Department of Aerospace and Geodesy
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Design, Build, and Test

a digital Altimeter based on a Barometer.

Spacecraft Electronics

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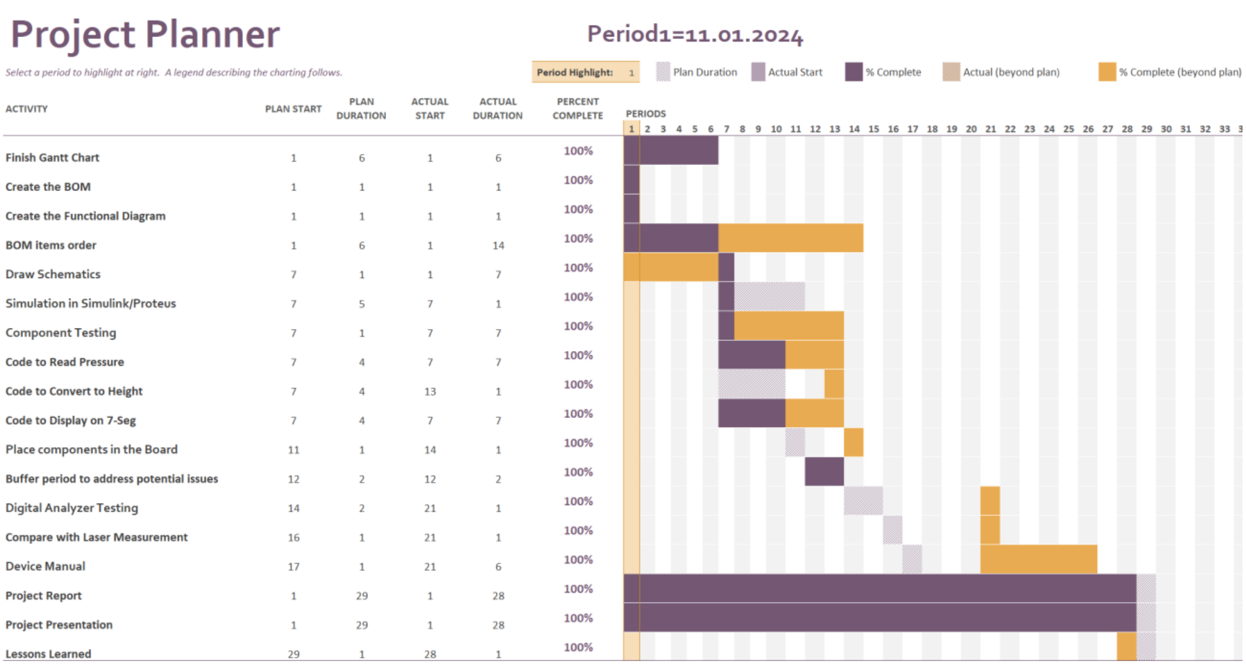
Project Management

We used a Gantt Chart for this project to organize our deadlines and tasks and ensure they were all considered. A Gantt chart is a pivotal tool in project management because it can visually represent the timeline of a project's tasks, milestones, and dependencies. By offering a clear and intuitive visualization of task schedules, Gantt charts enable project teams to understand the project's scope and deadlines briefly. They allowed us as project managers to define task dependencies, aiding in identifying critical paths and resource allocation. They enable real-time tracking of project progress against planned timelines, assisting in monitoring task completion and identifying deviations from the schedule. This is what our final Gantt chart looked like:



We were able to finish all our tasks, even though we had slight delays with our BOM, because we exchanged the LED display and finished our manual later than we planned. However, the Gantt chart was a well appreciated tool to plan and track our project progress.

Bill of Materials

The Bill of Materials (BOM) is a cornerstone in project management. It is an exhaustive inventory detailing all materials, components, sub-assemblies, and parts essential for constructing or assembling our final product. Moreover, the BOM acts as a blueprint for assembly and production, delineating the sequence of steps and components required at each stage.

This is what the final BOM for our altimeter looks like:

BILL OF MATERIALS				
	Item to be created:	Altimeter		
	Qty to create:	1		
COMPONENT	**DESCRIPTION**	**BASE QTY**	**COST PER UNIT**	**LINK**
MS5611	Barometer	1	16,12 €	https://www.conrad.de/de/p/gy-86-mpu-6050-beschleunigungssensor-gyroskop-hmc5883l-magnetfeldmesser-ms5611-barometer-838242671.html
TM1637	4 Digit 7-Segment Display Modul	1	15,33 €	https://www.amazon.de/Digital-Header-Display-Segmente-MRA041D/dp/B0B518GYCY/?_encoding=UTF8&pd_rd_w=YHJA3&content-id=amzn1.sym.5c5e380f-adae-4188-be75-d3ed6ab75549%3Aamzn1.symc.adba8a53-36db-43df-a081-77d28e1b71e6&pf_rd_p=5c5e380f-adae-4188-be75-d3ed6ab75549&pf_rd_r=X33EBBPGME58GQKGB32V&pd_rd_wg=rOesc&pd_rd_r=77e5f1dc-9244-45e5-90ab-46d327eb9c39&ref_=pd_gw_ci_mcx_mr_hp_atf_m

GLM 40	Laser Measurement Device	1	79,50 €	https://www.amazon.de/Bosch-Professional-GLM-Laser-Entfernungsmesser-Schutztasche/dp/B00R0Z7TFM/ref=asc_df_B00R0Z7TFM/?tag=googshopde-21&linkCode=df0&hvadid=214366492459&hvpos=&hvnetw=g&hvrand=2396604927259985288&hvpone=&hvptwo=&hvqmt=&hvdev=c&hvdvcmdl=&hvlocint=&hvlocphy=9042419&hvtargid=pla-422200191735&psc=1&mcid=1de3dd0de0bb3b0785ca28c28883ed18&th=1&psc=1
Teensy 4.0	Microcontroller	1	28,56 €	https://www.conrad.de/de/p/joy-it-teensy40-mikrocontroller-teensy40-2240247.html
9V Battery	Batterie Duracell Plus Power	2	3,35 €	https://www.conrad.de/de/p/batterie-duracell-plus-power-6lf22-9v-block-blister-9v-alkaline-805016989.html
9V Battery Clip	Beltrona 9V-I-Clip Batterieclip	2	0,83 €	https://www.conrad.de/de/p/beltrona-9v-i-clip-batterieclip-1x-9-v-block-druckknopfanschluss-l-x-b-x-h-26-x-13-x-8-mm-624691.html
Breadboard	TRU COMPONENTS EIC-104-3	1	12,60 €	https://www.conrad.de/de/p/tru-components-eic-104-3-steckplatine-polzahl-gesamt-1360-l-x-b-x-h-215-x-100-x-11-3-mm-1-st-1569983.html
Hartpapier	TRU COMPONENTS SU527769 Europlatine Hartpapier	1	3,35 €	https://www.conrad.de/de/p/tru-components-su527769-europlatine-hartpapier-l-x-b-160-mm-x-100-mm-35-m-rastermass-2-54-mm-inhalt-1-st-1570681.html
Steckbrücken	TRU COMPONENTS 98001c421 Steckbrücken	1	7,97 €	https://www.conrad.de/de/p/tru-components-98001c421-steckbruecken-set-bunt-polzahl-gesamt-1-75-teile-1662102.html
Steckbrücken	TRU COMPONENTS Steckbrücken-Set	1	5,29 €	https://www.conrad.de/de/p/tru-components-steckbruecken-set-l-x-b-x-h-172-x-100-x-22-mm-350-st-2899209.html
DC-DC Converter	mini AMS1117-5 5V DC-DC Step-Down Spannungsregler	2	1,26 €	https://www.conrad.de/de/p/mini-ams1117-5-5v-dc-dc-step-down-spannungsregler-voltage-regulator-convertor-802244044.html

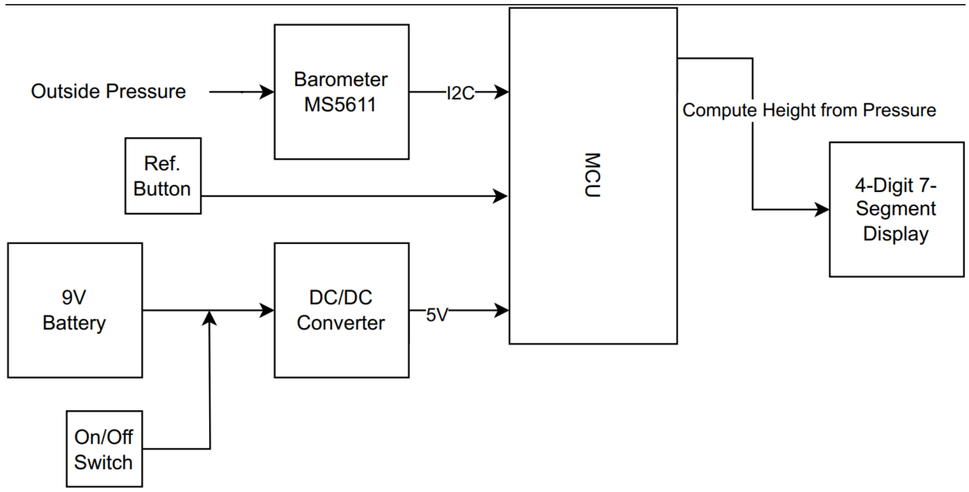
7-Seg Display with dots	4 Digit Tube LED 7 Segment Display	1	6,75 €	https://www.amazon.de/R%C3%B6hren-LED-7-Segment-Anzeigemodul-Elektronisches-LED-Streifen-Array-TM1637-Treiberchip-R%C3%B6hrenuhranzeige-36-Zoll-LED-Modul/dp/B0B1N78RFW/ref=sr_1_9?__mk_de_DE=%C3%85M%C3%85%C5%BD%C3%95%C3%91&crid=1QDYHBEN310S7&keywords=U146+4+digit+LED+display&qid=1705578948&sprefix=u146+4+digit+led+display%2Caps%2C97&sr=8-9
TOTAL COST:			186,35 €	

Designing the Altimeter

The altimeter design combines the precision of the MS5611 barometer with the processing power of the Teensy 4.0 microcontroller, offering accurate real-time altitude measurements. The integration of the MS5611 barometer ensures a resolution of 10 cm altitude changes, providing reliable altitude data for various applications. The Teensy 4.0 microcontroller processes the sensor data and controls a 4-digit 7-segment LED display, showing accurate altitude information. With its ON/OFF switch, a transportable size of 50mm x 50mm x 20mm and light weight, it is easy to handle. Its versatile operational voltage range, from 6V to 12V, allows for flexible power supply options and the option to set a new reference plane in real time, makes it a solid solution for altitude monitoring and the tracking of altitude differences.

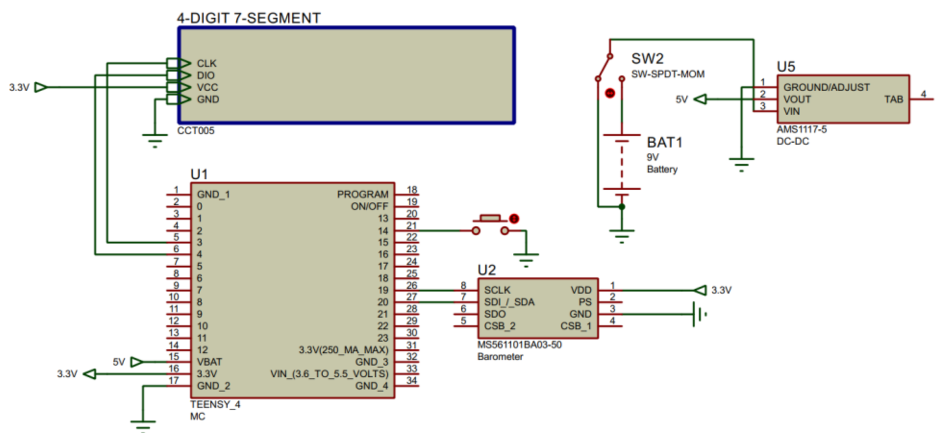
Functional Diagram

The functional diagrams illustrate a system or device's overall operation and functionality. Unlike schematics, which focus on a circuit's physical connections and components, functional diagrams provide a higher-level view, highlighting the flow of signals or data through the system and how different components interact to achieve a specific function. They served as a roadmap for development, guiding the detailed design work that follows. Here’s what our functional diagram looks like, whereby the ON/OFF switch and the reference plane setting are features that exceed the needed basics for a working altimeter.



Schematics

Schematics visually represent the circuit layout, component connections, and functionality. They allow designers/engineers to understand the circuit's structure, identify potential issues, and plan for efficient assembly and troubleshooting. Schematics also serve as a universal language in the electronics industry, facilitating communication between team members, manufacturers, and other stakeholders involved in the design and production process.



Building the Altimeter

Component Testing

We initiated the altimeter construction by methodically testing all individual components to ensure functionality. We confirmed that all delivered components worked properly and validated the accuracy of the barometer readings in Visual Studios as well as validated the operational status of the Teensy 4.0 microcontroller.

4-Digit Display

We then developed and uploaded a customized Arduino code to the Teensy 4.0, enabling it to accurately read altitude information from the barometer and display it on the 4-digit LED. The code included calibration parameters for precise altitude readings. Thorough component testing was conducted, making necessary adjustments to ensure seamless integration.

Barometer

The MS5611 barometer was connected to the Teensy 4.0 through the I2C interface, establishing the core of the altitude measurement system. The barometer measurements were processed in the microcontroller and with the formulas of the next chapter transformed into the altitude output on the LED display.

DC-DC Converter

To ensure consistent power, a DC-DC converter was introduced to step down the voltage from a 9V battery to a stable 5V. Subsequently, a 4-digit LED display was incorporated into the circuit, linked to the Teensy 4.0 for real-time altitude visualization.

Pictures of the process of building the altimeter can be found in the Annex.

Altitude Calculation

There are multiple ways to calculate the Altitude. Since our sensor (MS5611) gives us pressure and temperature readings, we can calculate the current Altitude.

After some research, we have found two common ways to calculate the Altitude given temperature and pressure as input parameters.

Hypsometric Formula

The hypsometric equation, also known as the thickness equation, relates an atmospheric pressure ratio to the equivalent thickness of an atmospheric layer considering the layer mean of virtual temperature, gravity, and occasionally wind. It is derived from the hydrostatic equation and the ideal gas law.

$$h = \frac{\left(\left(\frac{P_0}{P}^{\frac{1}{5.2757}}\right) - 1\right) * (T + 273.15)}{0.0065}$$

Where:

- h= Altitude (m)
- P_0= reference pressure at sea level (1013.25hPa)
- P= measured pressure (Pa) from the sensor
- T= measured temperature (C^0)

The second used equation is described below.

Barometric Formula

$$h = 44330 * \left(1 - (P/P_0)^{\frac{1}{5.255}}\right)$$

Where:

- h= Altitude (m)
- P_0= reference pressure at sea level (1013.25hPa)
- P= measured pressure (Pa) from the sensor

The Altitude calculated from those formulas will give us the current Altitude with respect to the sea level.

Accuracy and Precision

To reduce the noise and stabilize the measured values from the sensor, we applied a digital filter.

Digital filtering is a technique used to process and smooth out noisy sensor data to obtain a more stable and accurate signal. There are different types of digital filters, and the choice depends on the specific requirements of the application.

Moving Average Filter:

- A moving average filter calculates the average of a set of recent data points to smooth out fluctuations in the signal.
- The formula for a simple moving average is:
- $Filtered\,Value(n) = \frac{1}{N}\sum_{i=0}^{N-1} \Pr e\,ssure(n-i)$
- N is the number of data points to include in the average.

We then use the filtered pressure value to calculate the altitude and add an additional layer of filtering and smoothing out the altitude curve. We use a Kalman filter for the altitude values.

Kalman Filter

A Kalman filter is an advanced and versatile digital filtering technique that can be used for sensor fusion and state estimation. It is particularly effective in situations where there is both measurement noise and process noise. It is a recursive estimator. This means that only the estimated state from the previous time step and the current measurement are needed to compute the estimate for the current state.

Prediction step:

$$\hat{x} = \hat{x}$$

Update step:

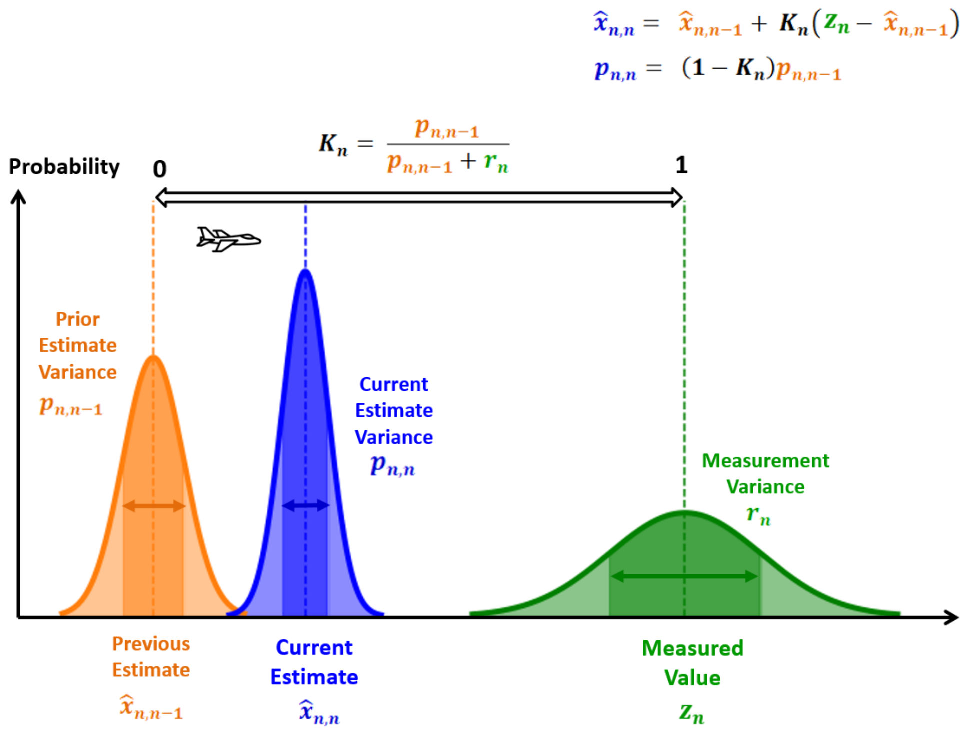
$$K = \frac{P}{P+R}$$

$$\hat{x} = \hat{x} + K.(z - \hat{x})$$

$$P = (1 - K).P$$

Where:

- x^ is the estimated state.
- P is the estimated error covariance.
- Q is the process noise covariance.
- R is the measurement noise covariance.
- K is the Kalman gain.
- z is the measurement.



For the Tuning of the Kalman filter's parameters, we did an online tuning of the parameters, so we tried different values of Q and R and we were satisfied with the values of Q = 0.0001, R = 0.332.

Below follows a short description of what the measurement noise covariance R and process noise covariance mean.

Measurement Noise Covariance (*R*):

- R represents the covariance of the measurement noise. It reflects the accuracy of the sensor measurements.
- If R is set too low, the filter will give too much weight to the measurements, potentially leading to noisy or unstable output.
- If R is set too high, the filter will trust the model predictions more than the measurements, potentially causing slow response to changes.

Process Noise Covariance (*Q*):

- Q represents the covariance of the process noise. It reflects the uncertainty in the system dynamics or model predictions.

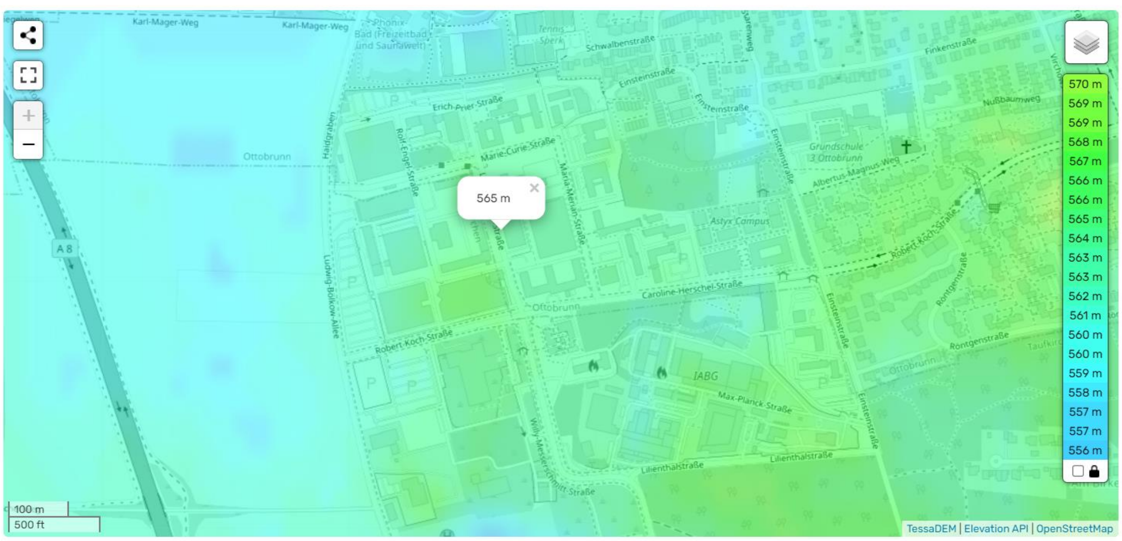
- If Q is set too low, the filter will overly trust the model predictions, potentially leading to sluggish response to changes or underestimation of the true uncertainty.
- If Q is set too high, the filter will overly rely on the measurements, potentially causing instability or overfitting to the noise in the measurements.

Testing the Altimeter

Accuracy and Sensitivity Test

To conduct the Accuracy and Sensitivity Test for our altimeter, we carefully placed the device in front of our lab and using a known reference from Bavaria topology map, we compared the altimeter's readings to the actual values, ensuring accuracy compared to sea level. The Bavarian topology map gives an altitude of 565m, same as our altimeter.

Click on the **map** to display **elevation**.



To check the height difference, we set the lab floor as our reference plane and put the altimeter on a table. Our device gave the reading of one meter, which was within an acceptable margin of error (5%), when compared to the Bosch Laser measurement device that we used for comparison purposes.

Altitude Simulation Test

Additionally, we subjected the altimeter to subtle changes in altitude to assess its sensitivity and responsiveness to minor variations. The test results provided sufficient confirmation about the altimeter's precision and its ability to capture nuanced (~10 cm) altitude changes. However, we also noticed that our altimeter has trouble with noticing very minor changes in altitude below 10 centimeters.

Response Time Test

For the Response Time Test of our altimeter, we introduced rapid altitude changes in our lab to evaluate the device's speed in registering and displaying accurate readings. Thereby we noticed that our altimeter adjusts in real time, even though the stabilization on the correct altitude can take up to two seconds.

Power Supply Variation Test

We assessed our altimeter's resilience to voltage fluctuations by introducing varying power inputs from both a 9V battery and from various laptop USB connections. This test evaluated the device's ability to maintain accuracy and functionality under different power conditions, ensuring reliability in real-world scenarios if the output power limit of 12V is not exceeded.

Communication Interface Test

In our communication interface test, we checked the interaction between the barometer and the Teensy 4.0 microcontroller. The data exchange via the I2C interface was reliable throughout our testing and we experienced a flawless transmission of the altitude measurements. Regarding the accuracy of altitude readings, we noted some fluctuations even though the altimeter was in a stable position. However, this is not linked to the communication interface testing.

Furthermore, we used the Logic Analyzer device Saleae with the software Logic 2.
From the datasheet, we can see the following flowchart for the functionality of the I2C protocol.

PRESSURE AND TEMPERATURE CALCULATION

Start
Maximum values for calculation results:
P_{MIN} = 10mbar P_{MAX} = 1200mbar
T_{MIN} = -40°C T_{MAX} = 85°C T_{REF} = 20°C

Read calibration data (factory calibrated) from PROM

Variable	Description | Equation	Recommended variable type	Size [1] [bit]	Value min	Value max	Example / Typical
C1	Pressure sensitivity | $SENS_{T1}$	unsigned int 16	16	0	65535	40127
C2	Pressure offset | OFF_{T1}	unsigned int 16	16	0	65535	36924
C3	Temperature coefficient of pressure sensitivity | TCS	unsigned int 16	16	0	65535	23317
C4	Temperature coefficient of pressure offset | TCO	unsigned int 16	16	0	65535	23282
C5	Reference temperature | T_{REF}	unsigned int 16	16	0	65535	33464
C6	Temperature coefficient of the temperature | TEMPSENS	unsigned int 16	16	0	65535	28312

Read digital pressure and temperature data

Variable	Description | Equation	Recommended variable type	Size [1] [bit]	Value min	Value max	Example / Typical
D1	Digital pressure value	unsigned int 32	24	0	16777216	9085466
D2	Digital temperature value	unsigned int 32	24	0	16777216	8569150

Calculate temperature

Variable	Description | Equation	Recommended variable type	Size [1] [bit]	Value min	Value max	Example / Typical
dT	Difference between actual and reference temperature [2] $dT = D2 - T_{REF} = D2 - C5 \cdot 2^8$	signed int 32	25	-16776960	16777216	2366
TEMP	Actual temperature (-40…85°C with 0.01°C resolution) $TEMP = 20°C + dT \cdot TEMPSENS = 2000 + dT \cdot C6 / 2^{23}$	signed int 32	41	-4000	8500	2007 = 20.07 °C

Calculate temperature compensated pressure

Variable	Description | Equation	Recommended variable type	Size [1] [bit]	Value min	Value max	Example / Typical
OFF	Offset at actual temperature [3] $OFF = OFF_{T1} + TCO \cdot dT = C2 \cdot 2^{16} + (C4 \cdot dT) / 2^7$	signed int 64	41	-8589672450	12884705280	2420281617
SENS	Sensitivity at actual temperature [4] $SENS = SENS_{T1} + TCS \cdot dT = C1 \cdot 2^{15} + (C3 \cdot dT) / 2^8$	signed int 64	41	-4294836225	6442352640	1315097036
P	Temperature compensated pressure (10…1200mbar with 0.01mbar resolution) $P = D1 \cdot SENS - OFF = (D1 \cdot SENS / 2^{21} - OFF) / 2^{15}$	signed int 32	58	1000	120000	100009 = 1000.09 mbar

Display pressure and temperature value

Notes
[1] Maximal size of intermediate result during evaluation of variable
[2] min and max have to be defined
[3] min and max have to be defined
[4] min and max have to be defined

Figure 2: Flow chart for pressure and temperature reading and software compensation.

Reset Sequence

RESET SEQUENCE

The reset can be sent at any time. In the event that there is not a successful power on reset this may be caused by the SDA being blocked by the module in the acknowledge state. The only way to get the MS5611-01BA to function is to send several SCLKs followed by a reset sequence or to repeat power on reset.

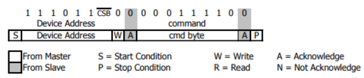
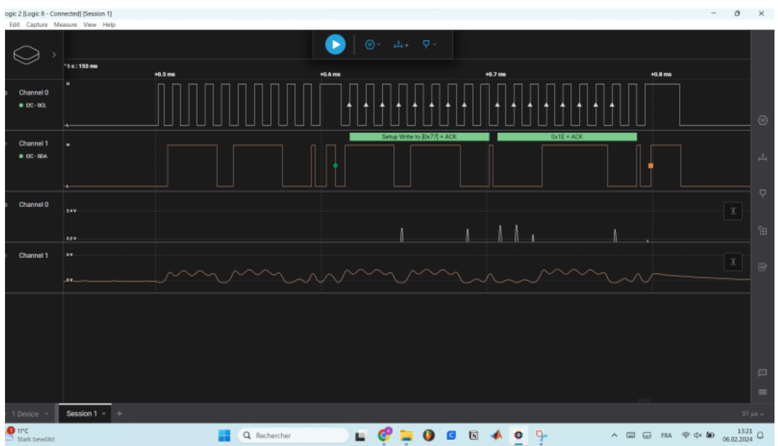
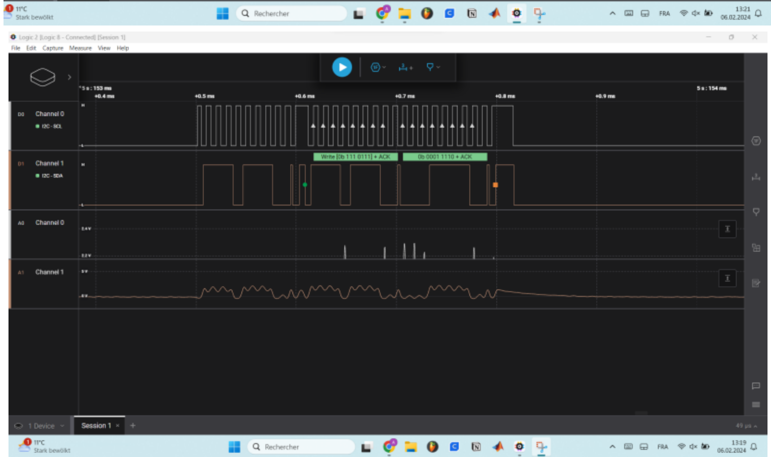


Figure 10: I²C Reset Command





Read Calibration Data

PROM READ SEQUENCE

The PROM Read command consists of two parts. First command sets up the system into PROM read mode. The second part gets the data from the system.

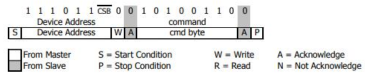


Figure 11: I²C Command to read memory address= 011 (Coefficient 3)

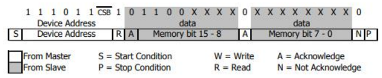
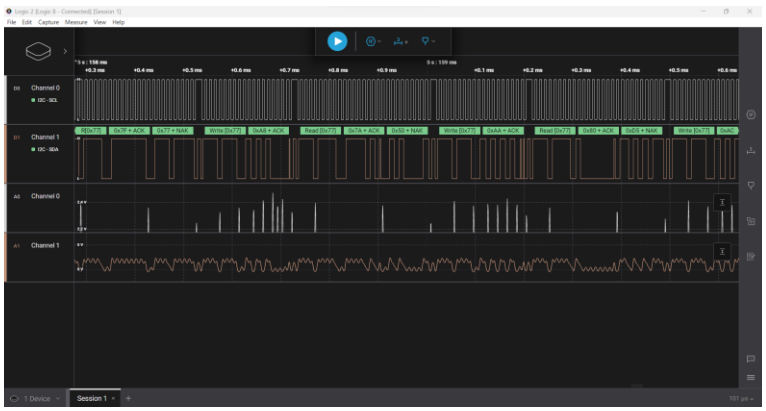
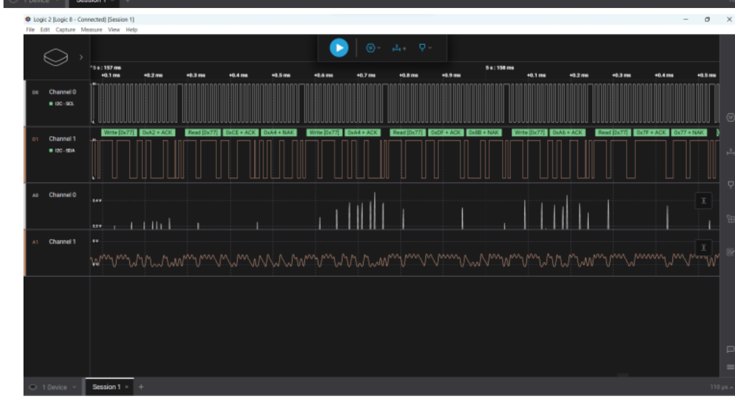
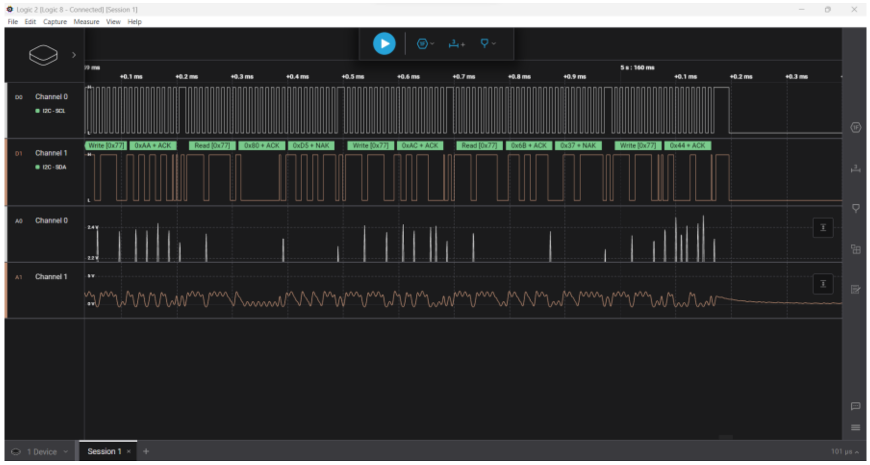
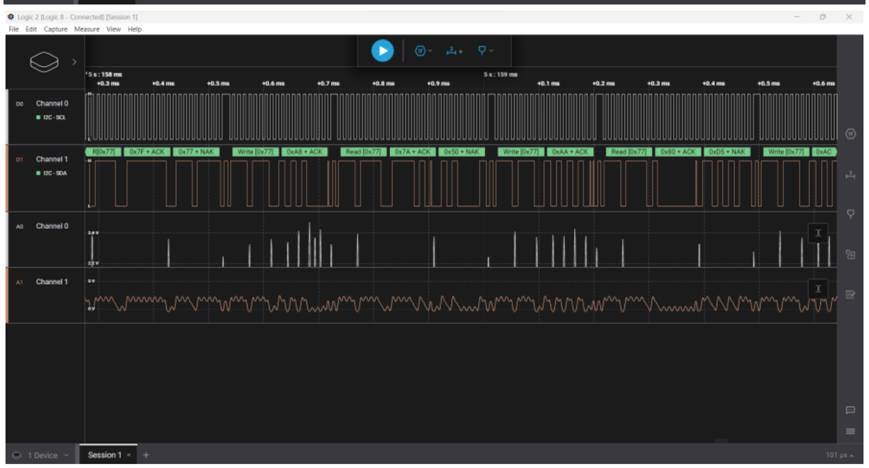


Figure 12: I²C answer from MS5611-01BA






Channel 0
Channel 1
Channel 0
Channel 1
1 Device
Session 1


Channel 0
Channel 1
Channel 0
Channel 1
1 Device
Session 1

Reading D1

CONVERSION SEQUENCE

A conversion can be started by sending the command to MS5611-01BA. When command is sent to the system it stays busy until conversion is done. When conversion is finished the data can be accessed by sending a Read command, when an acknowledge appears from the MS5611-01BA, 24 SCLK cycles may be sent to receive all result bits. Every 8 bit the system waits for an acknowledge signal.

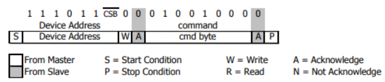


Figure 13: I²C Command to initiate a pressure conversion (OSR=4096, typ=D1)

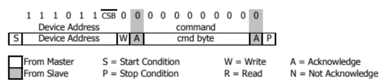


Figure 14: I²C ADC read sequence

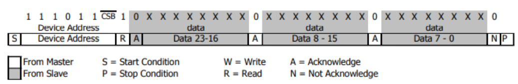


Figure 15: I²C answer from MS5611-01BA

COMMANDS

Size of each command is 1 byte (8 bits) as described in the table below. After ADC read commands the device will return 24 bit result and after the PROM read 16bit result. The address of the PROM is embedded inside of the PROM read command using the a2, a1 and a0 bits.

	Command byte								**hex value**
Bit number	0	1	2	3	4	5	6	7	
Bit name	PRM	COV	-	Typ	Ad2/ Os2	Ad1/ Os1	Ad0/ Os0	Stop	
Command									
Reset	0	0	0	1	1	1	1	0	0x1E
Convert D1 (OSR=256)	0	1	0	0	0	0	0	0	0x40
Convert D1 (OSR=512)	0	1	0	0	0	0	1	0	0x42
Convert D1 (OSR=1024)	0	1	0	0	0	1	0	0	0x44
Convert D1 (OSR=2048)	0	1	0	0	0	1	1	0	0x46
Convert D1 (OSR=4096)	0	1	0	0	1	0	0	0	0x48
Convert D2 (OSR=256)	0	1	0	1	0	0	0	0	0x50
Convert D2 (OSR=512)	0	1	0	1	0	0	1	0	0x52
Convert D2 (OSR=1024)	0	1	0	1	0	1	0	0	0x54
Convert D2 (OSR=2048)	0	1	0	1	0	1	1	0	0x56
Convert D2 (OSR=4096)	0	1	0	1	1	0	0	0	0x58
ADC Read	0	0	0	0	0	0	0	0	0x00
PROM Read	1	0	1	0	Ad2	Ad1	Ad0	0	0xA0 to 0xAE

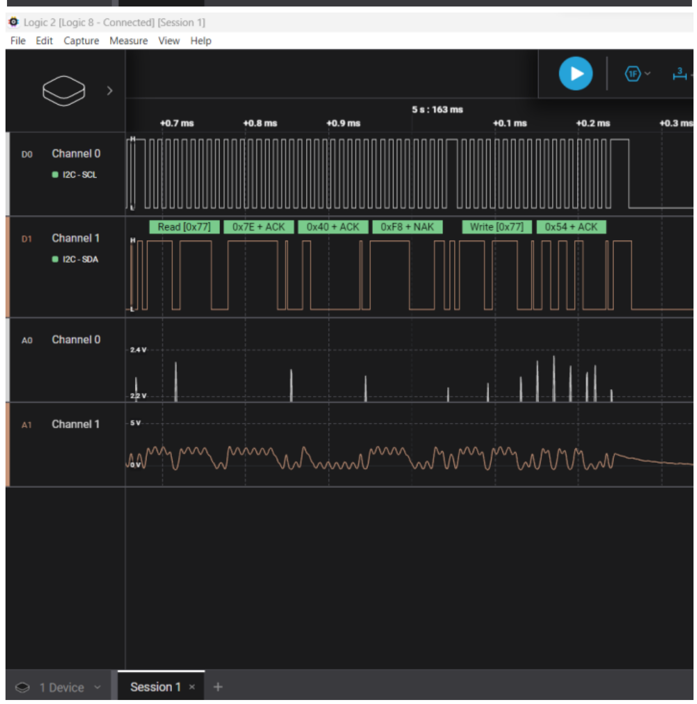
Figure 4: Command structure


Logic 2 [Logic 8 - Connected] [Session 1]
File Edit Capture Measure View Help
Channel 0
Channel 1
Write [0x77]
0xAA + ACK
Read [0x77]
0x80 + ACK
0xD5 + NAK
Write [0x77]
0xAC + ACK
Read [0x77]
0x6B + ACK
0x37 + NAK
Write [0x77]
0x44 + ACK
Channel 0
Channel 1


Logic 2 [Logic 8 - Connected] [Session 1]
File Edit Capture Measure View Help
5 s : 166 ms
+0.8 ms
+0.9 ms
+0.1 ms
D0
Channel 0
I2C - SCL
D1
Channel 1
I2C - SDA
Read [0x77]
0x83 + ACK
0x28 + ACK
0x58 + NAK
A0
Channel 0
2.4 V
2.2 V
A1
Channel 1
5 V
0 V

Reading D2


Logic 2 [Logic 8 - Connected] [Session 1]
File Edit Capture Measure View Help
5 s : 163 ms
+0.7 ms
+0.8 ms
+0.9 ms
+0.1 ms
+0.2 ms
+0.3 ms
D0 Channel 0
I2C - SCL
D1 Channel 1
I2C - SDA
Read [0x77]
0x7E + ACK
0x40 + ACK
0xF8 + NAK
Write [0x77]
0x54 + ACK
A0 Channel 0
2.4 V
2.2 V
A1 Channel 1
5 V
0 V
1 Device
Session 1


Logic 2 [Logic 8 - Connected] [Session 1]
File Edit Capture Measure View Help
5 s : 163 ms
+0.7 ms
+0.8 ms
+0.9 ms
+0.1 ms
+0.2 ms
+0.3 ms
D0 Channel 0
I2C - SCL
D1 Channel 1
I2C - SDA
Read [0x77]
0x7E + ACK
0x40 + ACK
0xF8 + NAK
Write [0x77]
0x54 + ACK
A0 Channel 0
2.4 V
2.2 V
A1 Channel 1
5 V
0 V
1 Device
Session 1

Results

So we did multiple tests of the device inside and outside the Lab Building, below are some pictures of the testing and afterwards is a table with benchmarking. We basically did two tests to make sure our results are as accurate as possible.

The data shows relatively consistent measurements between Test 1 and Test 2 for each level. This consistency indicates that the altimeter is providing reliable and repeatable measurements.

Some minor discrepancies can be observed between Test 1 and Test 2 measurements for each level. For example, the measurements for the first floor in Test 1 are 5.1, while in Test 2, they are slightly higher at 5.3. Similarly, there are slight variations in measurements for other floors between the two tests. These minor differences could be attributed to factors such as variations in the altimeter's positioning or environmental conditions during each test.

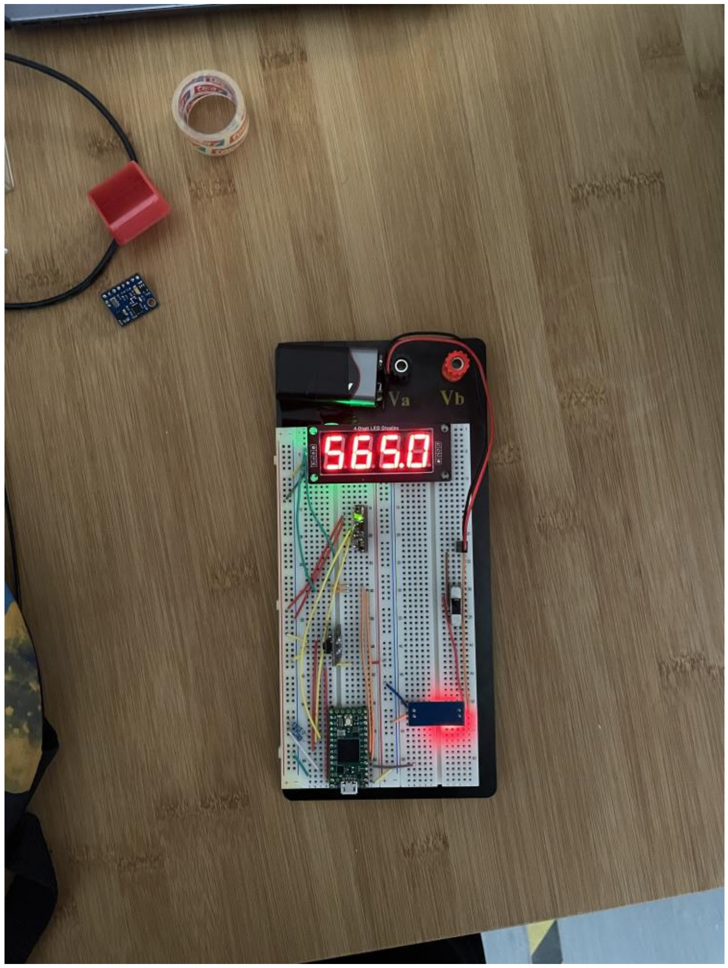


Figure 1: Measurement of Altitude wrt. Sea Level

Figure 2: Resetting at Ground Level

Figure 3: Measurement at First Floor

Figure 4: Measurement at 2nd Floor

Figure 5: Another Measurement at Second Floor

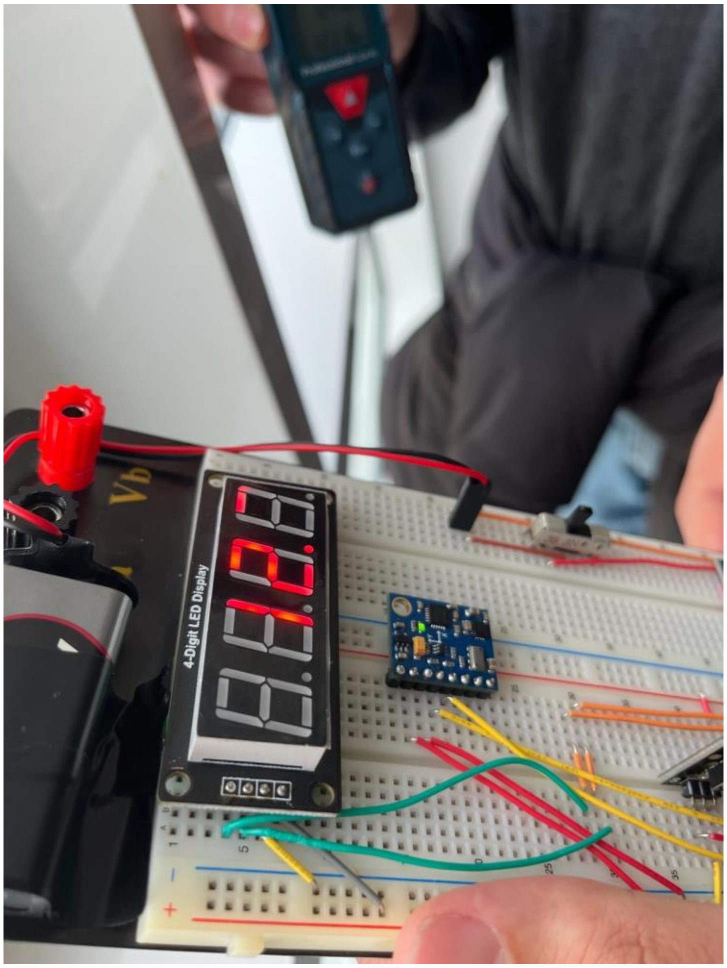


Figure 6: Measurement at Third Floor

Level	Bosch GLM40	Altimeter	Bosch GLM40	Altimeter
	Test 1		Test 2	
At Ground (wrt. Sea Level)	-	565.0	-	565.0
First Floor	5.07	5.1	5.07	5.3
Second Floor	8.625	8.7	8.625	8.5
Third Floor	12.125	12.2	12.125	12.3

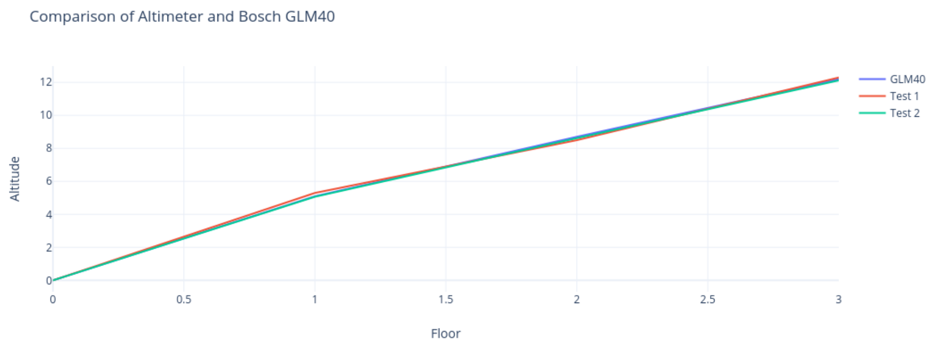


Figure 7: Graph of Test Results

References

https://www.kalmanfilter.net/kalman1d.html

https://en.wikipedia.org/wiki/Hypsometric_equation

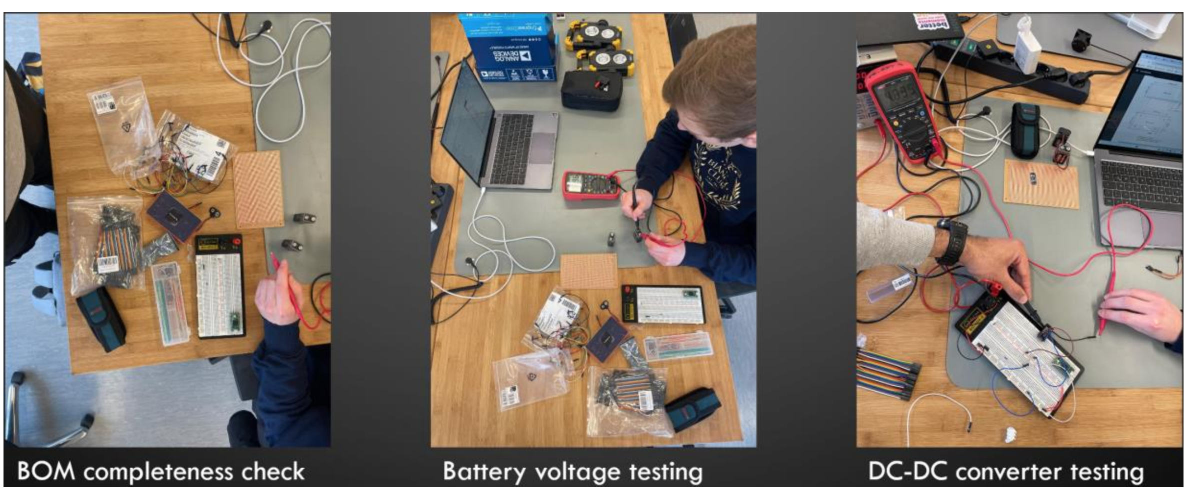
https://en.wikipedia.org/wiki/Barometric_formula

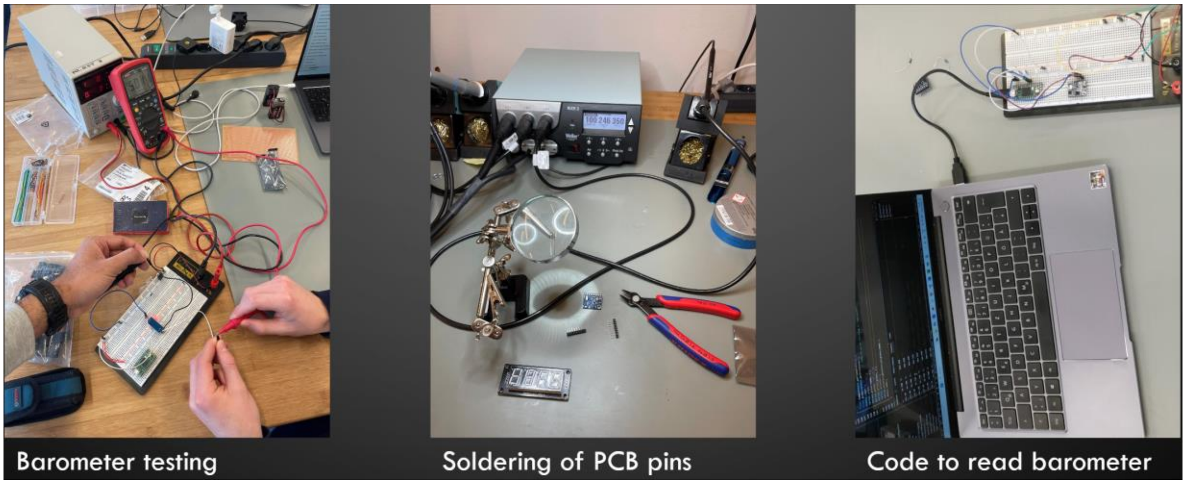
https://www.saleae.com/downloads/

https://en-gb.topographic-map.com/map-j7n9m/Bavaria/?center=48.0525%2C11.65572&zoom=16&popup=48.05311%2C11.65442

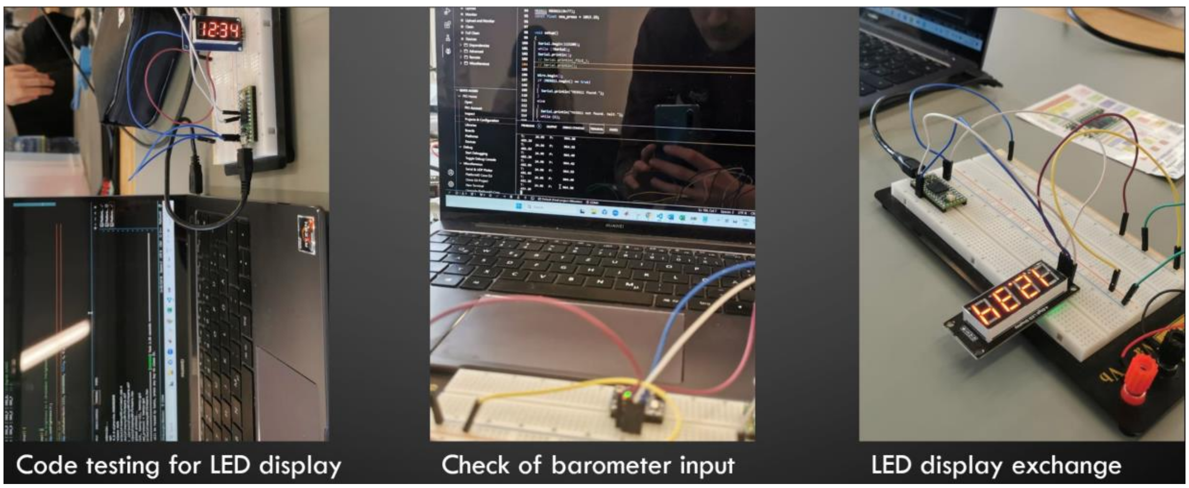
Annex

Pictures of our work:

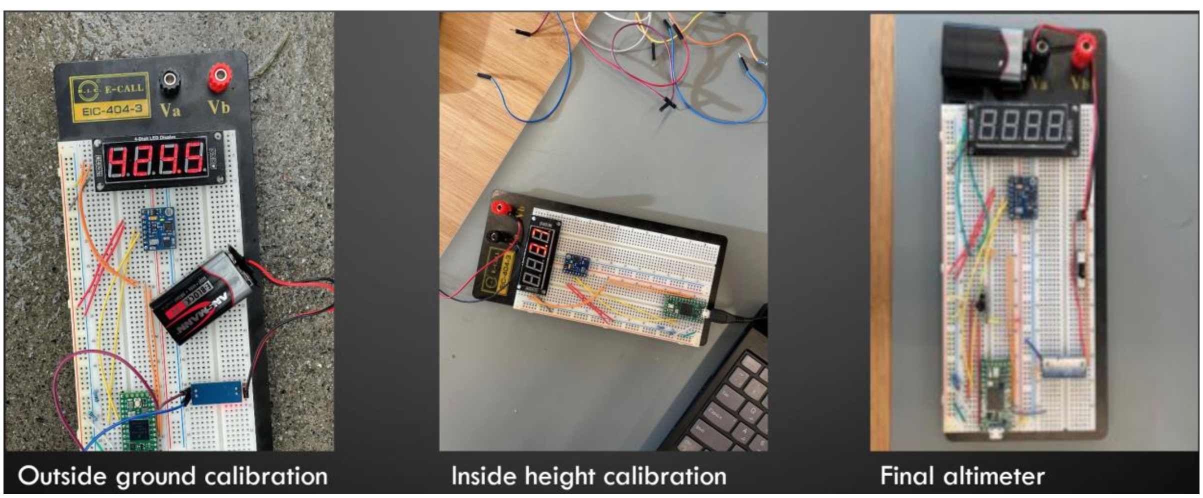




Barometer testing | Soldering of PCB pins | Code to read barometer



Code testing for LED display | Check of barometer input | LED display exchange



Outside ground calibration | Inside height calibration | Final altimeter

Manual of our altimeter:

Department of Aerospace and Geodesy
TUM School of Engineering and Design
Technical University of Munich

Manual of Group 3: Altimeter based on MS5611 barometer with four-digit LED display.

Table of Contents

1. Introduction

The altimeter based on the MS5611 barometer, and a four-digit seven segment LED display is designed to provide accurate altitude measurements compared to an individually set reference plane in real-time. This manual gives information about the assembly, calibration, and usage of the altimeter.

2. Technical Specifications

Description	Value
Altitude range	Maximum: 999.9 meters (about the height of the Burj Khalifa, the tallest building in the world)
Sensor calibration	Altitude Calibration Range: Maximum of 999.9 meters. Accuracy: ±0.1 meter
Size	215 x 100 x 35 mm
Operational Voltage	6V to 12V
Current	Operating Current: 100mA
Power consumption	0.5 W
Operating temperature	-40°C to +85°C
Barometric sensor	Model: MS5611 Communication: I2C Pressure Range: 10mbar to 1200mbar Resolution: 0.012 mbar
Communication	I2C

3. Components and Connections

All components are connected on a breadboard to the 9V battery as power supply and grounded.

- **MS5611 Barometer:**
  - The barometer MS5611 is connected to the Teensy 4.0 microcontroller using the I2C interface.
- **Four-Digit LED Display TM1637:**
  - The four-digit display is connected to the Teensy40 microcontroller.
- **Teensy 4.0 Microcontroller:**
  - The Teensy 4.0 microcontroller is connected to the MS5611 and the display.
- **9V Battery:**
  - The 9V battery is connected to power the system.
- **DC-DC Converter:**
  - The DC-DC converter is used to step down the voltage from 9V to 5V to reliably power the Teensy 4.0 microcontroller.

4. Calibration

- **Usage to give altitude in comparison to sea level based on atmospheric pressure**
  Once the device is switched on, the display will show the altitude, measured by the atmospheric pressure, with the sea level as reference plane. The use of the altimeter for this purpose is not recommended, because it is not optimized for this purpose.
- **Usage to give height difference to individual set reference plane**
  The altimeter can be used to measure the height difference between its current position and a beforehand individually set reference plane in real-time. To set an individual reference plane, the separate knob on the altimeter needs to be pushed once. Then, the current altitude of the altimeter is set as reference plane. After the calibration the altimeter shows the altitude difference to the calibrated reference plane in real-time.

5. Usage Instructions

1. Make sure that the 9V battery is connected to power the system and that the switch is turned on. Now, the four-digit display will show the current altitude of the altimeter in comparison to the sea level in real-time.
2. If needed, push the calibration knob to set the current altitude as reference plane. Then, the four-digit display will show the height difference to the previous set reference plane. This step can be used iteratively to set new reference planes as needed.
3. Change the position of the altimeter and monitor the changes in altitude/height as needed.

6. Maintenance and Repair

No special maintenance is required. The instrument has no serviceable parts inside. If the battery is dead, it can be exchanged by the user. In the case of another malfunction, it must be sent to factory for a repair. Please get in touch with our Service team via mail or telephone.