Hochschule Bremerhaven
University of Applied Sciences

Wireless Node Design

and related Test Campaign

UNIVERSITY OF APPLIED SCIENCES BREMERHAVEN

Main Topics

- Challenges of the Test HW and SW
- Wireless Network System
- Wireless Sensor Node
- Access Point
- Sensor Node
- Hardware Design
- Software Design
- Test Campaign

Motivation for developing WSN

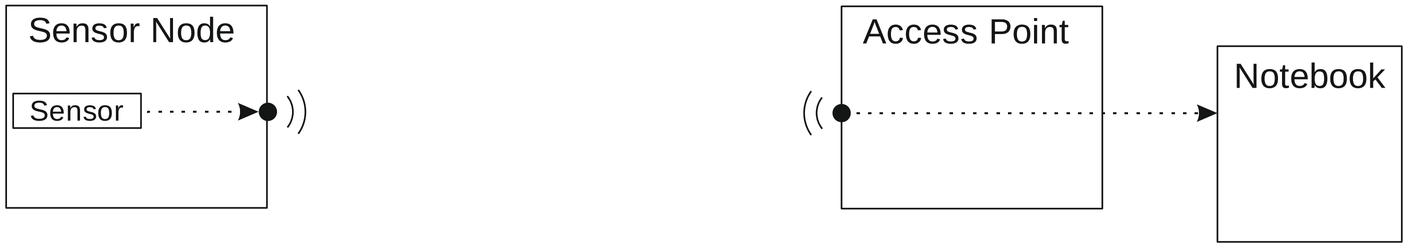
- Show the potential of using UWB technology in the aerospace industry
- Building a useful application that utilize the new radiation-hardened chip
- Test the new chip within the system level

Challenges of developing & testing WSN

- Show Sensor node can measure temperature (analog) and acceleration (smart sensor via SPI)
- Show Data transfer form Sensor Node and the Access Point
- Sensor node provides up to 10 ksamples per second
- Time stamping of measurement data for all system sensors with an accuracy <10 µs
- End-to-end latency between output of sensor and data transmission to avionic bus < 40 ms

This requires a new, challenging measurement system in which plenty of parallel data processing in FPGA hardware is necessary!!!

Wireless Network System



- The Network System consists of **two types of Wireless Nodes**: An **Access Point (AP)** and one or more **Sensor Nodes (SN)**.
- The Wireless Nodes are designed for the use with new **UWB radio module from IHP** or **COTS radio module**.

Deterministic Real-Time

- **Measurement Precision**
  - Optimized Components: Ensures efficient data processing, minimal interference.
- **Reliable sampling**
  - Problem: Several processes have access to data buffers which if not organized, may cause data corruption and data loss.
  - Solution: Ring buffers are used along with **resource access control** to guarantee data integrity and safe sampling.
- **Sampling Predictability**
  - Fixed Intervals by **hardware interrupts**: Guarantees workload management; crucial for real-time use.
- **Real-time operation**
  - Data latency less than 40 ms.
- **Highly synchronized network**
  - Time-stamping accuracy better than 10 μs.

Wireless Node Design by UBH

- **Customized FPGA programmable logic capable of:**
  - Interfacing to smart and analog sensors.
  - Providing accurate mechanisms for measuring Time-stamping accuracy and Data Latency measurements.
  - Providing a configurable time-stamping clock.
- **Application processor capable of:**
  - Data acquisition.
  - Data compression for efficient wireless communication.
  - Performing functional testing.
  - Effective communication with higher levels (PC / Notebook) through Ethernet TCP/IP.
- **Graphical User Interface (GUI) program capable of:**
  - Control of WSN.
  - Data plotting.
  - Data logging.

Wireless Node Architecture (AP / SN)

- For the COTS hardware, the BBP is already integrated in the UWB Front End Board.

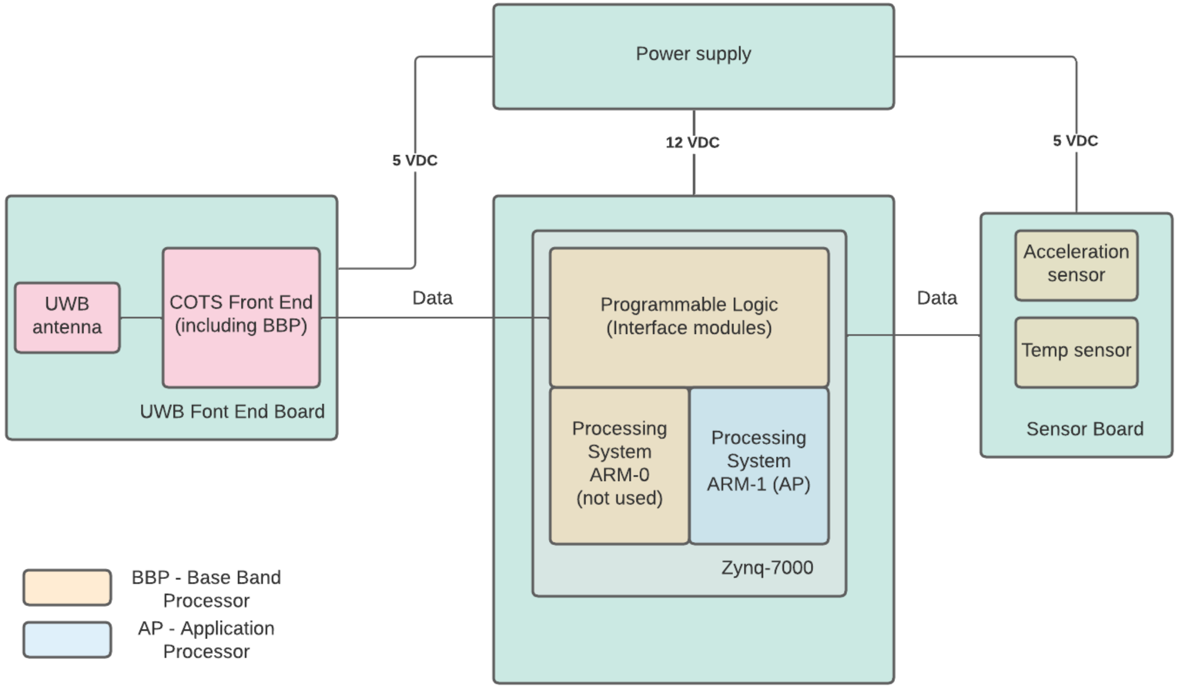


Figure by UBH and CDS

Wireless Node Architecture (AP / SN)

- For the new UWB Front End the Programmable Logic is used for the implementation of the BBP

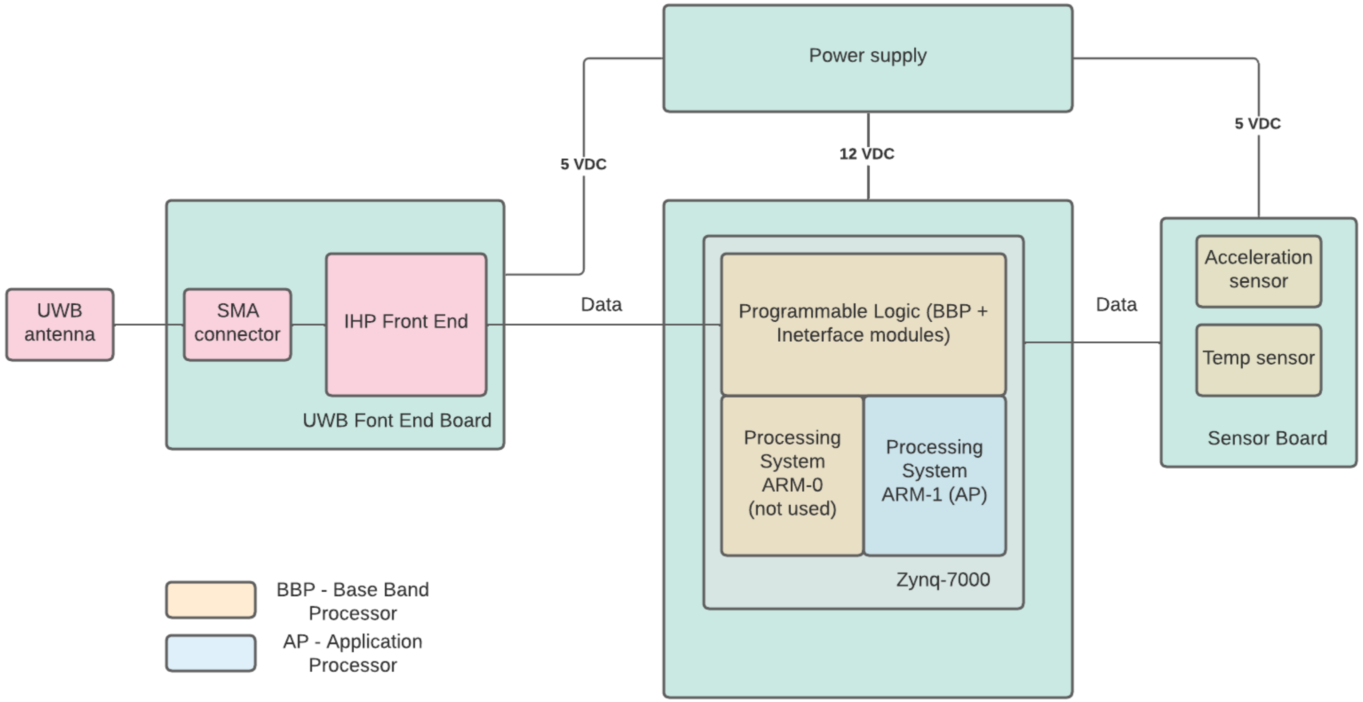


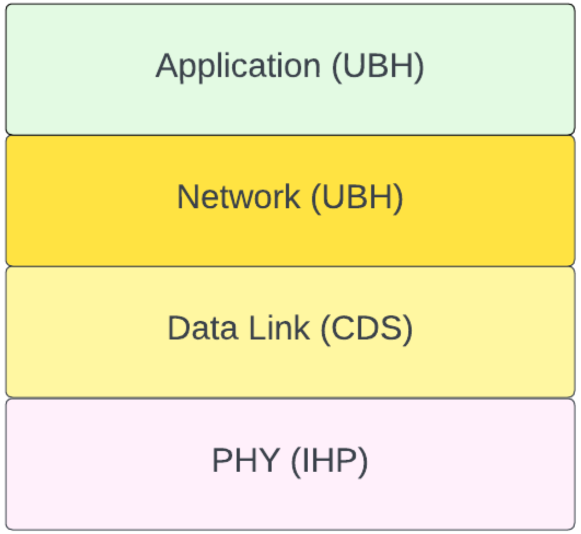
Figure by UBH and CDS

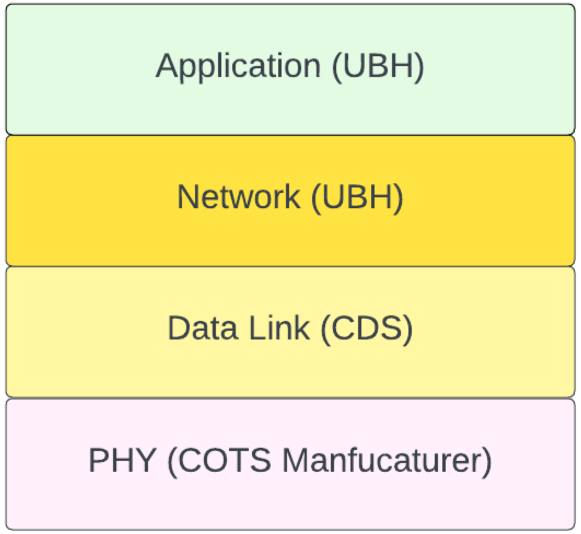
Software Components

- FPGA implementation
- Core 0 – UWB RF Communication & Sensor Acquisition
- Software Architecture – Access Point
- Software Architecture – Sensor Node
- Graphical User Interface (GUI) program

Communication Stack

- Simple Network layer due to the star network topology

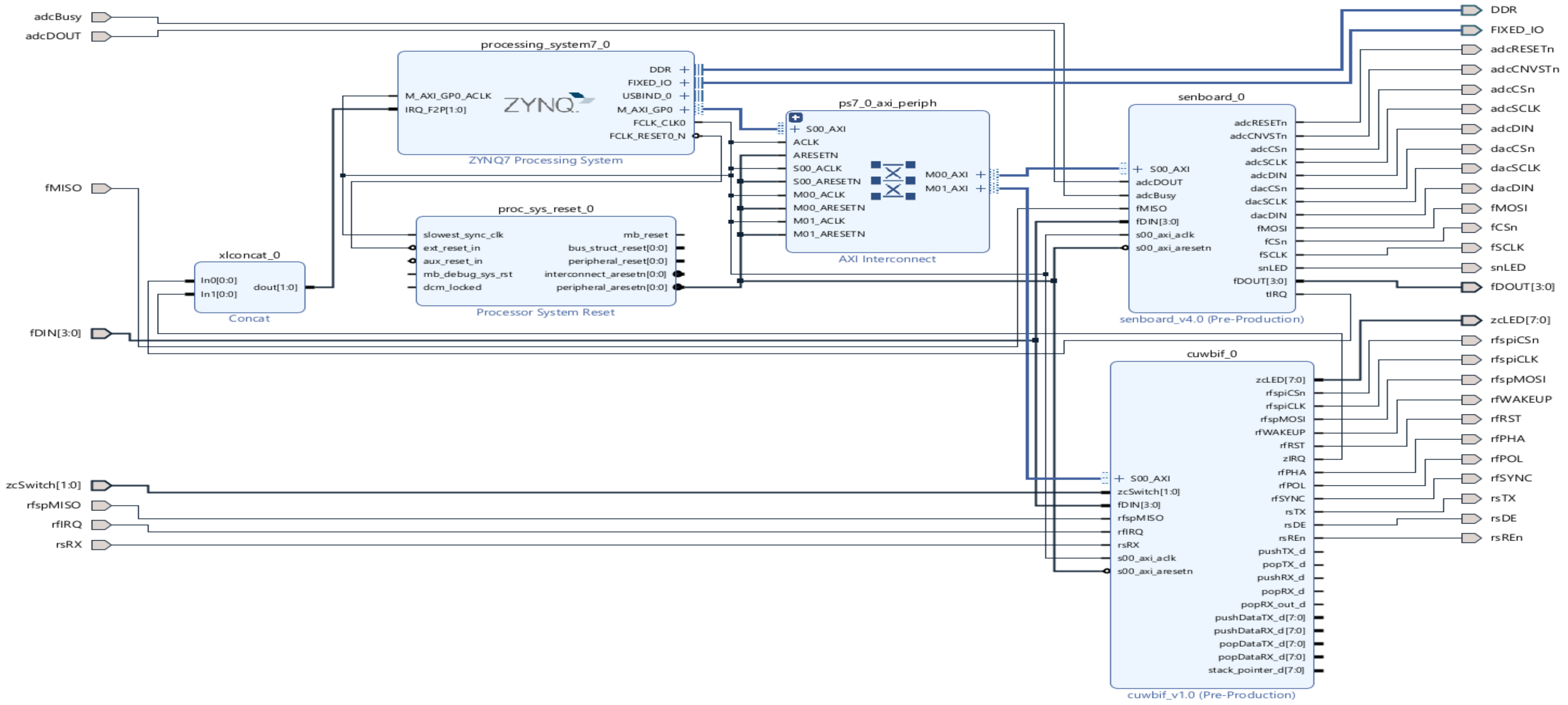




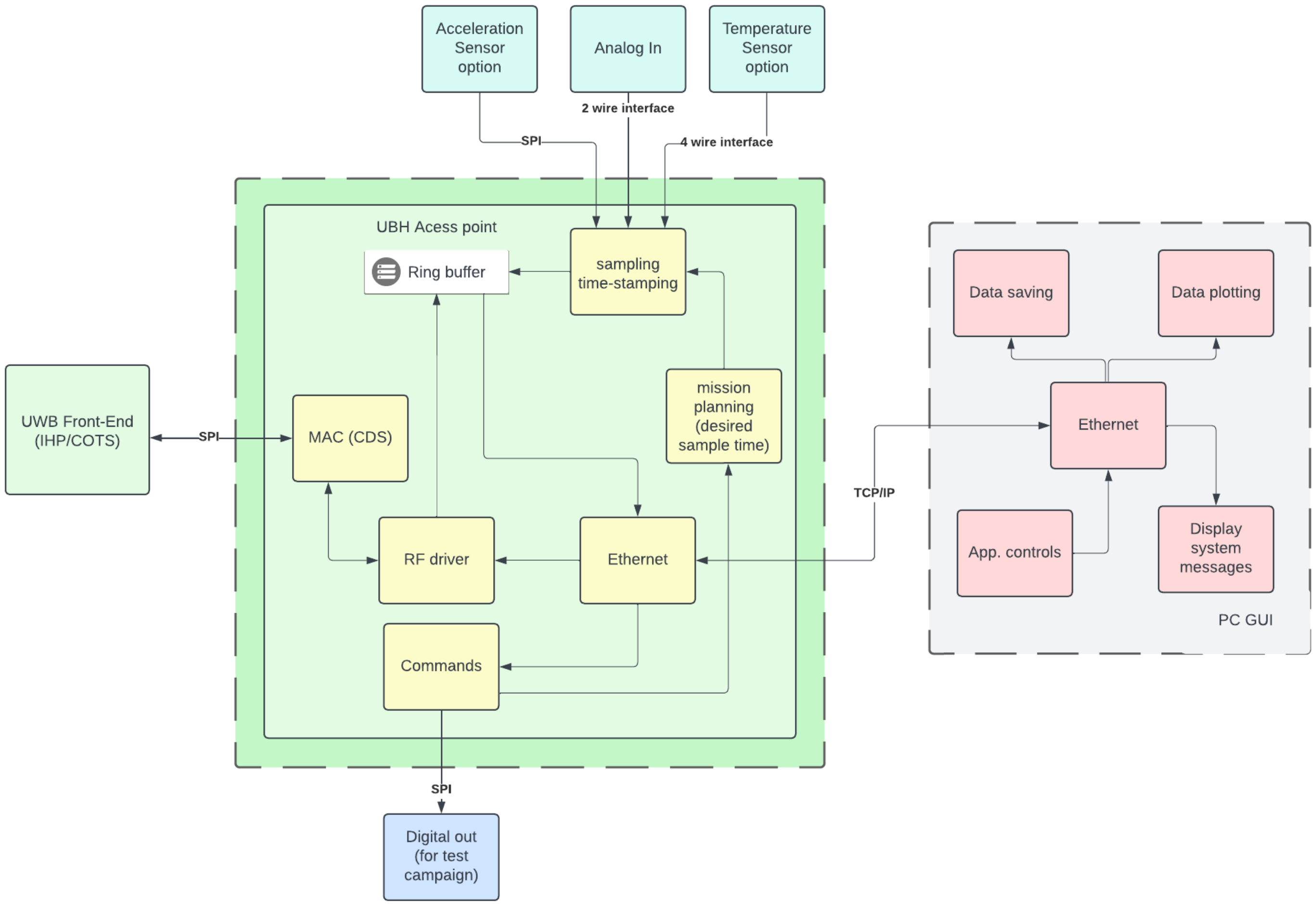
- With the new radiation hardened chip.
- Further development needed to integrate the PHY with the Data Link layer.

- With COTS hardware.

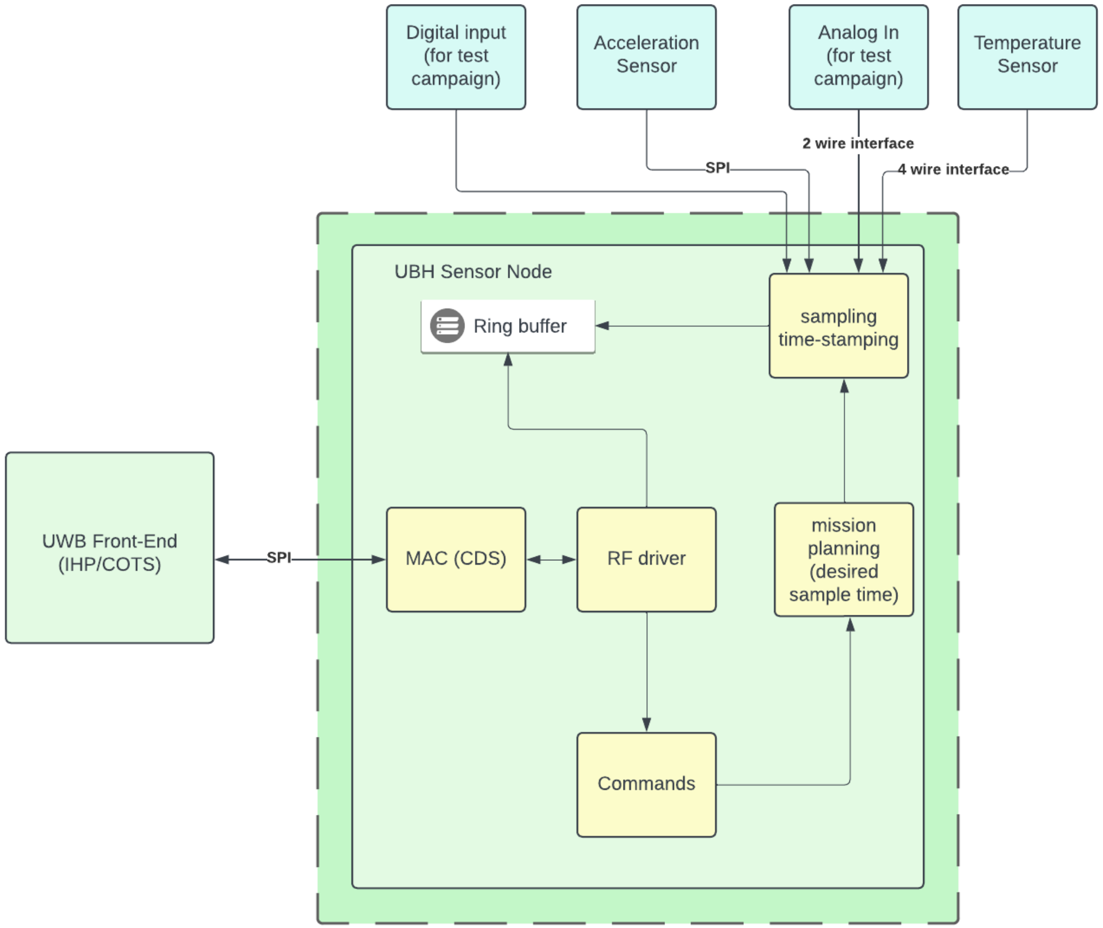
FPGA Implementation



Software Architecture – Access Point



Software Architecture – Sensor Node

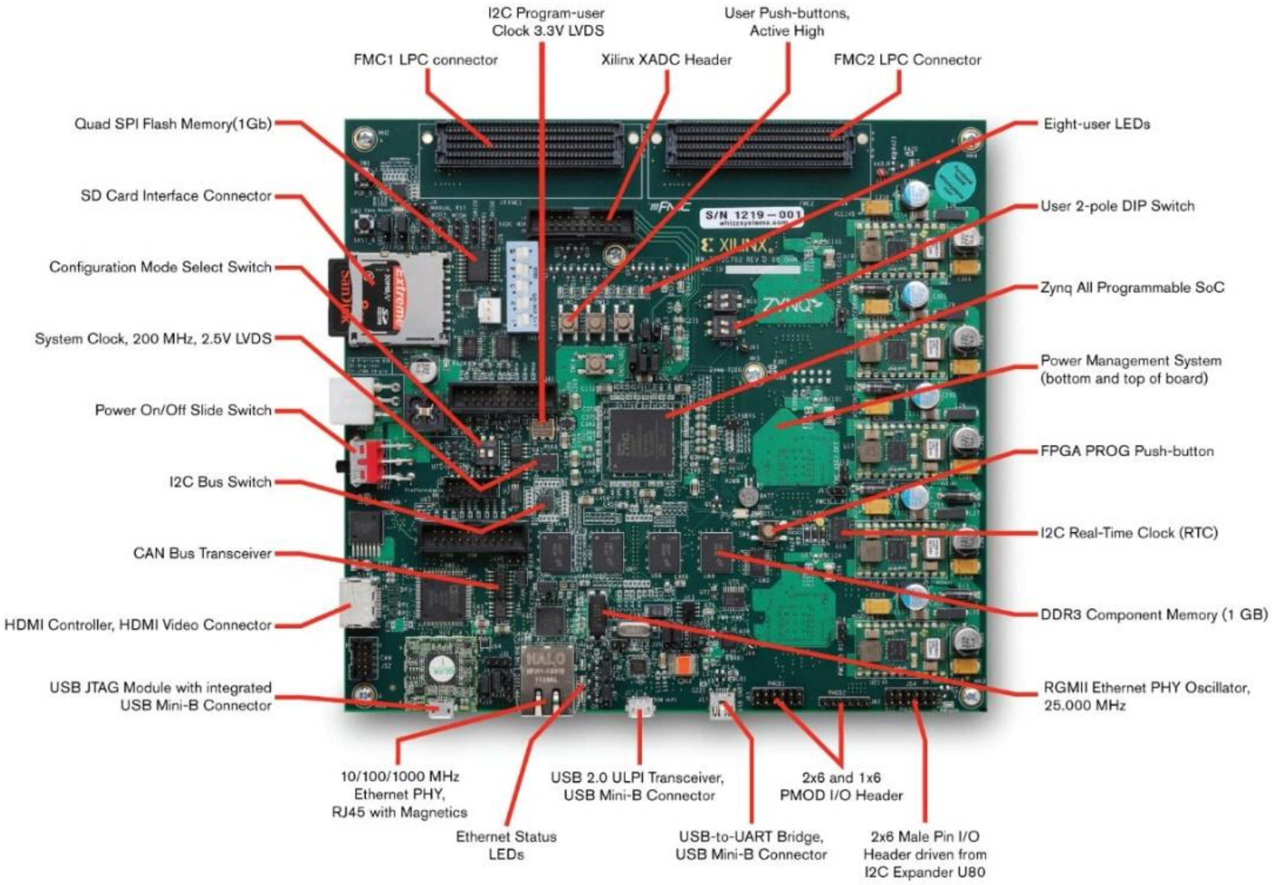


Hardware Design

- ZYNQ Board Xilinx XCZ702
- Sensor Board
  - Acceleration Sensor interface
  - Temperature Sensor interface
  - Digital I/O
  - Analog I/O
- RF Interface
  - DWM3000 by Qorvo (formerly known as Decawave)
  - IHP radiation hardened chip

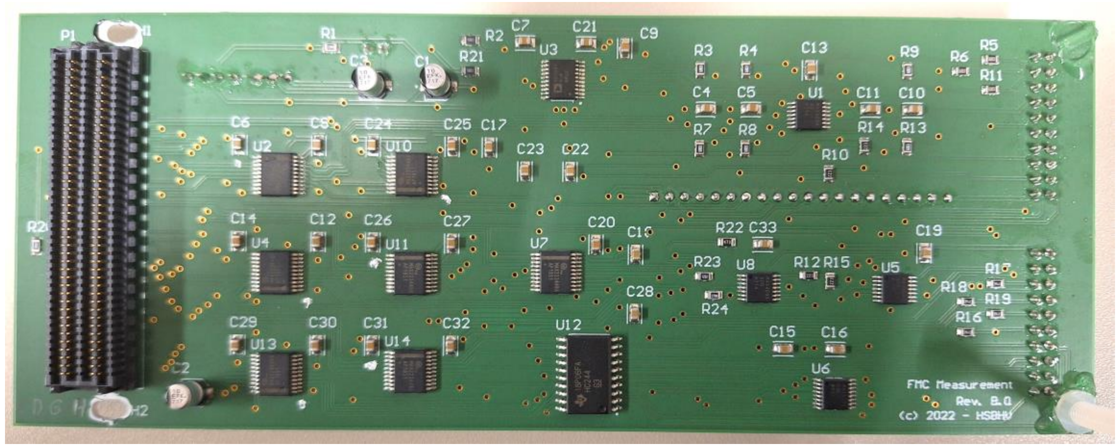
ZYNQ Board Xilinx XCZ702

- two FMC Connectors for
  - Measurement Board and
  - RF Interface

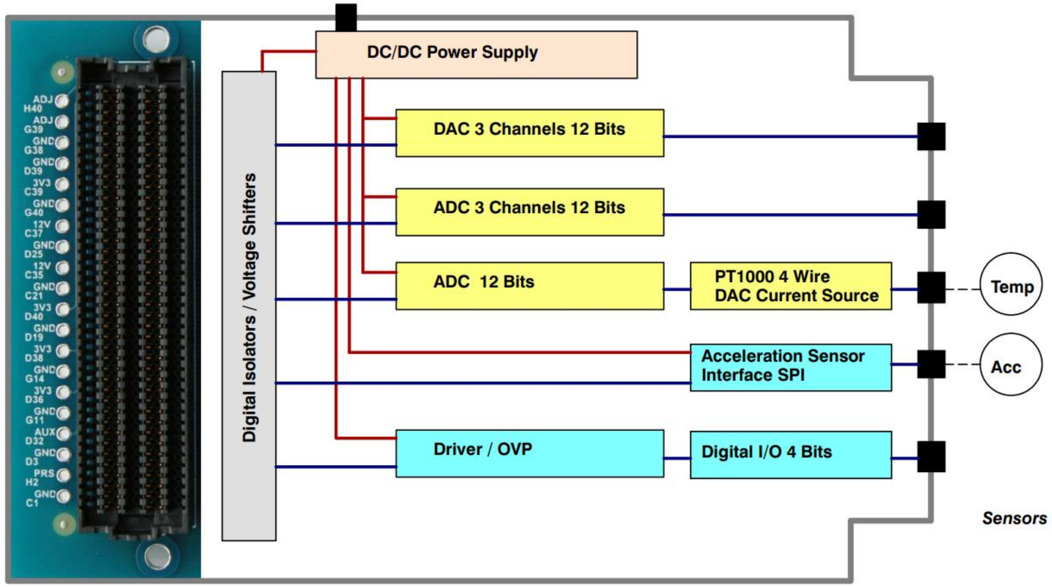


Sensor Board

- Typical example of an FMC Sensor Board

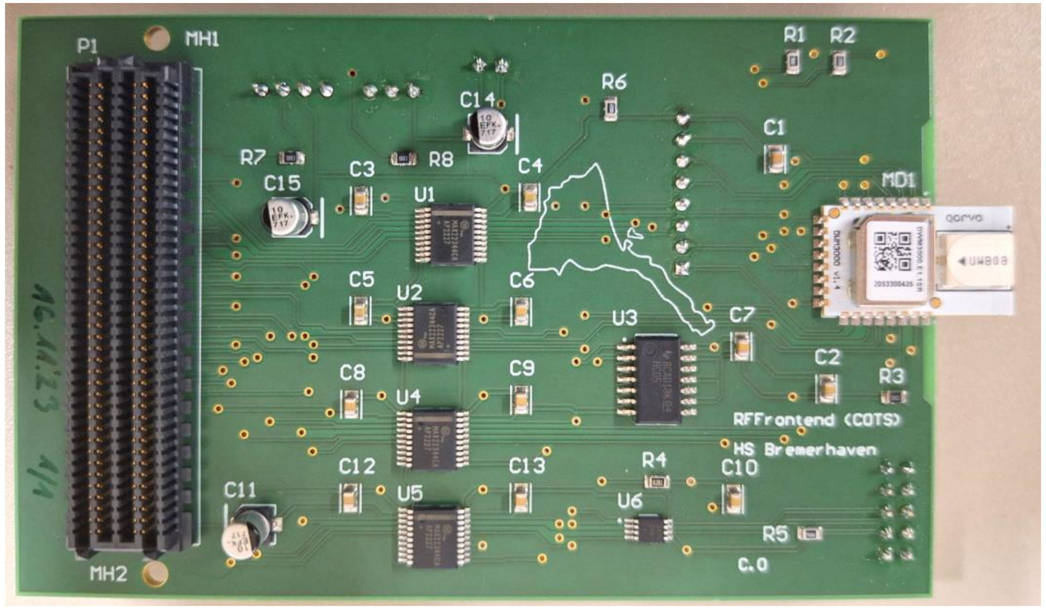


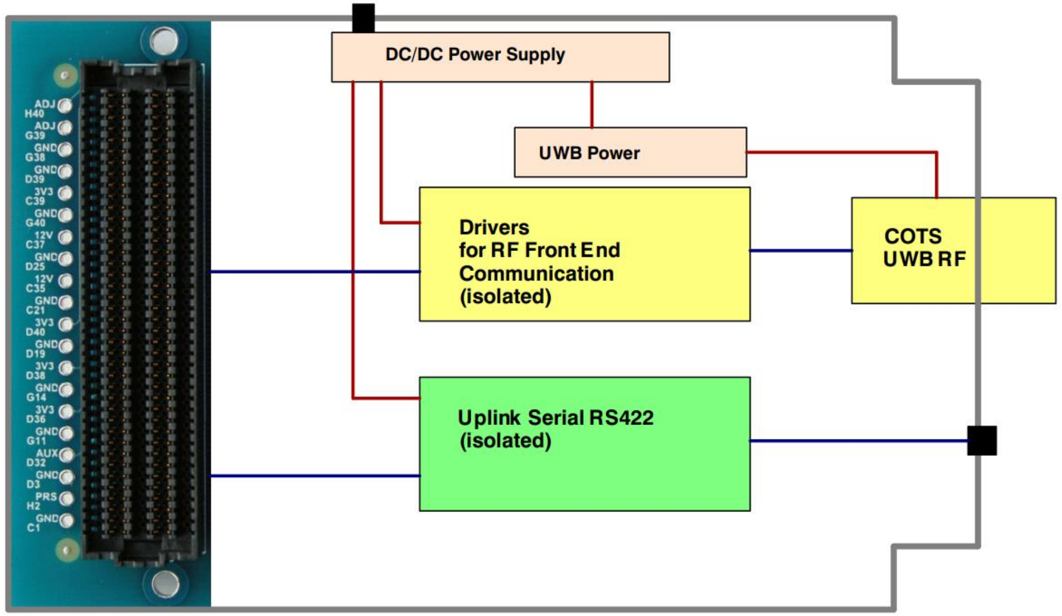
- FMC Sensor Board



COTS Front End Board

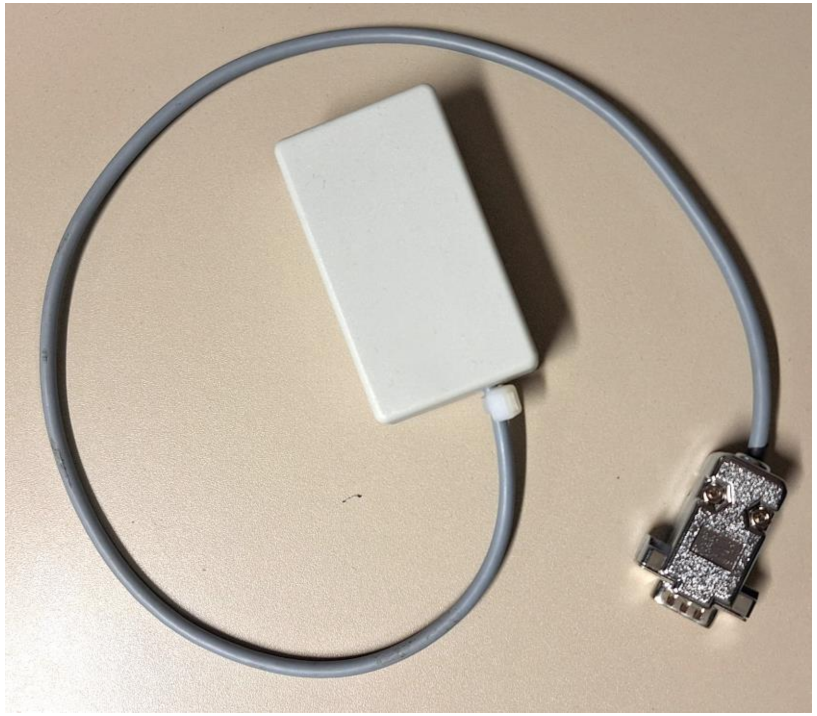
- Interface to UWB Front End Board

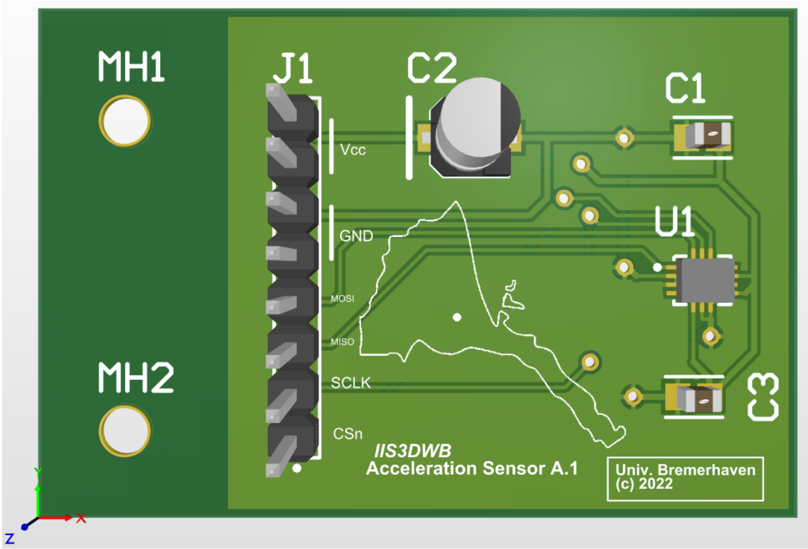




Acceleration Sensor

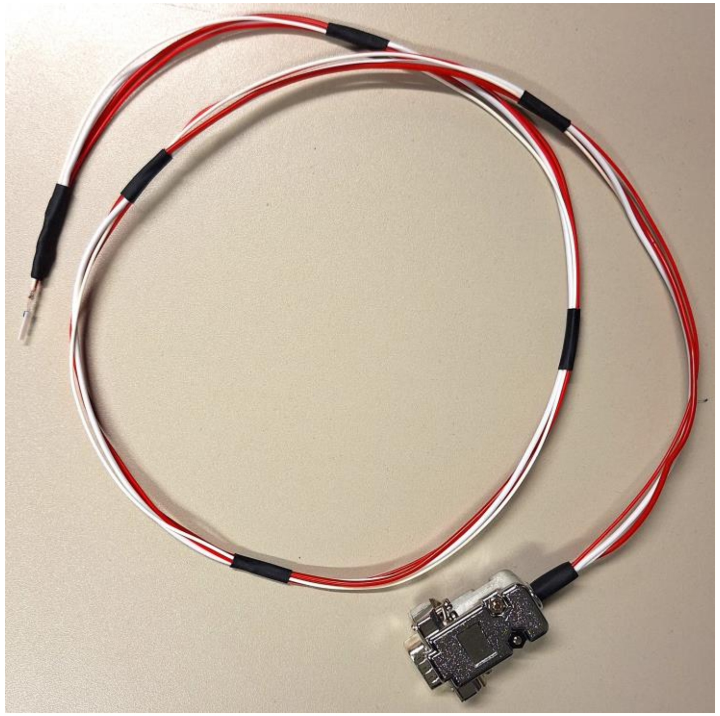
- Tri-axial acceleration sensor with DSUB-9 connector.



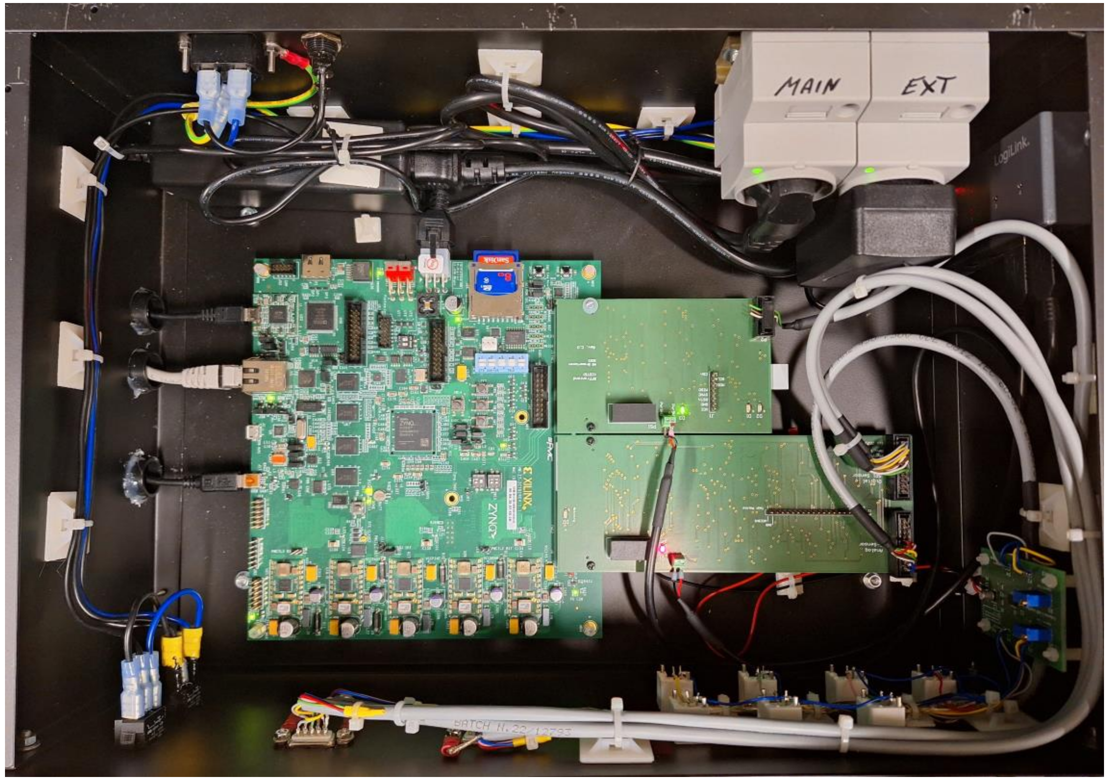


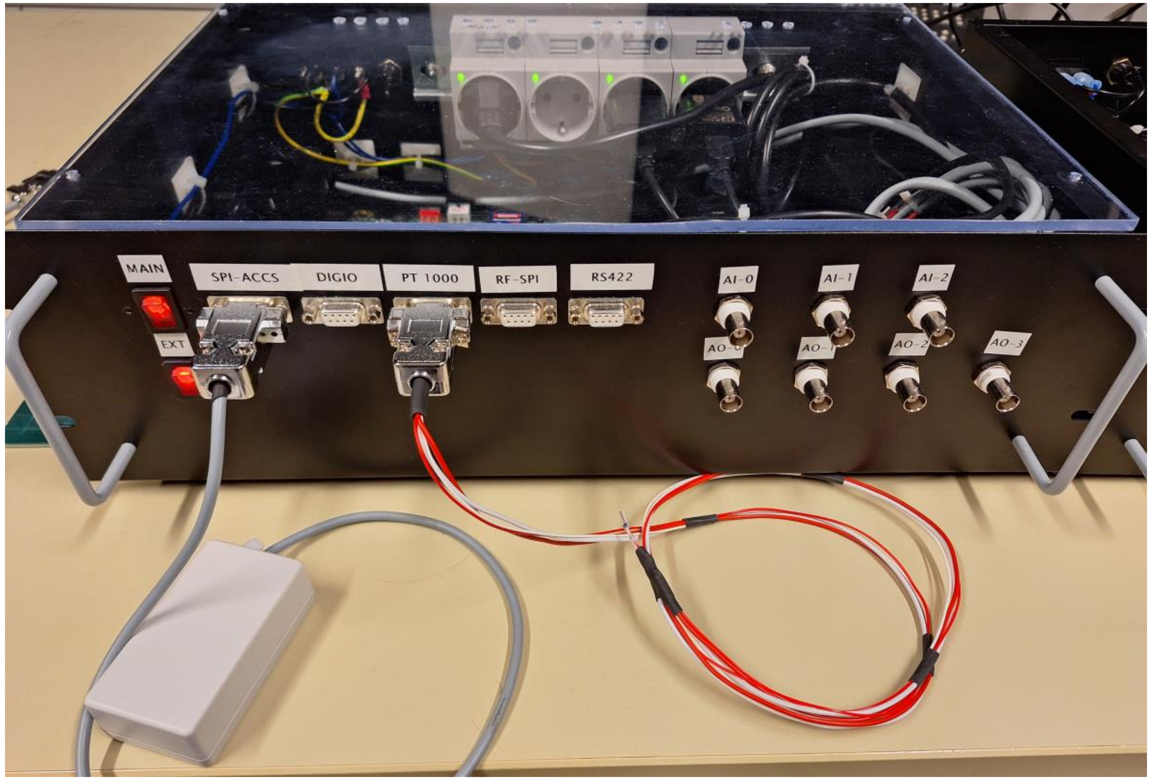
Temperature Sensor

- PT1000 sensor with DSUB-9 connector.



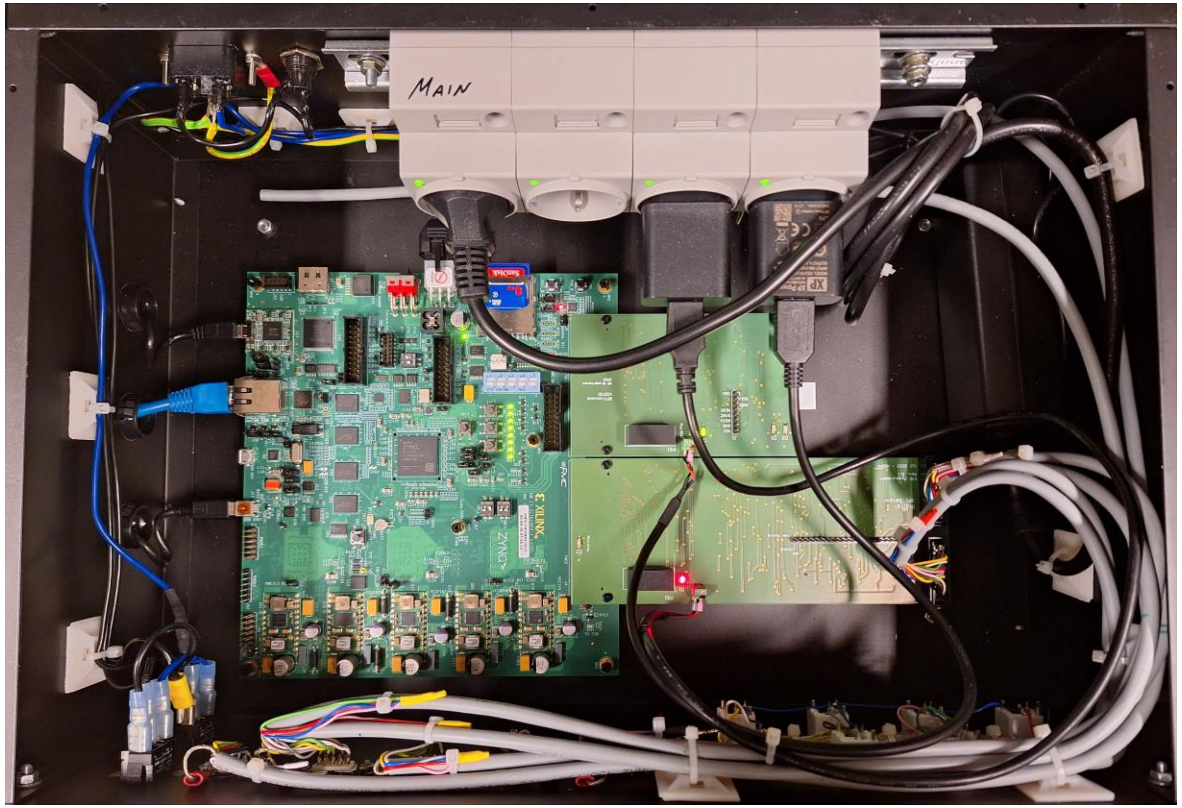
Sensor Node


MAIN
EXT

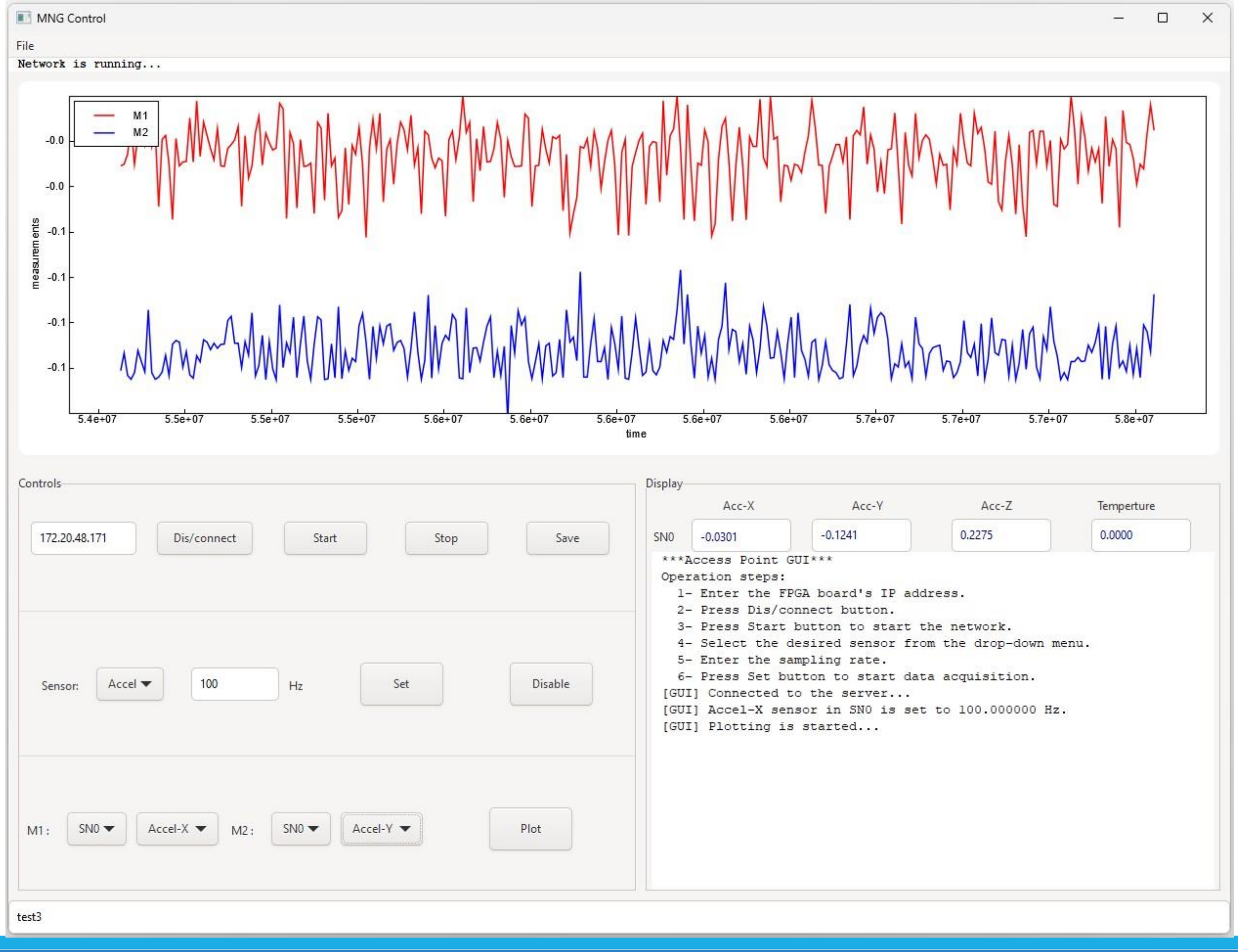

MAIN
EXT
SPI-ACCS
DIGIO
PT 1000
RF-SPI
RS422
AI-0
AI-1
AI-2
AO-3

Access Point

- The hardware of the Access Point (AP) is similar to the Wireless Sensor Node (SN).



Graphical User Interface Program



Test Campaign

Compliance shall be shown for the following requirements.

Test Case	**Requirement**	Objective	Comment
TC201 / TC202 / TC203	UWB-FUNC-018 UWB-FUNC-019 UWB-FUNC-020	- Show Sensor node can measure temperature. - Show Sensor node can measure acceleration. - Show Data transfer form Sensor Node and the Access Point.	Conducted using COTS in UBH
TC204	UWB-FUNC-021	Sensor node provides up to 10 k samples per second	Conducted using COTS in UBH.
TC205	UWB-FUNC-022	Time stamping of measurement data with accuracy <10 μs	Conducted using COTS in UBH
TC206	UWB-FUNC-023	Latency between output of sensor and data transmission < 40 ms	Conducted using COTS in UBH.
TC207	WN-DES-002	Wireless Nodes operate on UWB ch. 9, optionally on UWB ch. 5, 6 and 8	Conducted using IHP chip in IHP.
TC208	WN-DES-005	Wireless Nodes output PSD is limited to -41.3 dBm/MHz	Conducted using IHP chip in IHP
TC209	WN-DES -013	WN - UWB Board power consumption < 1.155 W (on average).	Conducted using IHP chip in IHP

Test Bench Setup

1 Access Point, equipped with:

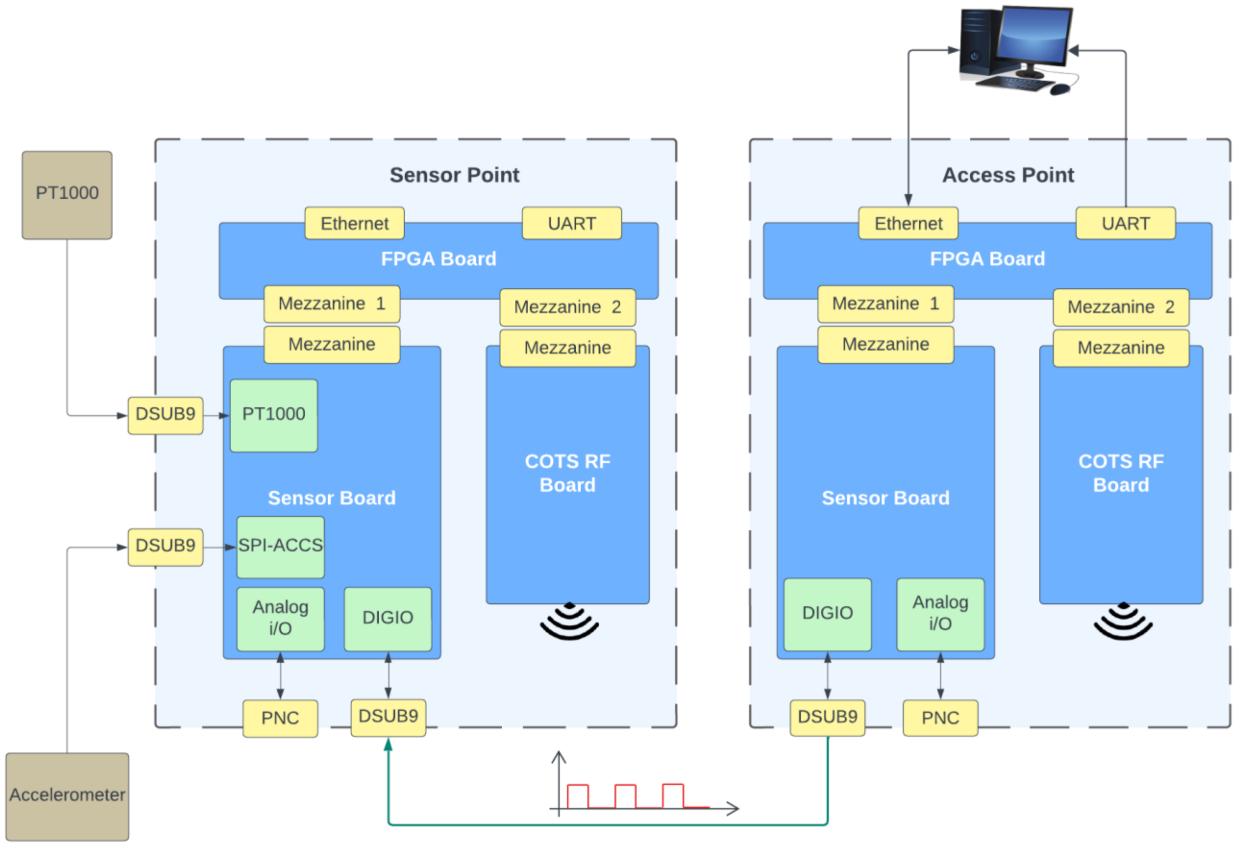
- 1 DW3000 RF Board.

1 Sensor Node, equipped with:

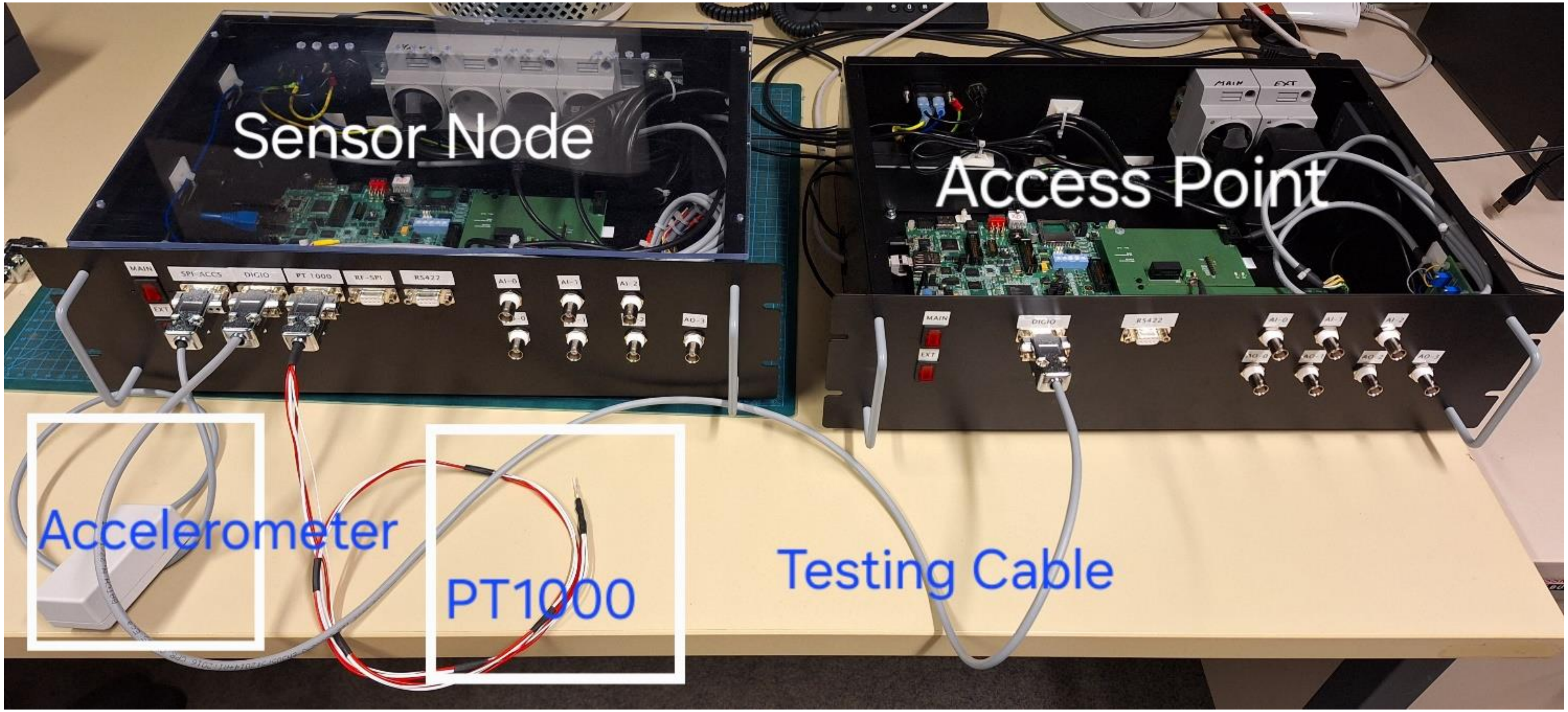
- 1 DW3000 RF Board.
- 1 Sensor Board.

1 Notebook.

1 Testing Cable.



Test Bench Setup



Test Campaign Results

Test Case	**Requirement**	Objective	Compliance
TC201 / TC202 / TC203	UWB-FUNC-018 UWB-FUNC-019 UWB-FUNC-020	- Show Sensor node can measure temperature. - Show Sensor node can measure acceleration. - Show Data transfer form Sensor Node and the Access Point.	Compliant
TC204	UWB-FUNC-021	Sensor node provides up to 10 k samples per second	Compliant. However, the wireless link was limited to 480 Samples/sec.
TC205	UWB-FUNC-022	Time stamping of measurement data with accuracy <10 μs	Compliant.
TC206	UWB-FUNC-023	Latency between output of sensor and data transmission < 40 ms	Complaint. However, the latency was measured only upto the AP.

Redesign Recommendations

1. **Higher Avionic Level Interface with TSN** (suggested by UBH)
2. **Maximizing Sample Rate**
   - **Sample Size Reduction** (suggested by UBH)
   - **RF Throughout Boost** (suggested by UBH & CDS)
3. **Minimizing Data Latency** (suggested by UBH)
4. **Maximizing Time-Stamping Accuracy**
   - **Precision Time Protocol** (suggested by UBH)
   - **Clock with 5 ppm** (suggested by CDS)
   - **SPI speed** (suggested by UBH)
5. **Setup Time of IHP Chip** (suggested by UBH)
6. **Multiple Sensor Nodes** (suggested by UBH &CDS)
7. **Application of Redundancy (**suggested by UBH)
8. **Interrupt handling** (suggested by CDS)
9. **DWM3000 official driver issues** (suggested by CDS)
10. **Work package for IHP and DW interoperability** (suggested by CDS)
11. **Sensor Board Redesign for more precise acceleration measurement** (suggested by UBH)

Higher Avionic Level Interface

- Early targeted with TTE Ethernet but replaced with Light-Weight Internet Protocol Ethernet for the unavailability of the higher avionic level

- Recommendation: more compatible deterministic Ethernet, e.g. Time-Sensitive Networking (TSN)

Maximizing Sample Rate

- **Sample Size Reduction**
  - Concurrent interrupts prevents further data compression
  - Possible solution is utilizing the two core of the microprocessor to manage the MAC layer and the application processor, instead of being managed by one core.
- **RF Throughout Boost**
  - Shorter super frame by shorter time-slot
  - Configurable allocation scheme for uplink and downlink slots
  - Boosting the RF Throughout will also improve the Data Latency

Maximizing Time-Stamping Accuracy

- Precision Time Protocol
- System clock with better frequency tolerance (5ppm)
- SPI speed improvement

Setup Time of IHP Chip

- Shorter setup time allows for a faster SPI transactions
- Setup time of 14 ns allowed maximum of 12.5 MHz for DW3000

Multiple Sensor Nodes

- The planned design for the Application and MAC layers support multiple Sensor Nodes
- However, the current implementation of the MAC supports peer to peer communication

Application of Redundancy

- For safety and reliability purposes, It could be beneficial to have redundant SNs
- Redundant SNs could introduce more latencies and reduce sample rate supported by the Wireless link
- Solution: WSN performance can be maintained if the several UWB channels (redundant channels)

Interrupt handling

- Current DW3000 driver and its lower SPI driver relies heavily on polling to check the status of the chip
- Requires separating the MAC layer from the Application processor and utilizing the two cores of the microprocessor

Work package for IHP and DW interoperability

- If some applications are foreseen where the DWM3000 device and IHP UWB chip coexist, the interoperability between these two devices will be then desired

Sensor Board Redesign for Better Acceleration measurements

- The acceleration sensor has an internal fixed sampling rate of 26667 samples/s or 37.5 µs sampling period.

- Since the sampling rate of the sensor is fixed, the may have inaccurate time-stamps up to 37.5 us

- The redesign will utilize a signal line from the sensor to accurately time-stamp the measurements

- The redesign may only be needed if the same sensor IIS3WB is planned for the future use

The End

Thank You!