



SENS4ICE

SENSORS AND CERTIFIABLE HYBRID ARCHITECTURES
FOR SAFER AVIATION IN ICING ENVIRONMENT

LILD – Local Ice Layer Detector

International Workshop on Atmospheric Icing of Structures (IWAIS) 2022

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Why Icing sensors?

- 💧 Ice accretion is always a risk in aviation
- 💧 Weather forecasts do not always correctly predict icing conditions
- 💧 Small and medium sized aircraft most prone due to lack of powerful deicing
- 💧 German Federal Bureau of Aircraft Accident Investigation (BFU):
 - 💧 15.02.2013 EMB500: Accident because Deicing system was not active
 - 💧 14.12.2017 Cessna 510: Loss of control on final approach
 - 💧 08.08.2017 PA46: Loss of control in icing and turbulence over Bodensee
- 💧 Sensing ice accretion could prevent accidents by activating deicing systems or evading icing conditions
- 💧 Small and low cost sensor especially suited for small and medium sized aircraft
- 💧 Applicability at icing prone surfaces is advantageous



Source: AOPA

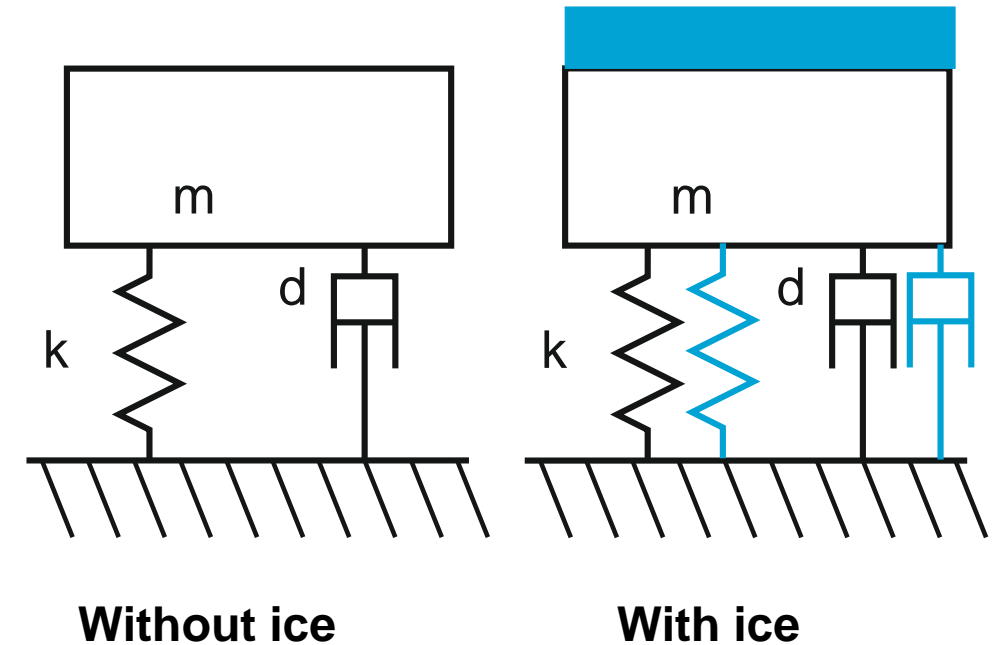
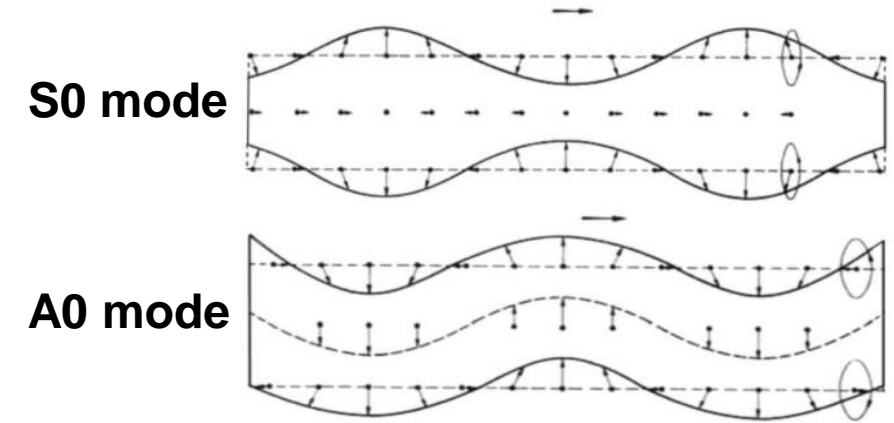


Source: BFU



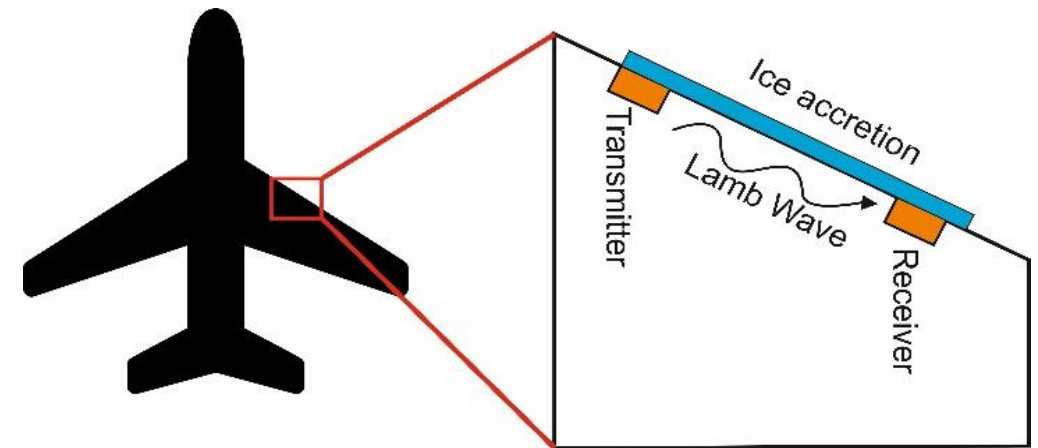
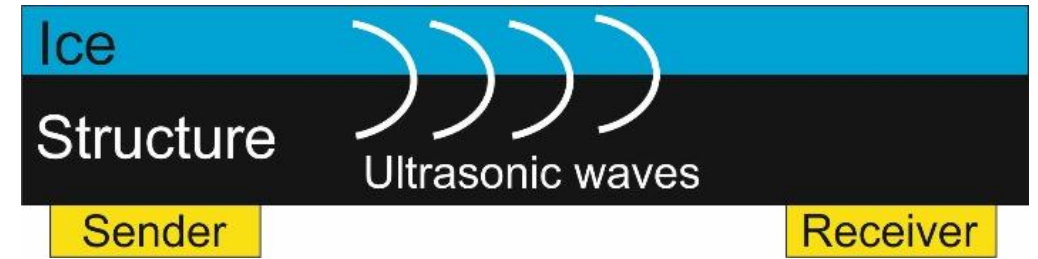
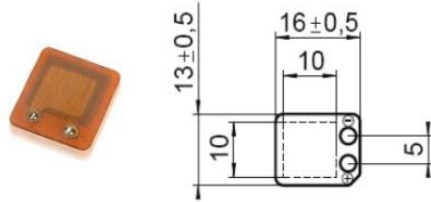
The Local Ice Layer Detector (LILD) principle

- Ultrasonic structure borne sound (lamb waves) can travel through panel structures
- Transmission behavior of ultrasonic lamb waves in aircraft outside panels changes with the presence of ice
- Ice accretion affects damping, stiffness and mass of panel structure
 - Amplitude and Group velocity of lamb wave are altered with presence of ice



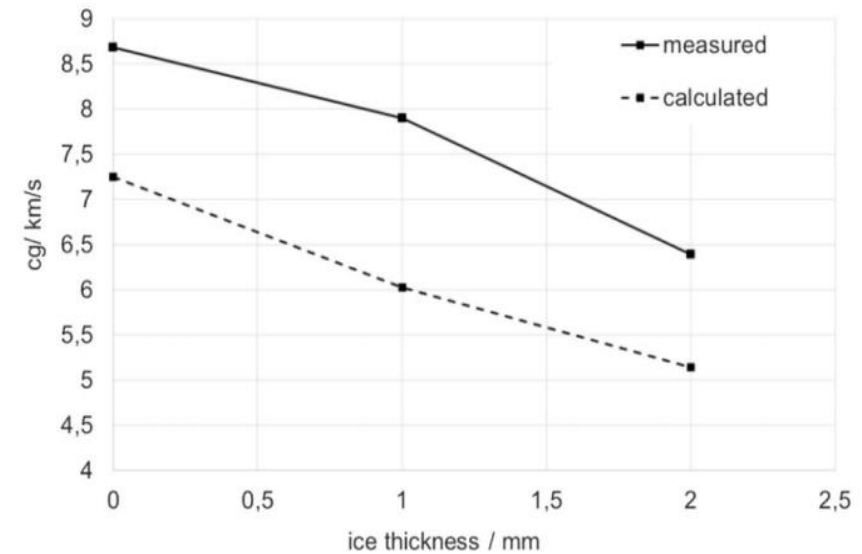
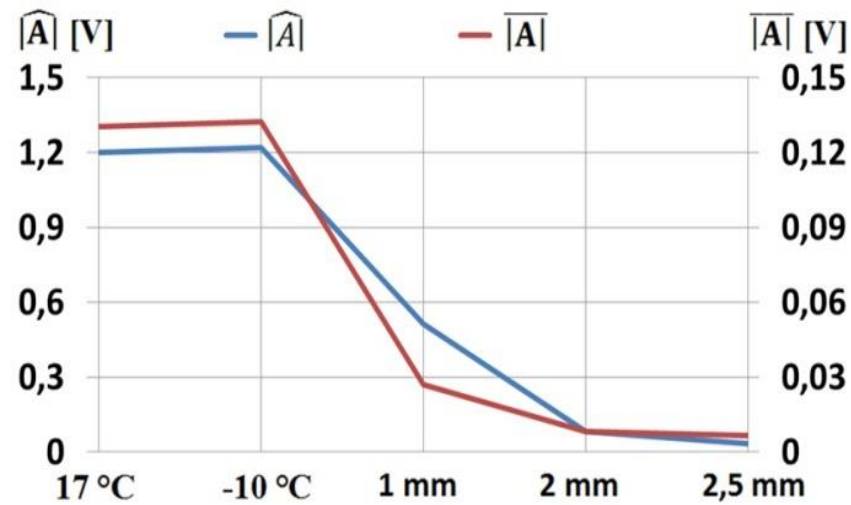
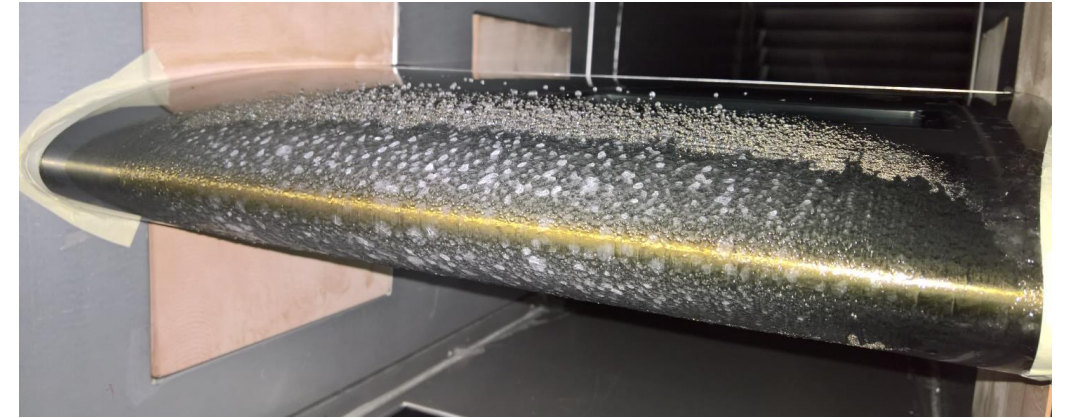
How to build a LILD sensor

- 💧 Application of piezoelectric transducers on the back side of icing prone structure as transmitter and receiver
- 💧 Transducer small in size
- 💧 Aircraft structure acts as wave guide
- 💧 Distance between transmitter and receiver approx. 30-50cm
- 💧 Sensor can be applied on leading edges of wings, empennage or other icing prone surfaces



How to build a LILD sensor

- 💧 Preliminary investigations of LILD principle by Christian Mendig
- 💧 Ice layer reduces amplitude and group velocity of lamb waves



Developing LILD Sensor in SENS4ICE

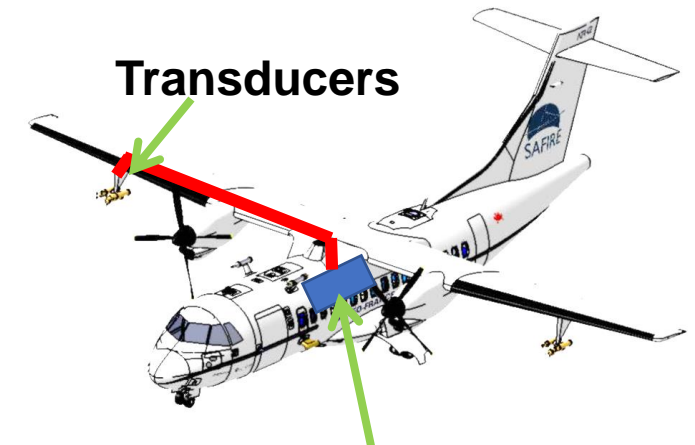
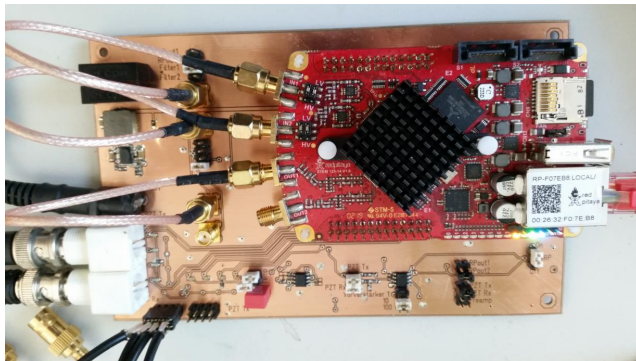
Miniturization and development of flight test capable sensor electronics

Icing wind tunnel tests

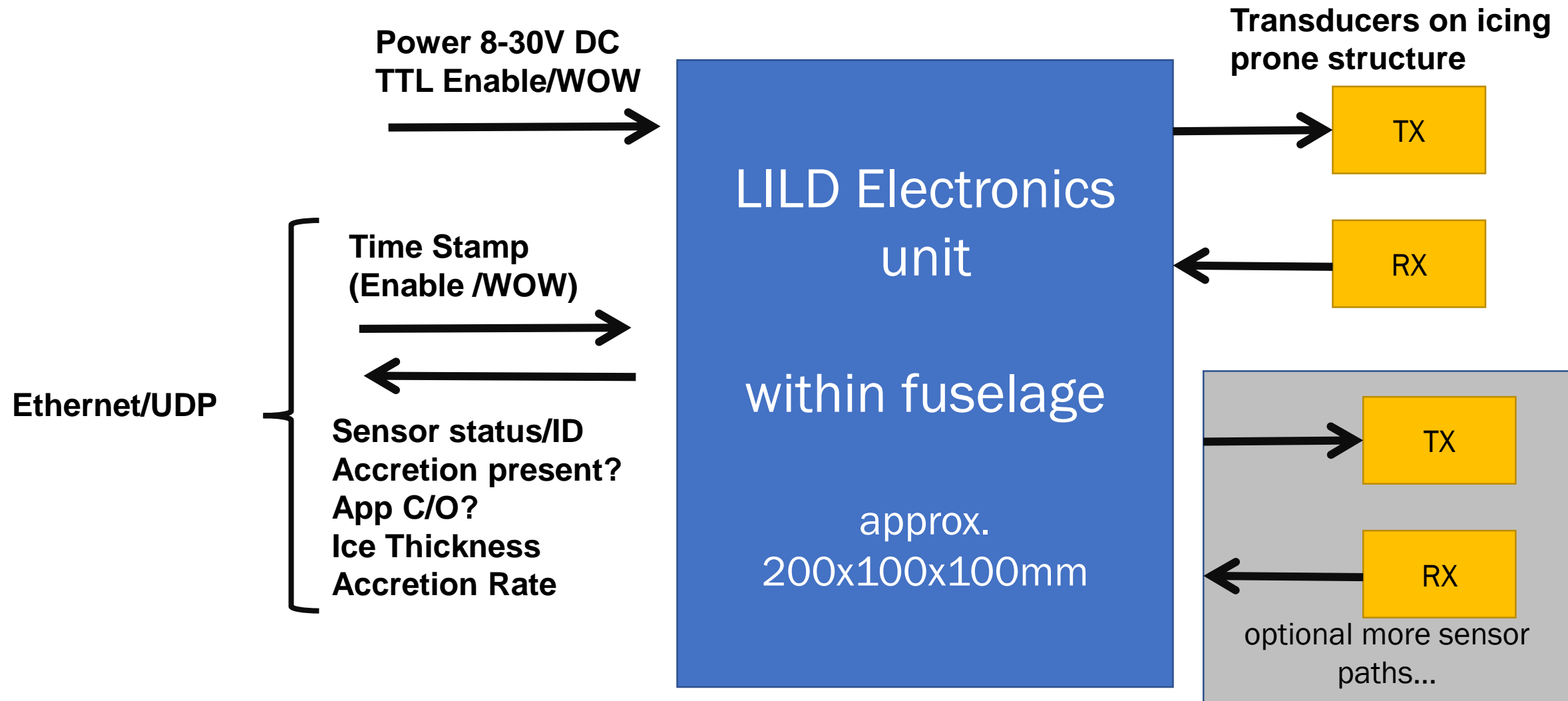
- Pretests at TU Braunschweig IAF facility
- Final test at TU Braunschweig ISM

Flight Test

- Safire ATR42
- Planned for 2023

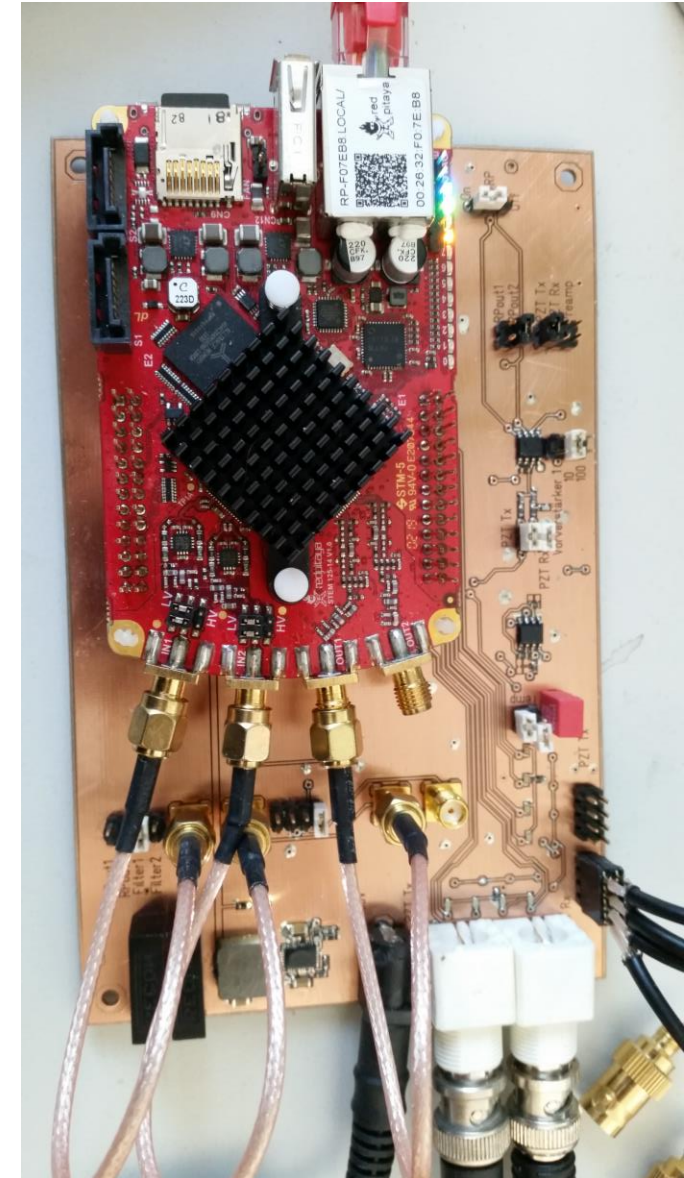


Overview of LILD sensor electronics



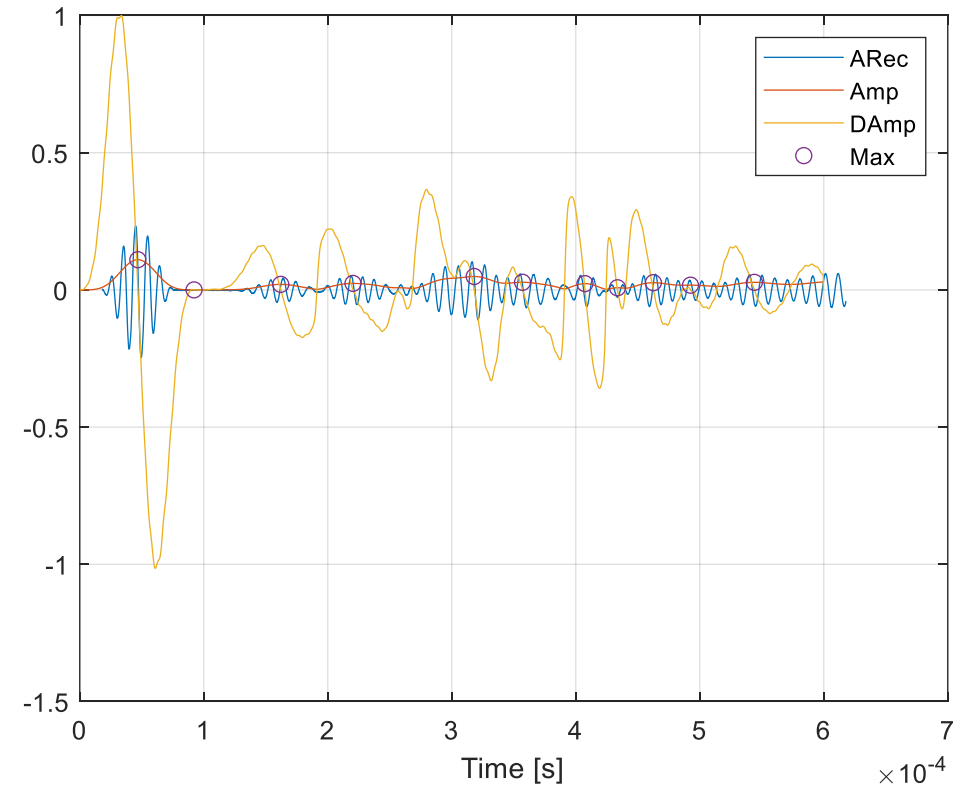
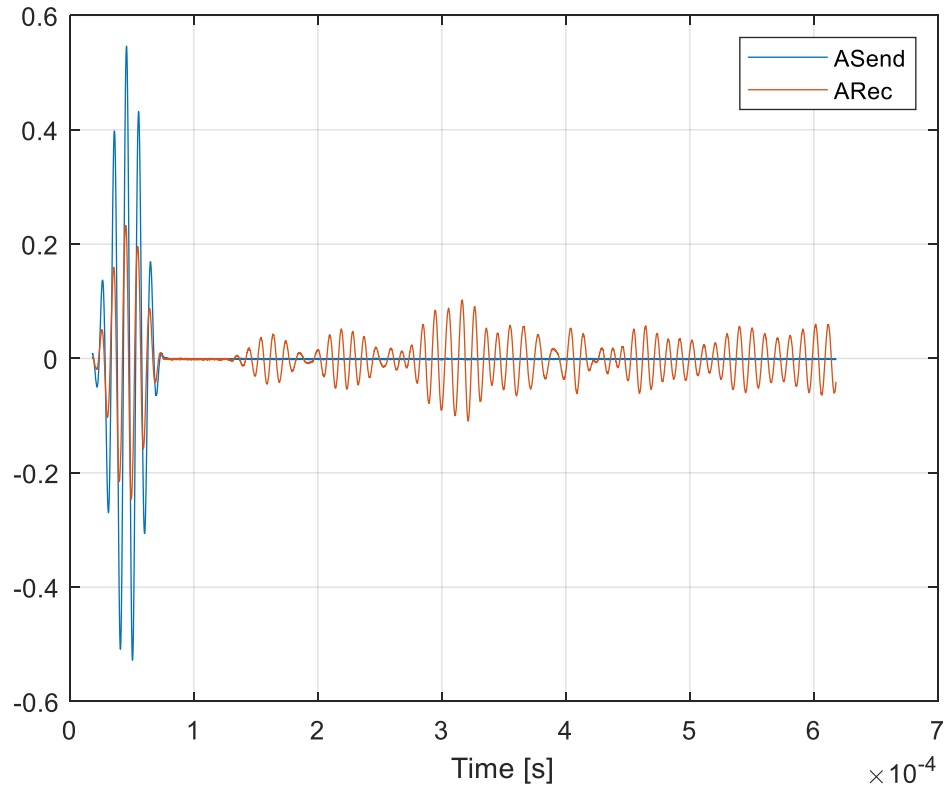
LILD Electronics characteristics

- 💧 Xilinx ZYNQ XC7Z01 FPGA and dual core microcontroller for signal acquisition and generation
- 💧 Output amplifier for max. 15V amplitude of lamb waves up to 1MHz
- 💧 Input bandpass filter 30kHz to 1MHz
- 💧 Sampling frequencies of 16.6MHz and 1.95Mhz
- 💧 Synchronous temperature measurement at transmitter location
- 💧 Data storage on USB device
- 💧 Ethernet on board



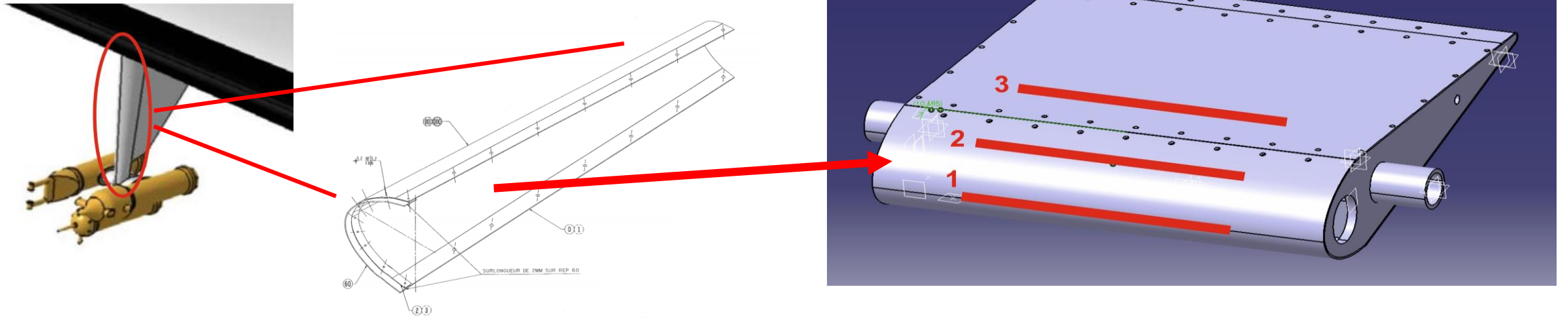
Analyzing the signals

💧 Finding the lag time and amplitude of lamb wave pulses



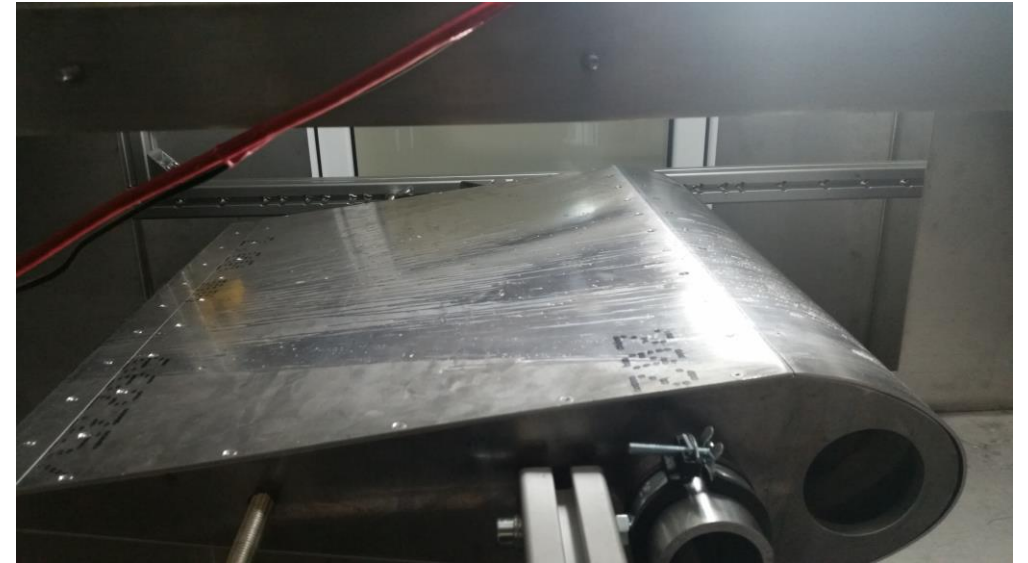
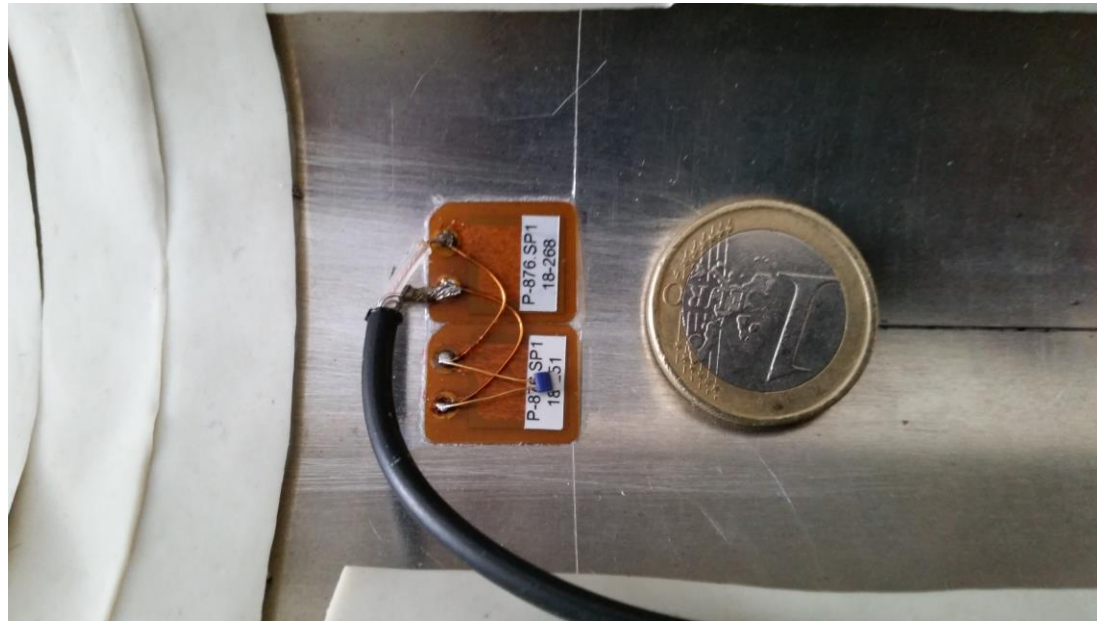
Analyzing the influence of ice on the signals

- 💧 Finding the pulses, which are susceptible to ice
- 💧 Build an airfoil demonstrator according to ATR42 pylon leading edge airfoil



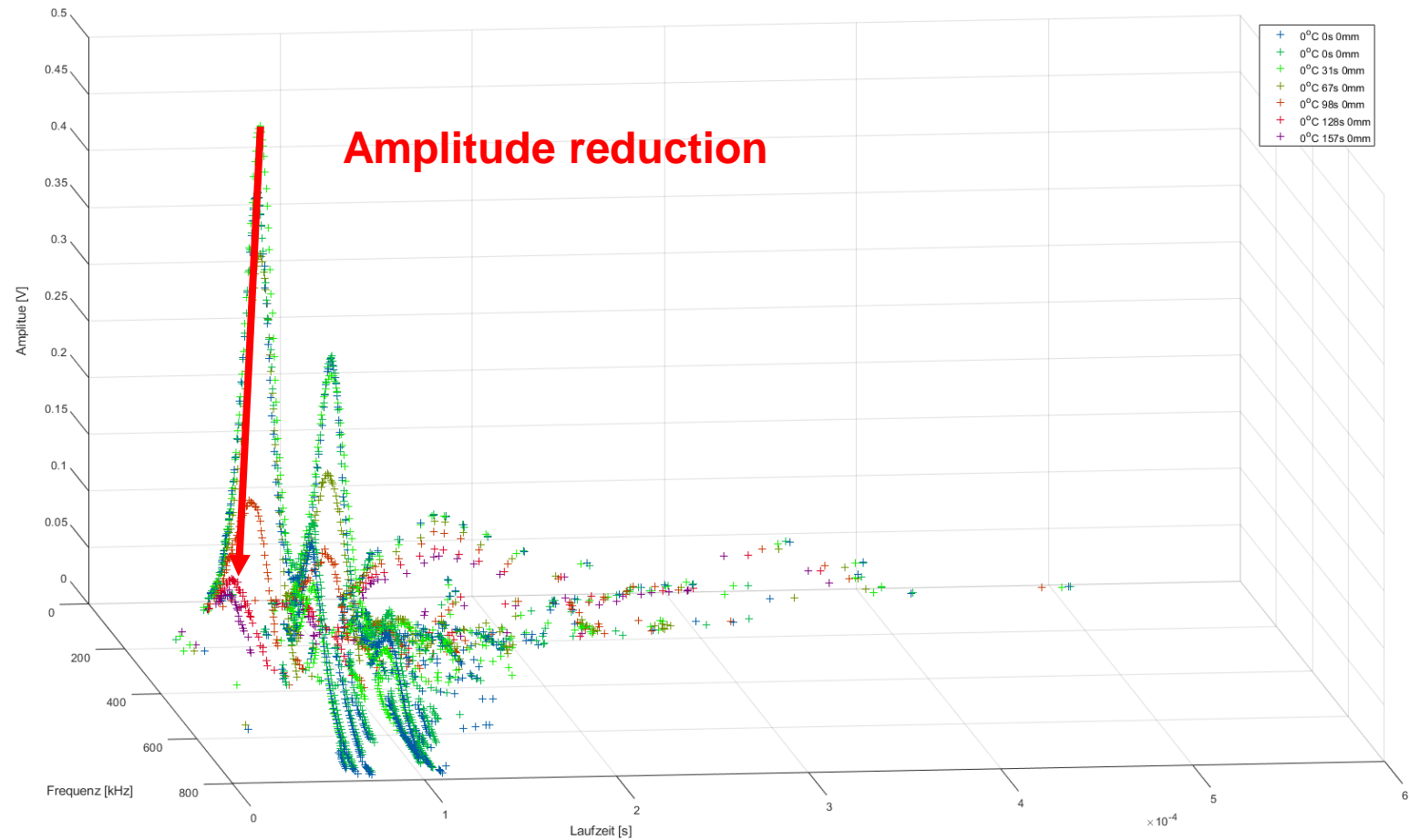
Analyzing the influence of ice on the signals

- 💧 Finding the pulses, which are susceptible to ice
- 💧 Build and airfoil demonstrator
- 💧 Application of piezoelectric transducers



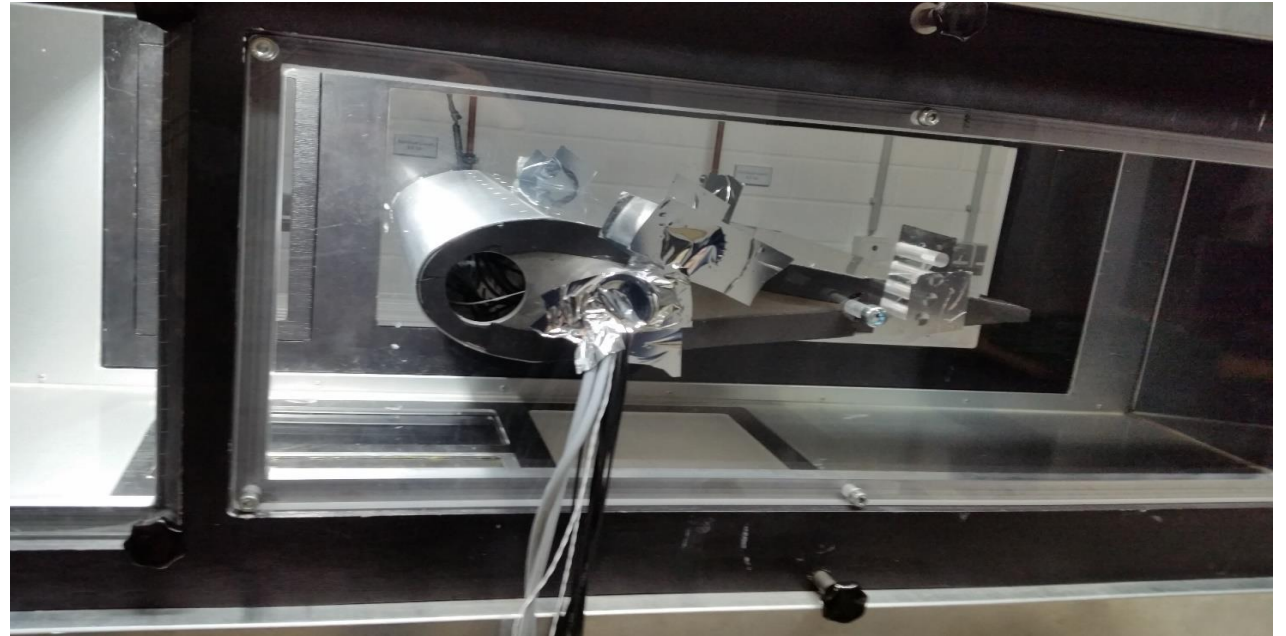
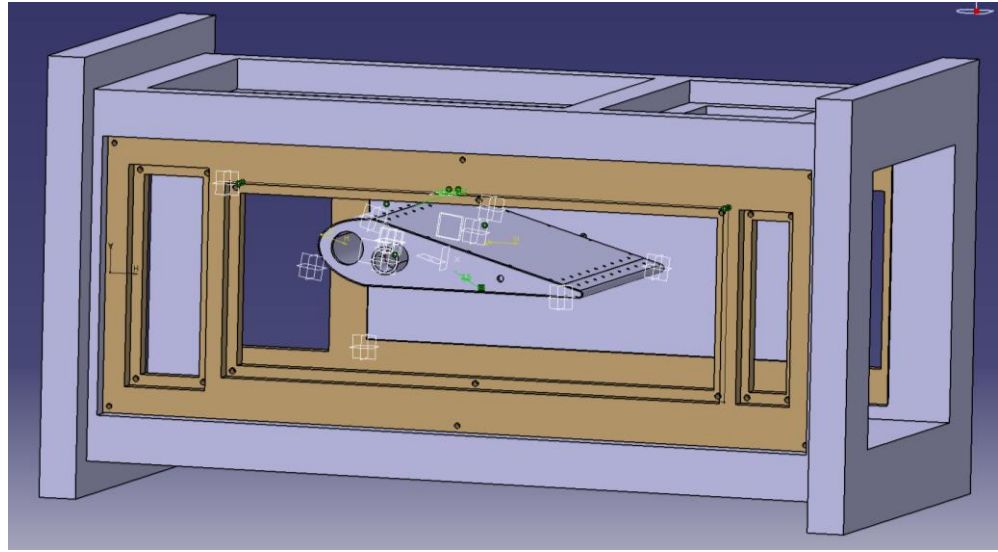
Analyzing the influence of ice on the signals

- 💧 Finding the pulses, which are susceptible to ice
- 💧 Frequency sweep
- 💧 30s ice accretion
- 💧 Ice layer reduces amplitude



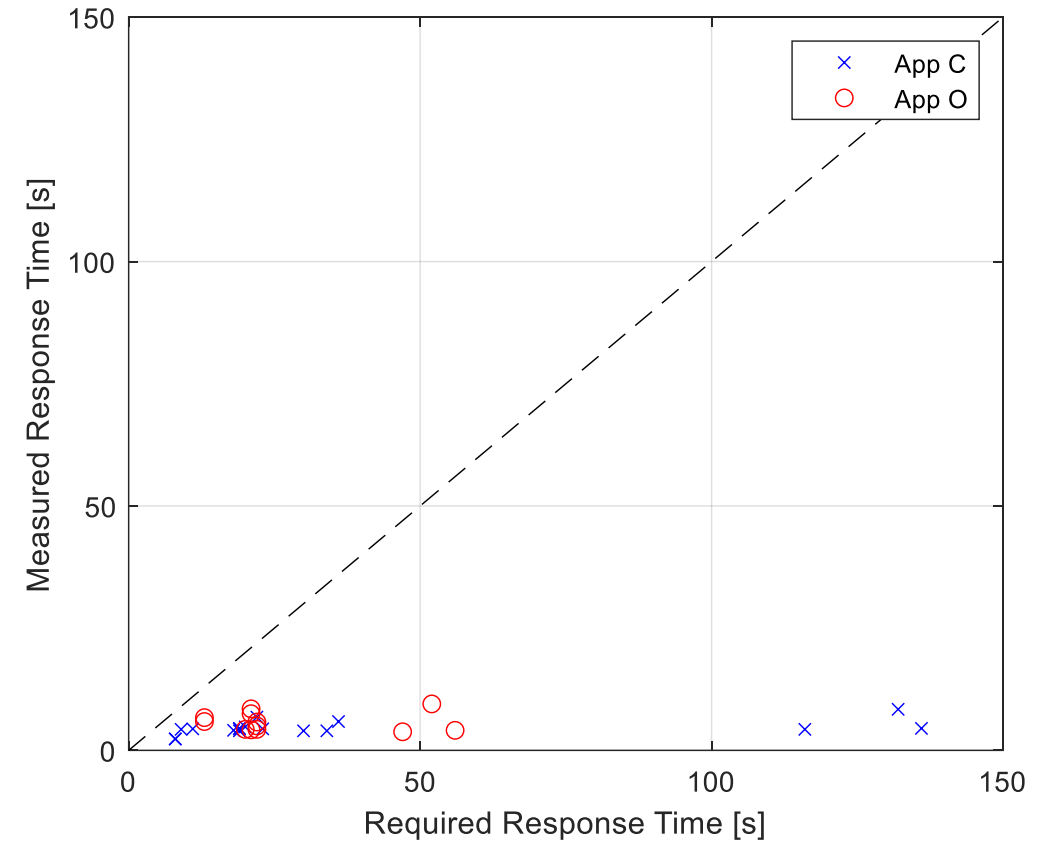
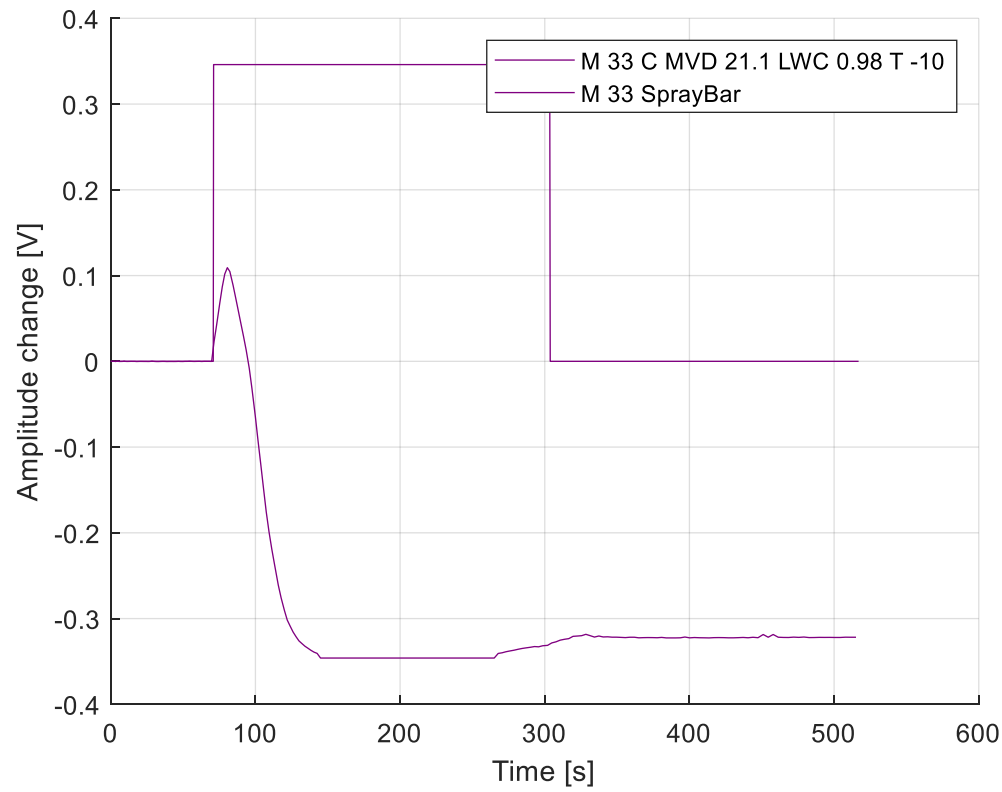
IWT test at TU BS ISM tunnel

- 💧 Fitting the demonstrator to the tunnel
- 💧 Plexiglass side panels
- 💧 1min dry time, maximum response time + 2min icing cloud, 3min dry
- 💧 17 App C and 20 App O test cases measured between -2°C and -20°C



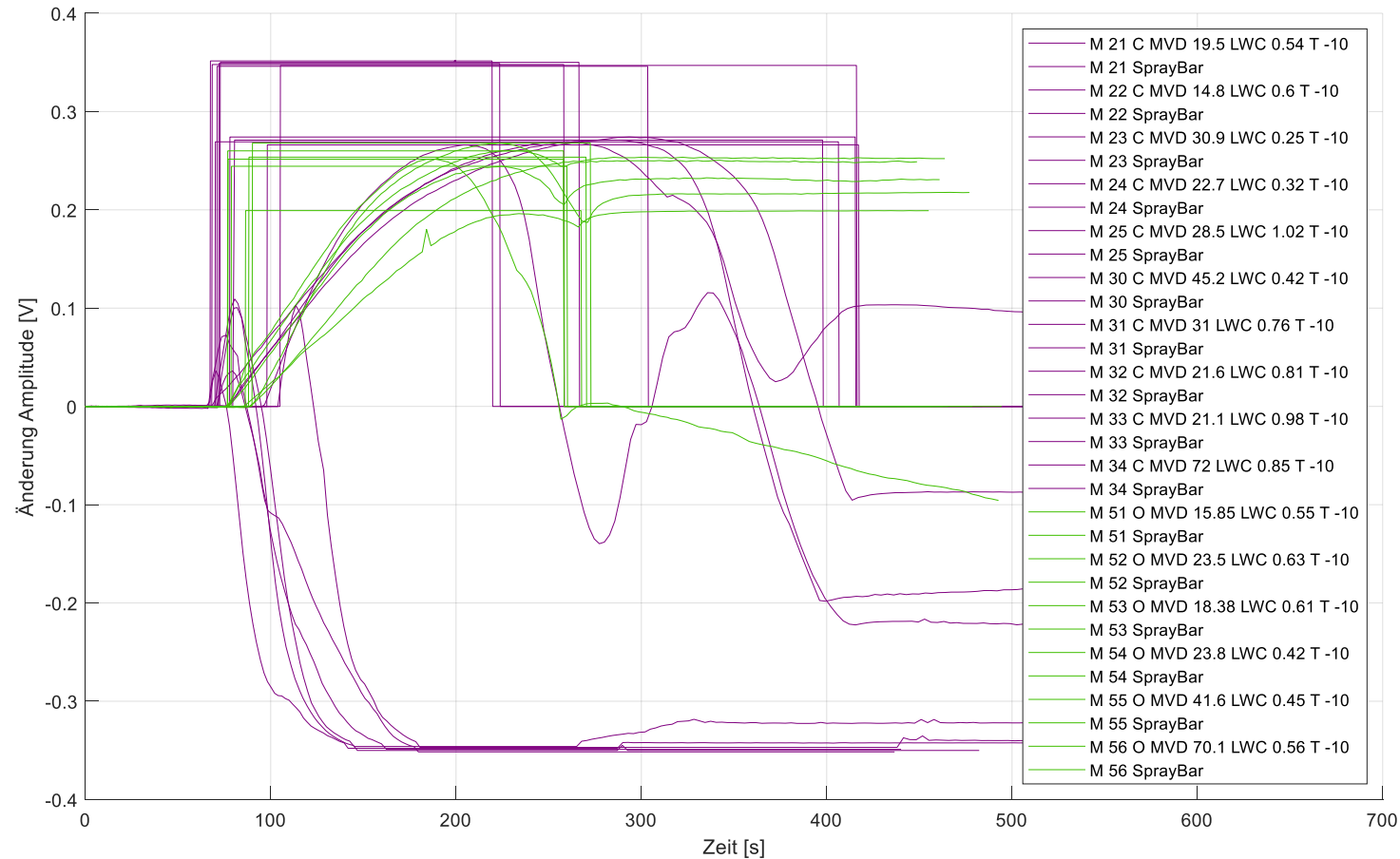
IWT test at TU BS ISM tunnel

- 💧 Response time is very low
- 💧 Amplitude changes instantly with ice accretion when airfoil is clean before

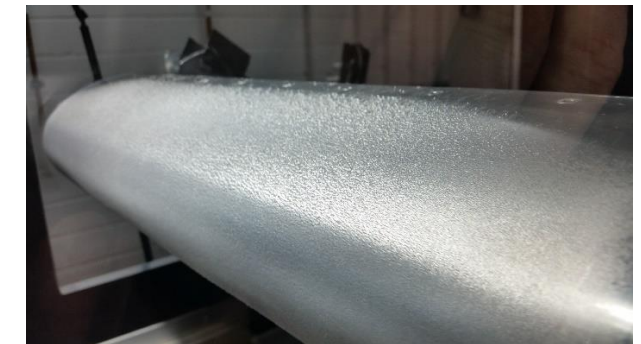


IWT at TU BS ISM tunnel

- 💧 No significant difference in amplitude change between App C and App O
- 💧 Amplitude may increase or decrease with ice accretion



App C MVD 45.2μm
LWC 0.42g/m³ -10°C

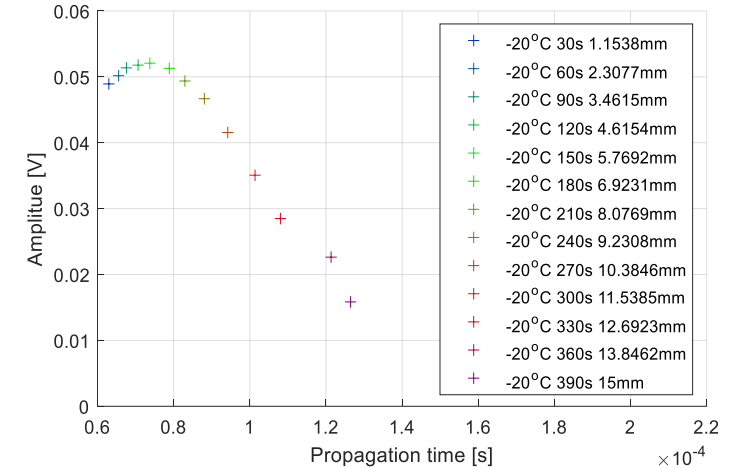


App O MVD 41.6μm
LWC 0.45 g/m³ -10°C

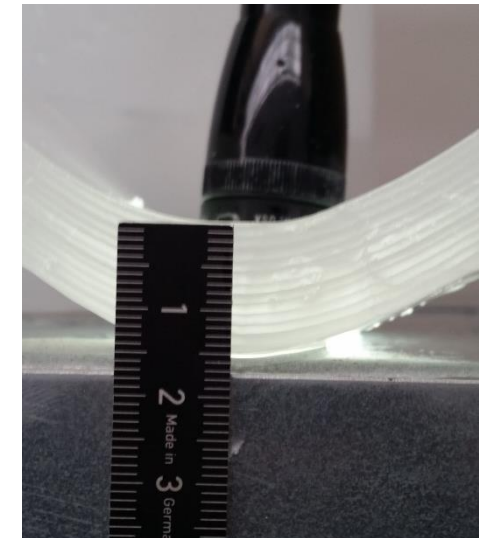


Conclusion IWT test

- 💧 Detection times for beginning ice accretion on clean airfoil are very short in the range of less than 10s for all test points
- 💧 Detection of end of positive ice layer growth or new ice layer growth with already present ice requires more time up to 1min
- 💧 Ice layers have been detected from <0.3mm up to 15mm
- 💧 With the tested App C and App O points, no significant differences in the measured signal were visible with the tested sensor setup and detection algorithms
 - 💧 Ice accretion for similar conditions (temperature, LWC, MVD) was comparable between App C and App O in TU BS IWT test
 - 💧 Ice accretion chord was more influenced by LWC and temperature than droplet size

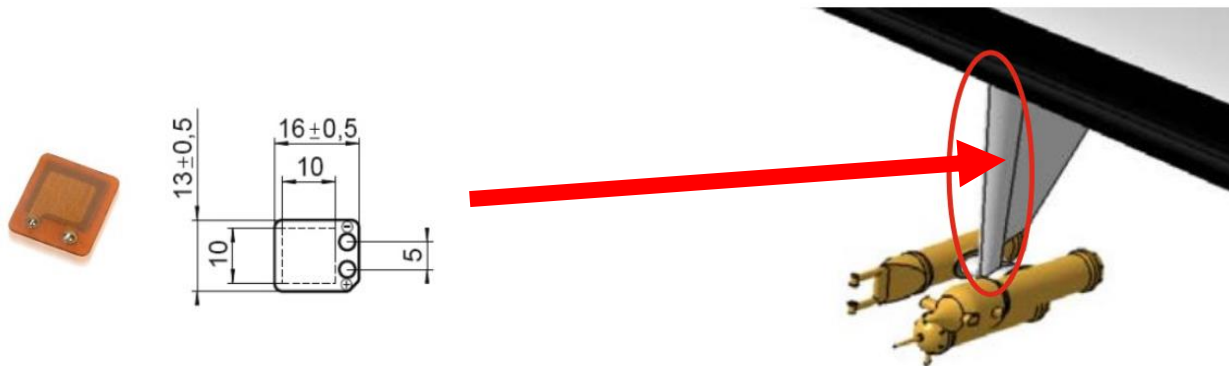
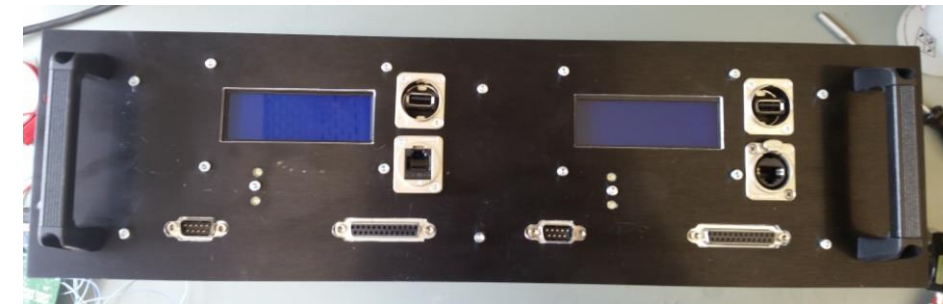
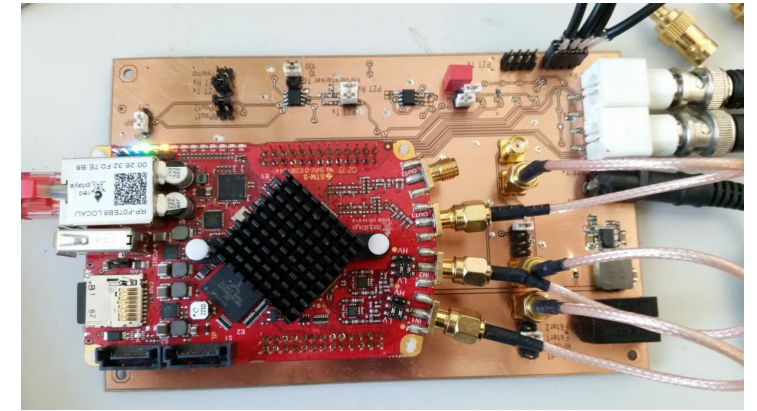


Signals with up to 15mm ice layer
(demonstrated in pretests)



LILD – next steps

- 💧 Design and fabrication of flight test electronics
 - 💧 Addition of user interface with status supervision and display, real time clock, fitting to 19" rack
 - 💧 Firmware adaptation for online ice detection and data storage
 - 💧 Ethernet interface programming for data exchange with aircraft and hybrid system
- 💧 Instrumentation of ATR42 pylon leading edge
- 💧 Characterization of wave transmission behavior of pylon leading edge
- 💧 Flight test in 2023 😊



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