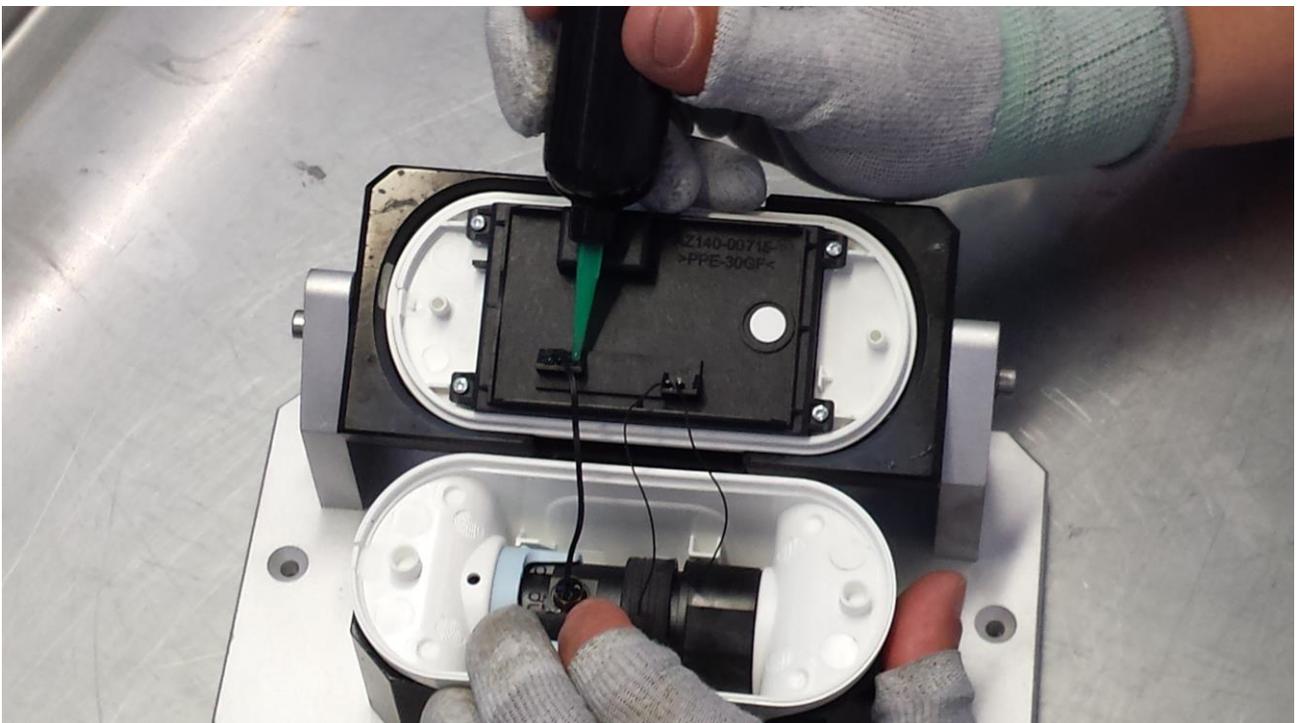


Figure 6: Sealing of soldering points with glue

- 5) Soldering the cables from thermistor and micro-turbine to the electronics and sealing of the contacts
- 6) Closing the DAIAD@feel prototype

The whole assembly is carried out by hand and from a single person. The assembly includes wet-processes for properly sealing the product, which increase overall production costs, but also increase product quality and reliability.

4.2. Product Quality / Testing

To reach high product quality, the production process is designed to incorporate 3 different test procedures (see Figure 7). In a first step, the printed circuit board (PCB) is mounted and soldered with the proper components; the microprocessor is then ready to be programmed. Note that the micro generator and the temperature sensor are not yet connected to the PCB. After the programming of the host microcontroller, the first test is performed. A sinusoidal voltage is used to simulate a high-speed generator and a resistor is used to simulate the temperature sensor. The host microcontroller checks if it measures the frequency of the simulated generator is as it expects it to be and if the measured simulated temperature is within a short expected window.

In parallel, the second test is started in the background. The BLE module starts announcing the unique ID of the host microcontroller over the air.

The first test is continued with a test of the LCD functionality. Four different screens are shown to the system operator with a characteristic display pattern. Each has to be confirmed by the operator. Once all screens are confirmed, the first test for functional electronics is successfully concluded.

Right after the first test is finished, the second test continues (in the background): the host microcontroller sends its unique ID via serial interface to the testing infrastructure where this information can be compare to the one that is being announced on the Bluetooth Low Energy channel. If the equality is successfully asserted, the second test is also passed and the smart meter is ready for the third test: the so-called product testing. Figure 6 illustrates this production step and shows the “tester” used to ensure product quality.

In the third test the now fully assembled smart meter is operated with water at a fixed flow rate. This way, each device is tested for successful operation and in addition can be calibrated as described in the report for Prototype deliverable D2.2.1 ‘Improved Precision’. Special test equipment, as depicted in Figure 8 and Figure 9, was developed and shipped to the production site.

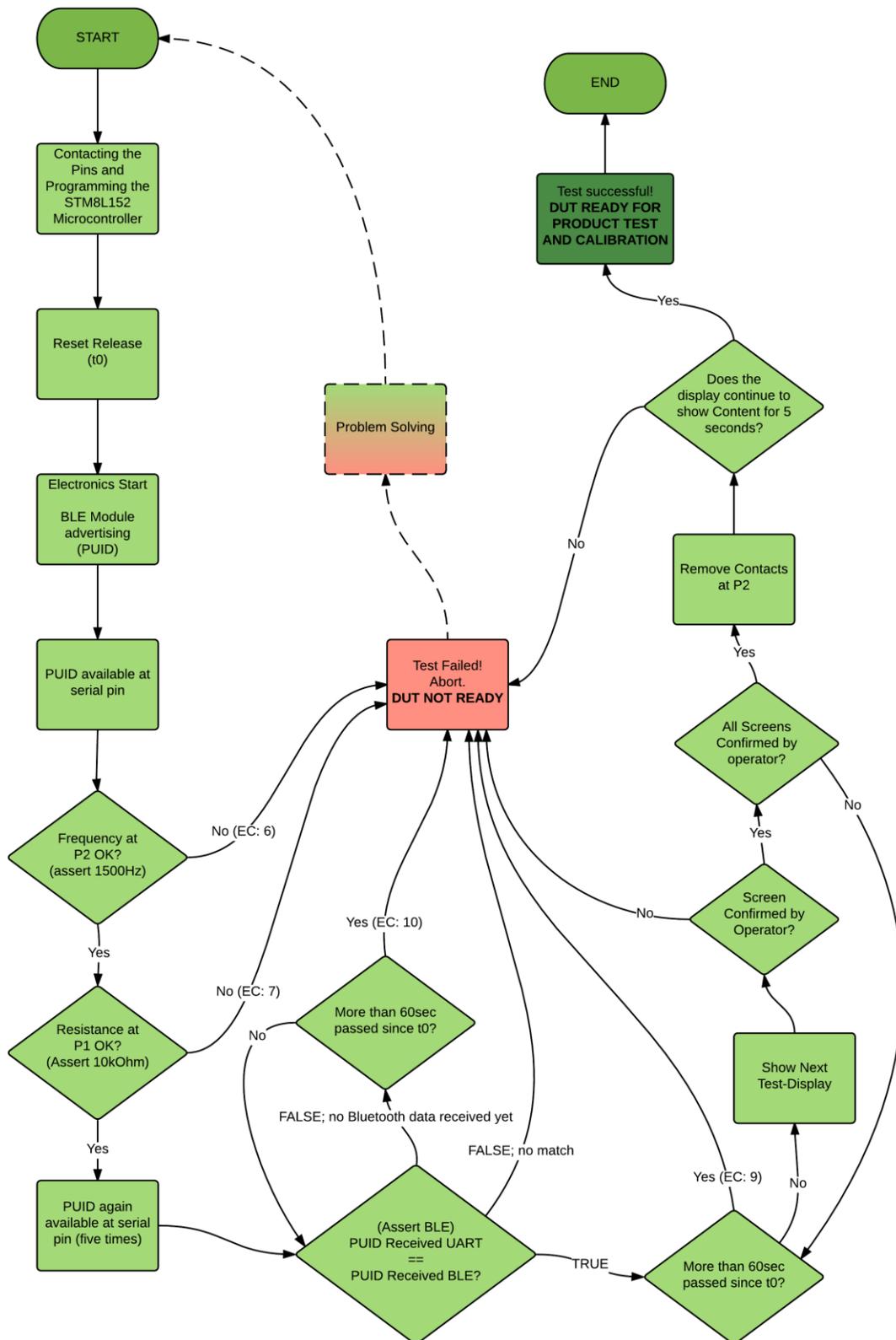


Figure 7: Flow chart of testing procedure in production

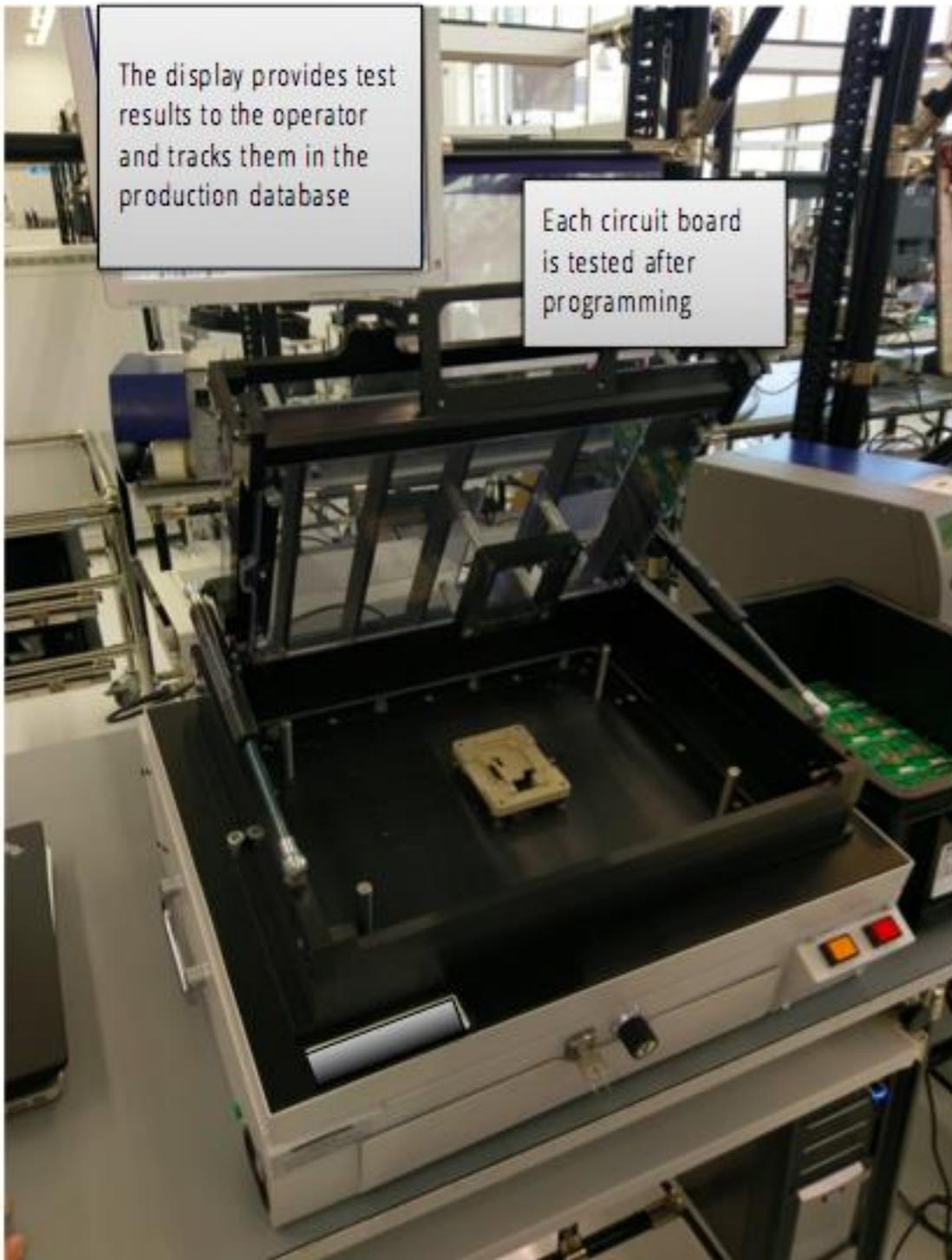


Figure 8: Tester for programming and testing of DAIAD@feel prototype electronics. The electronics are placed onto the white part in the middle of the machine. It then gets electrically connected from the bottom.



Figure 9: Calibration equipment at production site. The device is calibrated and tested with a water-flow similar to real water extractions.

5. Conclusion

In this report we cover the design and production process for the DAIAD@feel prototypes. 300 DAIAD@feel prototypes have already been produced and shipped to the trial households.

The DAIAD@feel prototype is powered solely by a micro-turbine, which harvests energy from the water-flow. Pressure-drop requirements and limited flow-rates limit the power-output of the harvester and adds massive power constraints to the electronics. Especially, RF-applications usually have high power demands and therefore sending real-time shower data by Bluetooth to a data aggregator is a non-trivial task. This power constraint made it necessary to carefully select every component of the DAIAD@feel prototype's electronics with respect to power consumption.

The main task of the DAIAD@feel prototype – to collect energy consumption of water extractions – was achieved by combining a temperature sensor with a flow-rate sensor and resulted in the general system design presented in section 2.1. This design features an MCU for sensor data processing and communication with a data aggregator. A carefully evaluated and selected BLE-Module includes the antenna design and a dedicated MCU running the BLE-Stack. Further, it communicates with the main MCU through a UART interface.

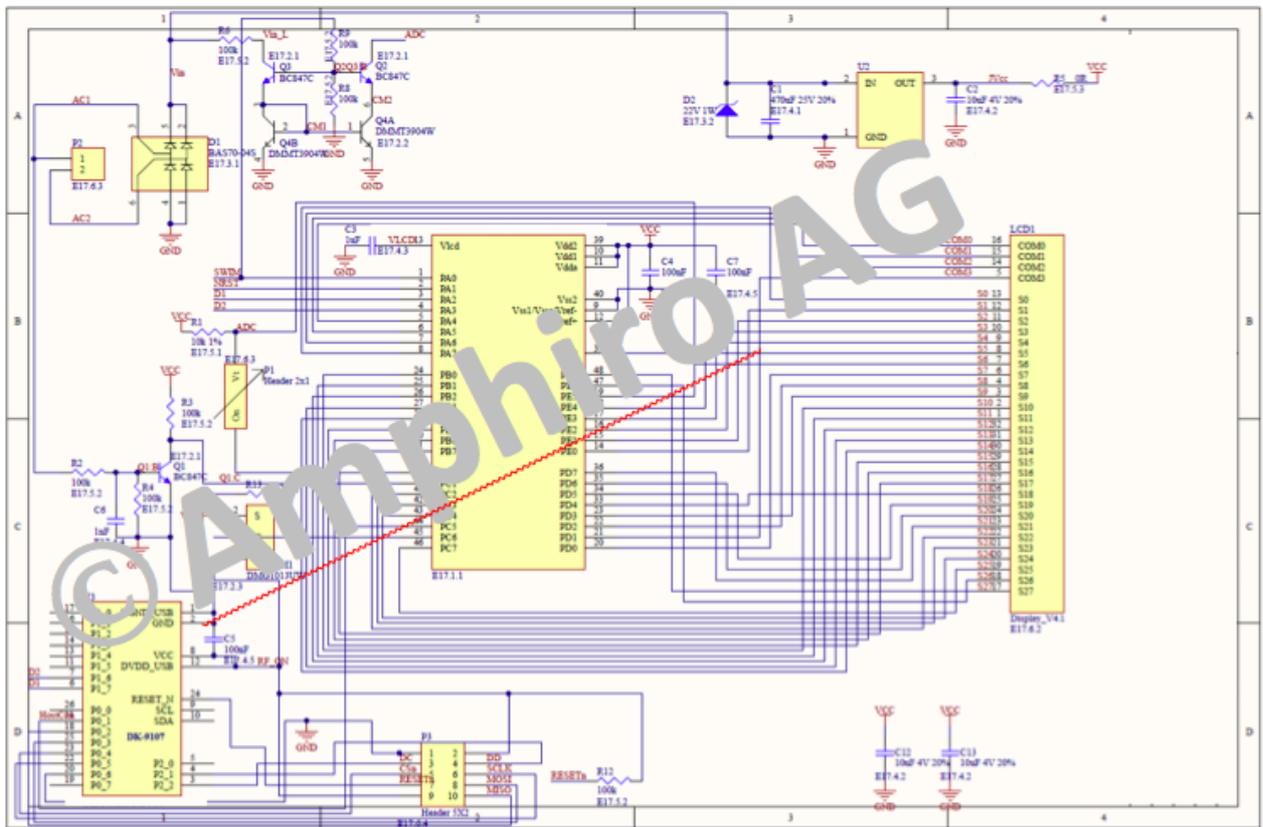
The production of the 300 DAIAD@feel prototypes was carried out in the EU. The assembly of the DAIAD@feel prototype includes more than 20 steps and is done by hand by one single person. Wet processes ensure the working sealing of the product, but also increase the production costs.

In order to meet high quality standards and extend the lifetime of the product to a maximum, several *in-production* tests have been introduced. There are two test-frames during production: The first one is right at the beginning after the electronics is programmed. Throughout this test each hardware component visible in the system design (section 2.1) is validated. The second test-frame takes place at the end of the assembly of the product and ensures both mechanical and electrical integrity. During this production test, a water-flow similar to a real shower is applied to the product. Therefore, not only mechanical water leakages could be detected, but also the product can be calibrated and compensated for production tolerances and changing electrical load as explained in the report for Prototype Deliverable D2.2.1 'Improved Precision'.

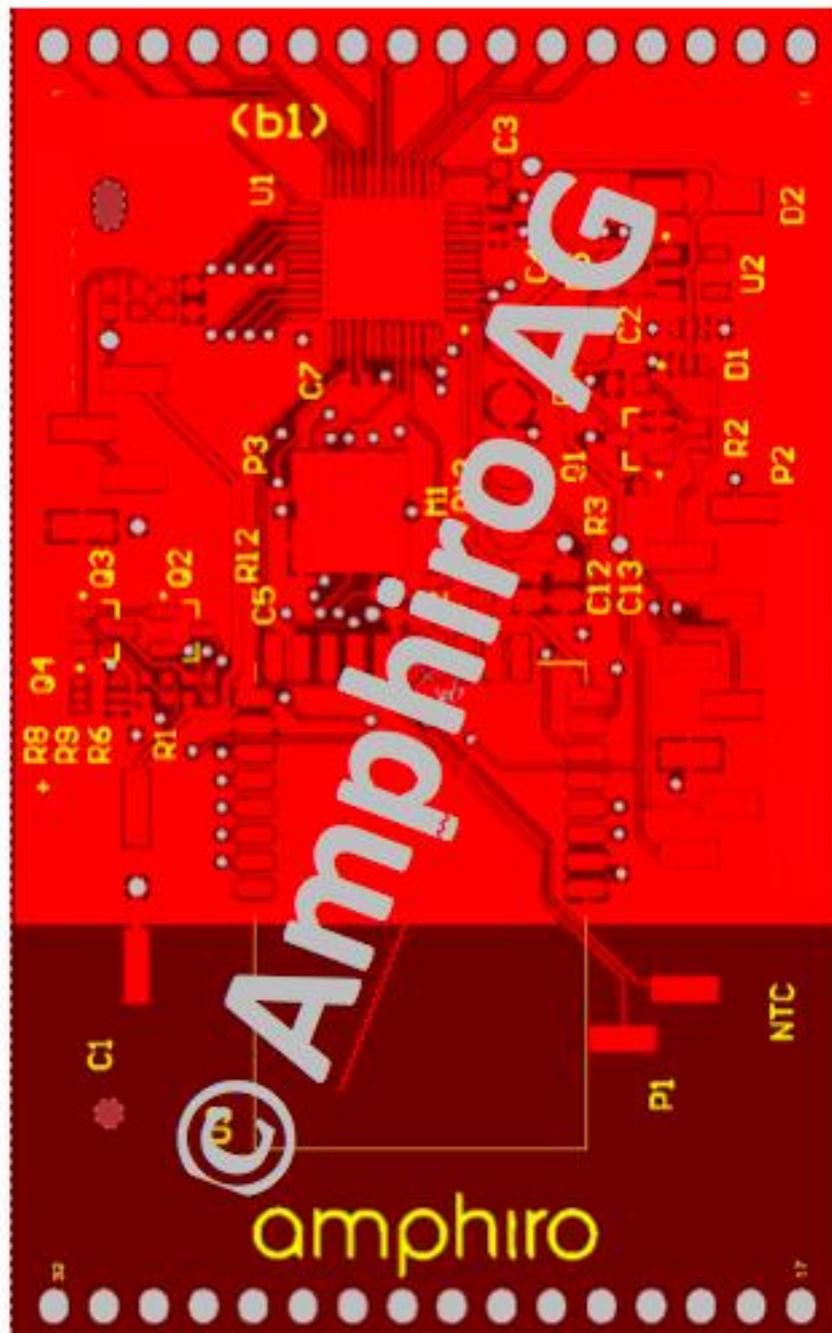
The careful electrical and mechanical design together with increased in production testing and intelligent software resulted in a high quality product, which is currently tested in more than 300 households.

6. Annex

6.1. Circuit



6.2. Board Layout (PCB)



6.3. Datasheet STM MCU



STM8L151x8 STM8L152x8 STM8L151R6 STM8L152R6

8-bit ultralow power MCU, up to 64 KB Flash + 2 KB data EEPROM, RTC, LCD, timers, USARTs, I2C, SPIs, ADC, DAC, comparators

Datasheet - production data

Features

- Operating conditions
 - Operating power supply: 1.65 to 3.6 V (without BOR), 1.8 to 3.6 V (with BOR)
 - Temp. range: -40 to 85, 105 or 125 °C
- Low power features
 - 5 low power modes: Wait, Low power run (5.9 µA), Low power wait (3 µA), Active-halt with full RTC (1.4 µA), Halt (400 nA)
 - Consumption: 200 µA/MHz+330 µA
 - Fast wake up from Halt mode (4.7 µs)
 - Ultra low leakage per I/O: 50 nA
- Advanced STM8 core
 - Harvard architecture and 3-stage pipeline
 - Max freq: 16 MHz, 16 CISC MIPS peak
 - Up to 40 external interrupt sources
- Reset and supply management
 - Low power, ultrasafe BOR reset with 5 programmable thresholds
 - Ultralow power POR/PDR
 - Programmable voltage detector (PVD)
- Clock management
 - 32 kHz and 1-16 MHz crystal oscillators
 - Internal 16 MHz factory-trimmed RC and 38 kHz low consumption RC
 - Clock security system
- Low power RTC
 - BCD calendar with alarm interrupt,
 - Digital calibration with +/- 0.5ppm accuracy
 - Advanced anti-tamper detection
- DMA
 - 4 ch. for ADC, DACs, SPIs, I²C, USARTs, Timers, 1 ch. for memory-to-memory
- LCD: 8x40 or 4x44 w/ step-up converter
- 12-bit ADC up to 1 Msps/28 channels
 - Temp. sensor and internal ref. voltage



- Memories
 - Up to 64 KB of Flash memory with up to 2 KB of data EEPROM with ECC and RWW
 - Flexible write/read protection modes
 - Up to 4 KB of RAM
- 2x12-bit DAC (dual mode) with output buffer
- 2 ultralow power comparators
 - 1 with fixed threshold and 1 rail to rail
 - Wakeup capability
- Timers
 - Three 16-bit timers with 2 channels (IC, OC, PWM), quadrature encoder
 - One 16-bit advanced control timer with 3 channels, supporting motor control
 - One 8-bit timer with 7-bit prescaler
 - 1 Window and 1 independent watchdog
 - Beeper timer with 1, 2 or 4 kHz frequencies
- Communication interfaces
 - Two synchronous serial interface (SPI)
 - Fast I²C 400 kHz SMBus and PMBus
 - Three USARTs (ISO 7816 interface + IrDA)
- Up to 67 I/Os, all mappable on interrupt vectors
- Up to 16 capacitive sensing channels supporting touchkey, proximity, linear touch and rotary touch sensors
- Fast on-chip programming and non-intrusive debugging with SWIM, Bootloader using USART
- 96-bit unique ID

Table 1. Device summary

Reference	Part number
STM8L151x8 STM8L152x8	STM8L151C8, STM8L152C8, STM8L151R8, STM8L152R8, STM8L151M8, STM8L152M8
STM8L151R6 STM8L152R6	STM8L151R6, STM8L152R6

July 2013

DocID17943 Rev 6

1/134

This is information on a product in full production.

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6.4. Datasheet BLE-Module



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Add: 12F-6, NO.81, Sec.1, Hsin Tai Wu Rd., Xizhi Dist., New Taipei City , Taiwan.

Specifications

• RF

- 2.4-GHz *Bluetooth* low energy Compliant and Proprietary RF System-on-Chip
- Supports 250-kbps, 500-kbps, 1-Mbps, 2-Mbps Data Rates
- Excellent Link Budget, Enabling Long- Range Applications Without External Front Modes
End
- Programmable Output Power up to 0 dBm
- Excellent Receiver Sensitivity (–94 dBm at 1 Mbps), Selectivity, and Blocking Performance
- Suitable for Systems Targeting Compliance
With Worldwide Radio Frequency
Regulations: ETSI EN 300 328 and EN 300
440 Class 2 (Europe), FCC CFR47 Part 15 (US) and ARIB STD-T66 (Japan)

• Microcontroller

- High-Performance and Low-Power 8051
Microcontroller Core With Code Prefetch
- In-System-Programmable Flash, 128- or 256-KB
- 8-KB RAM With Retention in All Power Modes
- Hardware Debug Support
- Extensive Baseband Automation, Including Auto-Acknowledgment and Address Decoding
- Retention of All Relevant Registers in All Power Modes

• Low Power

- Active-Mode RX Down to: 17.9 mA
- Active-Mode TX (0 dBm): 18.2 mA
- Power Mode 1 (4- μ s Wake-Up): 270 μ A
- Power Mode 2 (Sleep Timer On): 1 μ A
- Power Mode 3 (External Interrupts): 0.5 μ A
- Wide Supply-Voltage Range (2 V–3.6 V)

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Standard	Bluetooth low energy (BLE)
RF frequency range	Programmable in 2-MHz steps
RF data rate	1Mbps, GFSK, 250 kHz deviation
TX Current @ 0 dBm	18.2 mA
RX Current (normal gain)	17.9 mA
PM2 Current	0.9 uA
PM3 Current	0.4 uA
Max. output power	+0 dBm
Dimensions	25X17 mm
Operating temperature	-10~60°C
RF sensitivity	-Standard mode: typ. -87 dBm -High-gain mode: typ. -94 dBm
Output power	Typ. 0 dBm
Supply voltage	-0.3~3.9V

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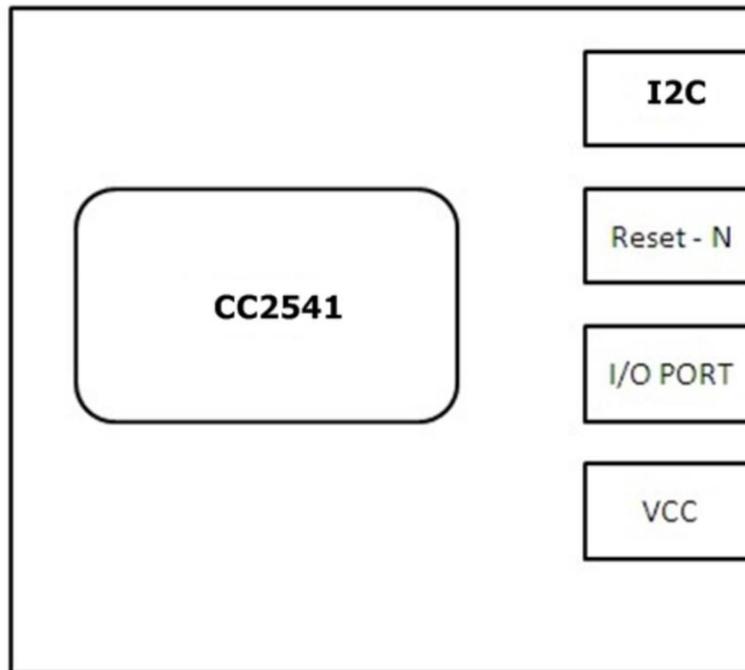




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Block Diagram

Block Diagram of DK9107 Module Board



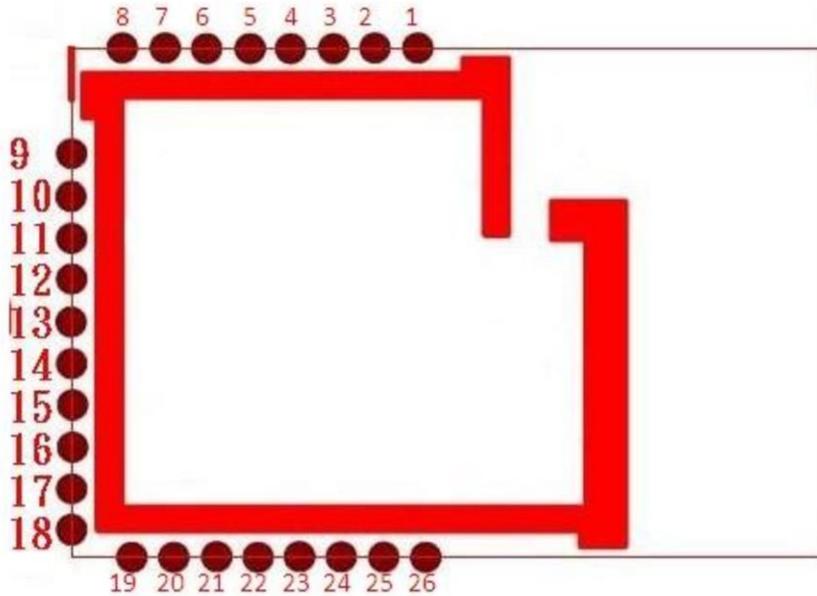
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Pin Assignment



Pin	Name	Description
1	DGND_USB	Connect to GND
2	GND	Connect to GND
3	P2_2	DC(debug port)
4	P2_1	DD(debug port)
5	P2_0	Port 2.0
6	P1_7	Port 1.7
7	P1_6	Port 1.6
8	VCC	2-V-3.6-V analog power-supply connection
9	SCL	SCL

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10	SDA	SDA
11	P1_5	Port 1.5
12	DVDD_USB	2-V-3.6-V digital power-supply connection
13	P1_4	Port 1.4
14	P1_3	Port 1.3
15	P1_2	Port 1.2
16	P1_1	LED+ (MAX 20mA)
17	P1_0	LED+ (MAX 20mA)
18	P0_2	Port 0.2
19	P0_7	Port 0.7
20	P0_6	Port 0.6
21	P0_1	Port 0.1
22	P0_5	Port 0.5
23	P0_4	Port 0.4
24	RESET_N	Reset, active-low
25	P0_3	Port 0.3
26	P0_0	Port 0.0

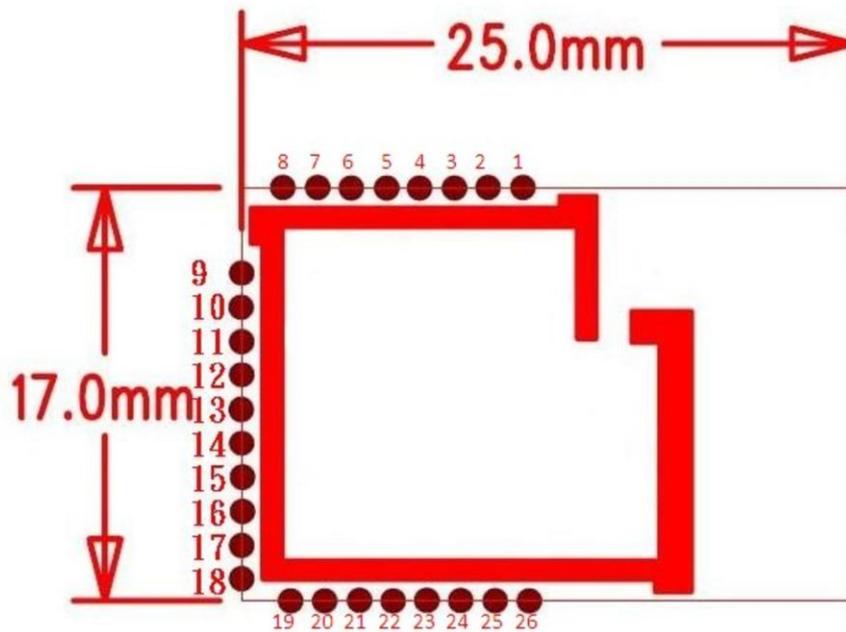
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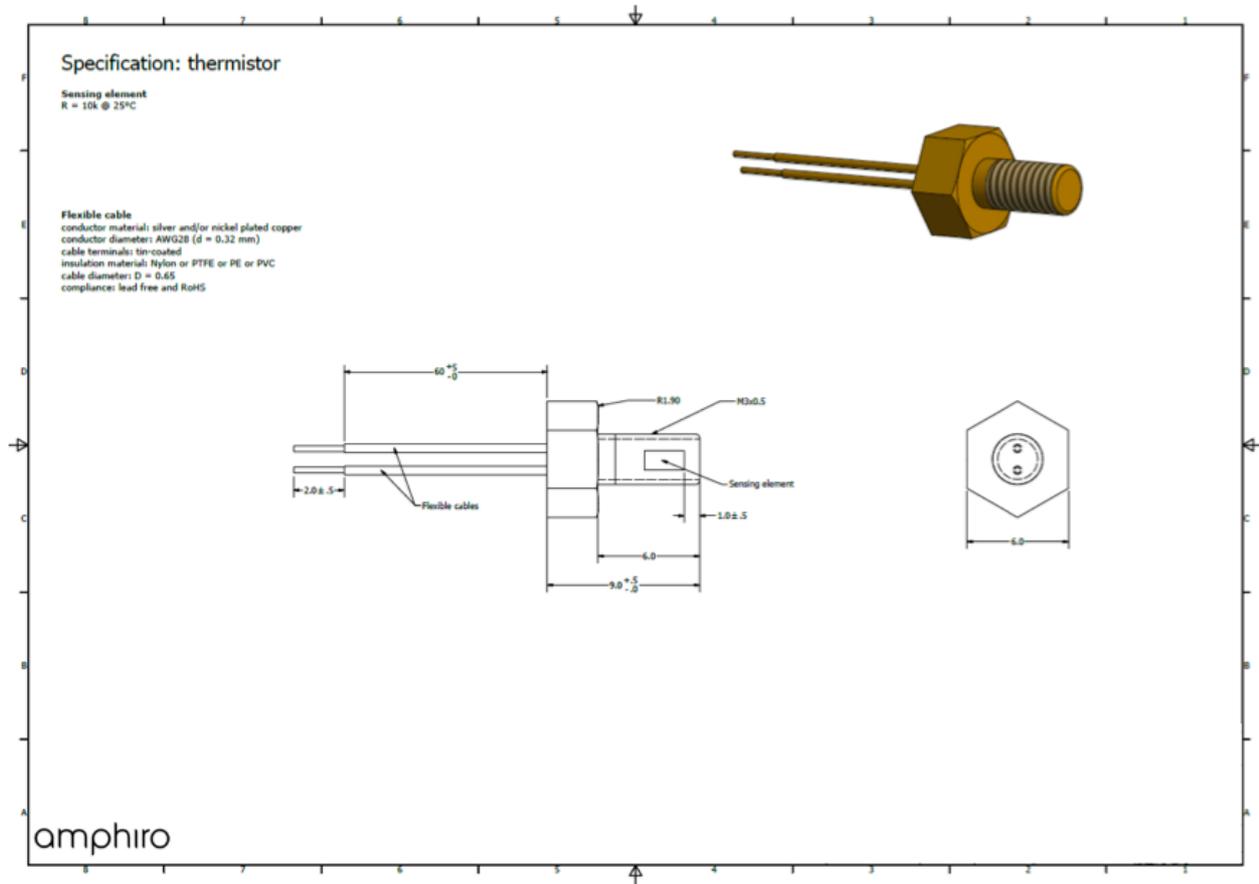
Mechanical Drawing



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6.5. Datasheet Thermistor



6.6. Display

