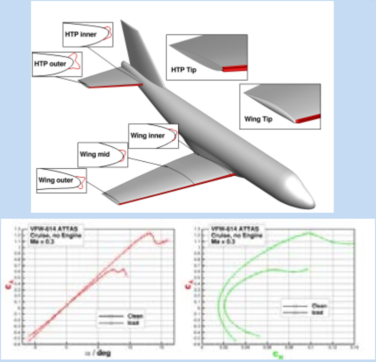
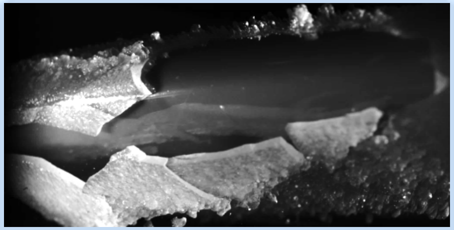


CFD Simulations
(DLR AS, J. Steiner & T. Kilian)

Icing Wind Tunnel
(TUBS ISM, S. Bansmer)

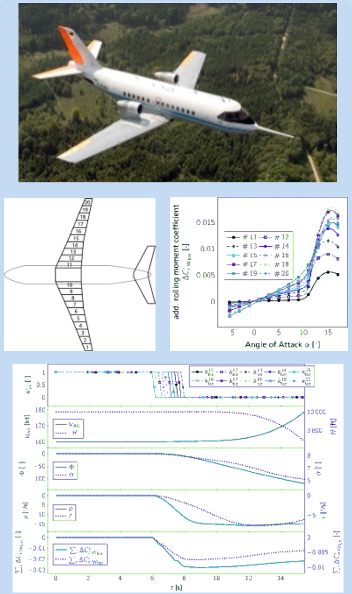


Low Frequency De-Icing
(TUBS IAF, M. Endres)

SuLaDI

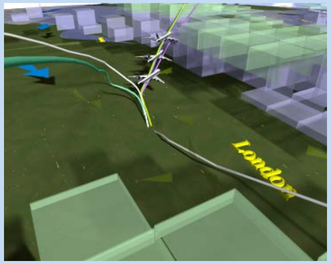
Supercooled Large Droplets Icing

Electro Impulse De-Icing
(TUBS IFL, H. Sommerwerk)



Flight Dynamics & Control
(DLR FT, C. Deiler)

AVES (Air Vehicle Simulator)



Flight Guidance
(DLR FL, A. Kuenz)

DLRK 2016 - ICE DETECTION BY MECHANICAL WAVES

Excitation of guided waves and sine sweep – Experiments on a NACA0012 - profile from CFC

Motivation/Advantages over the state of art

- Ice detection at the place of generation

  → Information about state of airplane icing
  → Increase of safety
  → Targeted use of thermal De-Icing
  → Lower energy consumption
  → Sensor application on the inner surface of the leading edge
  → Reduced aerodynamic resistance / lower operating costs

  - Maintenance

Measurement principle

- Generation of structure-borne noise:
  - Transmitter-receiver-principle:
    1.) Excitation with a defined frequency range
    → Analysis in time and frequency domain

    2.) Excitation with a fixed frequency
    → Excitation of ultra sonic guided waves , Analysis in time domain

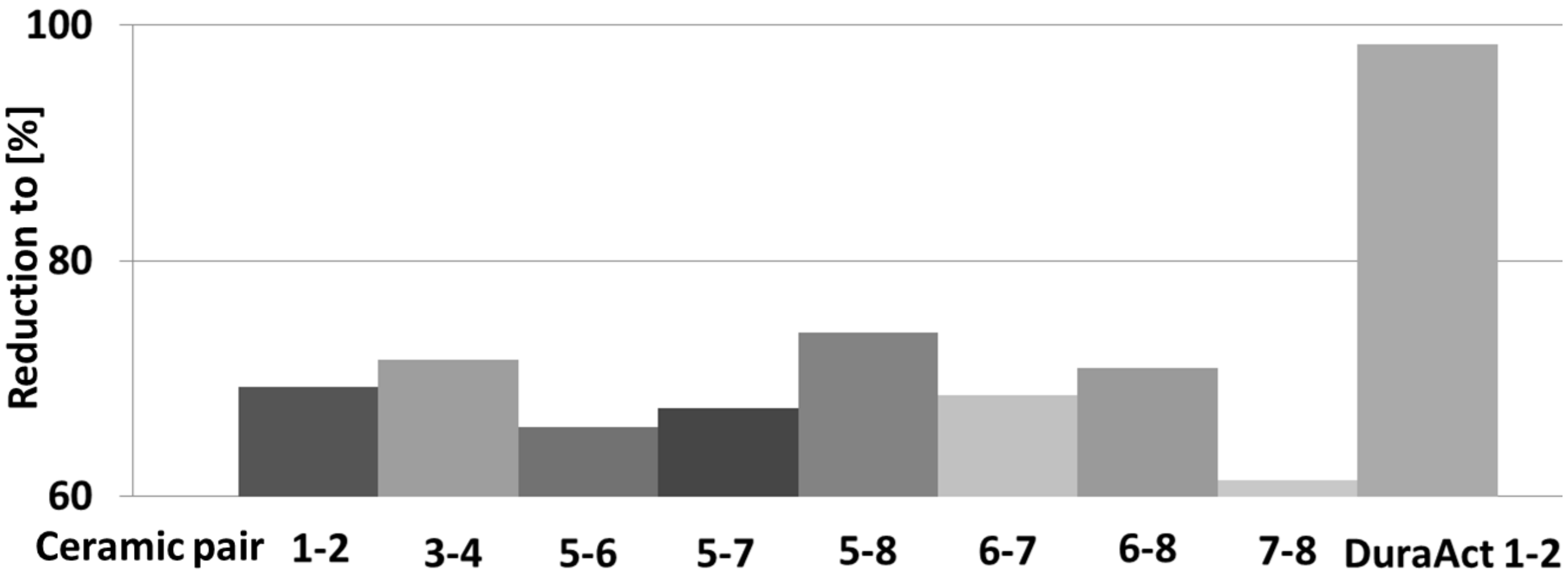
Experimental setup

- General:
  - 1 x NACA0012 – rear part from aluminium with 2 x leading edge from CFC → total lenght 1 m
  - Application with Sikomin SR 1710i / SD 8824 under vacuum
  - Electrical insulation by hot melt and influence of specimen fixing investigated beforehand

- Ultrasonic guided waves:
  - 2 x DuraAct Patch Transducer (rectangular)
  - Excitation frequency: 218 kHz, Sine
  - Cycle number: 1, 4, 10

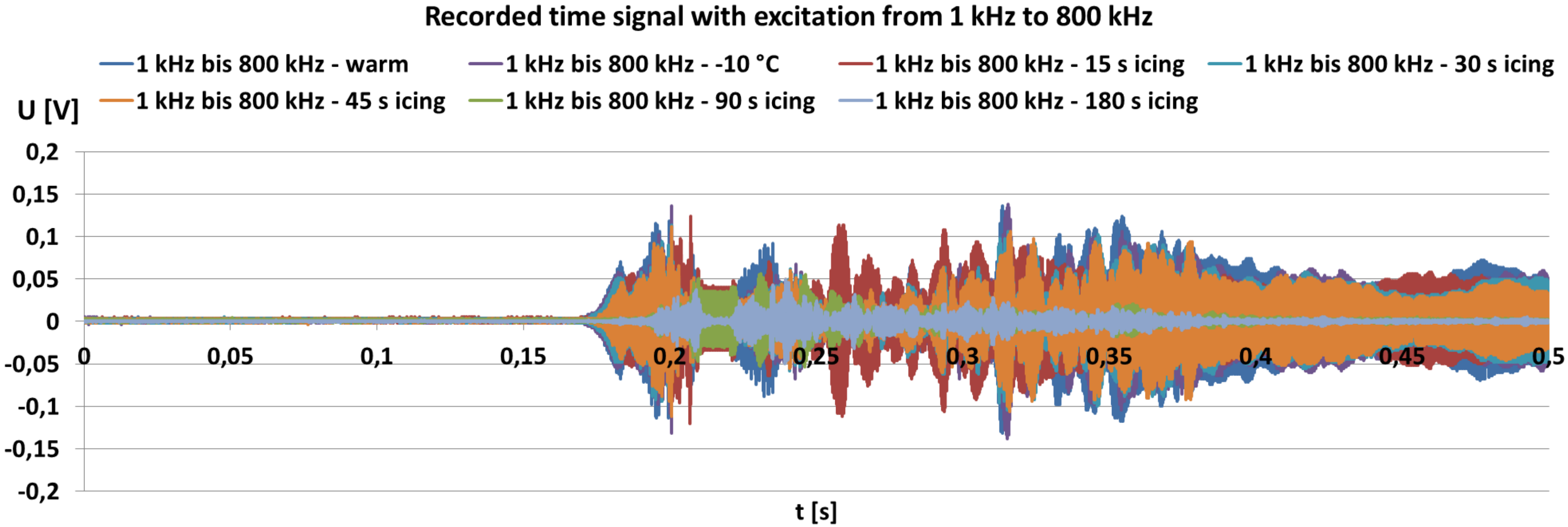
- Swept sine:
  - 8 x discs actuator (round)
  - Excitated frequency range from 1 kHz to 800 kHz

Influence of electric insulation



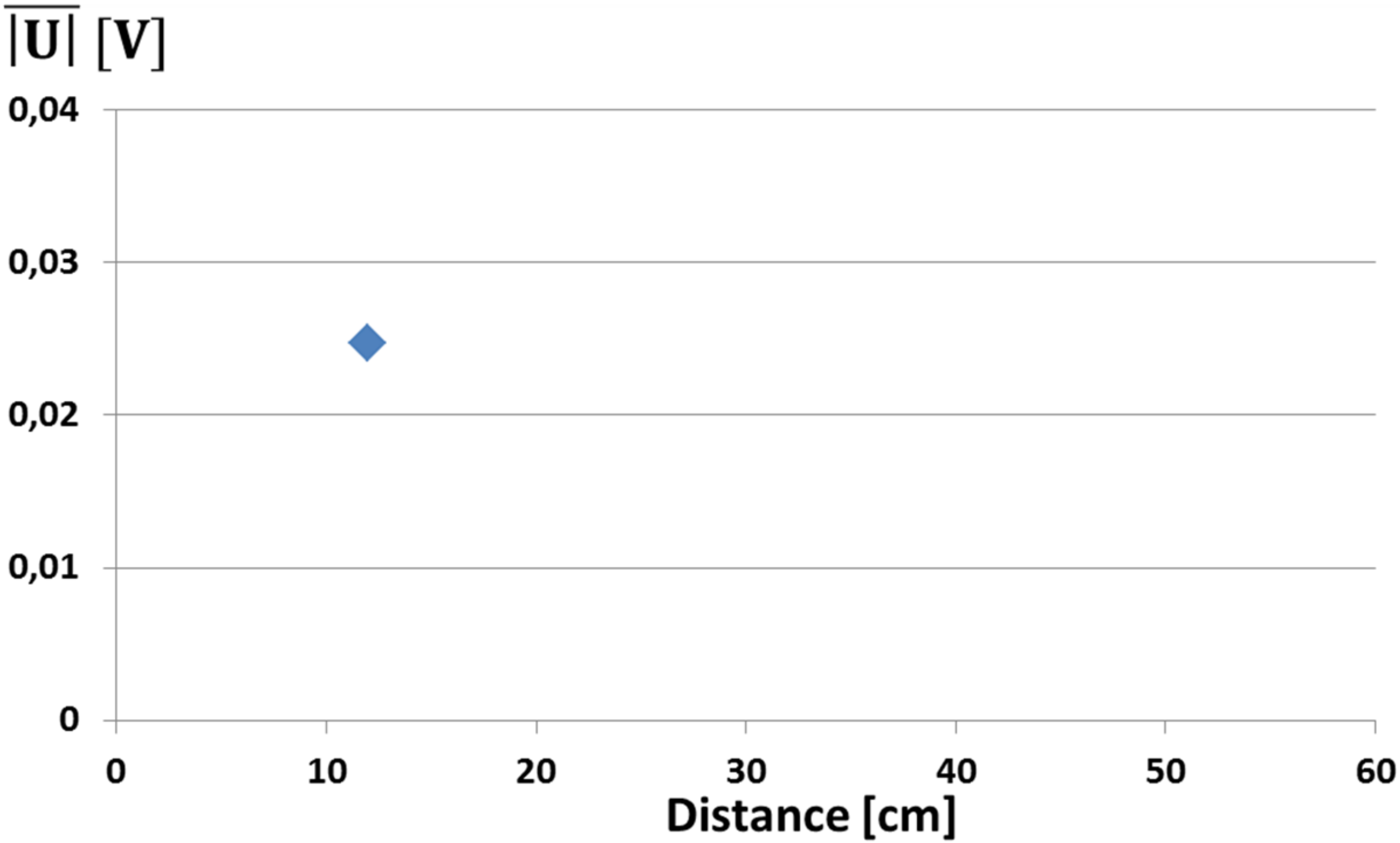
- **The diagram shows the decrease of the mean value of the absolute values.**

Examples of time signals

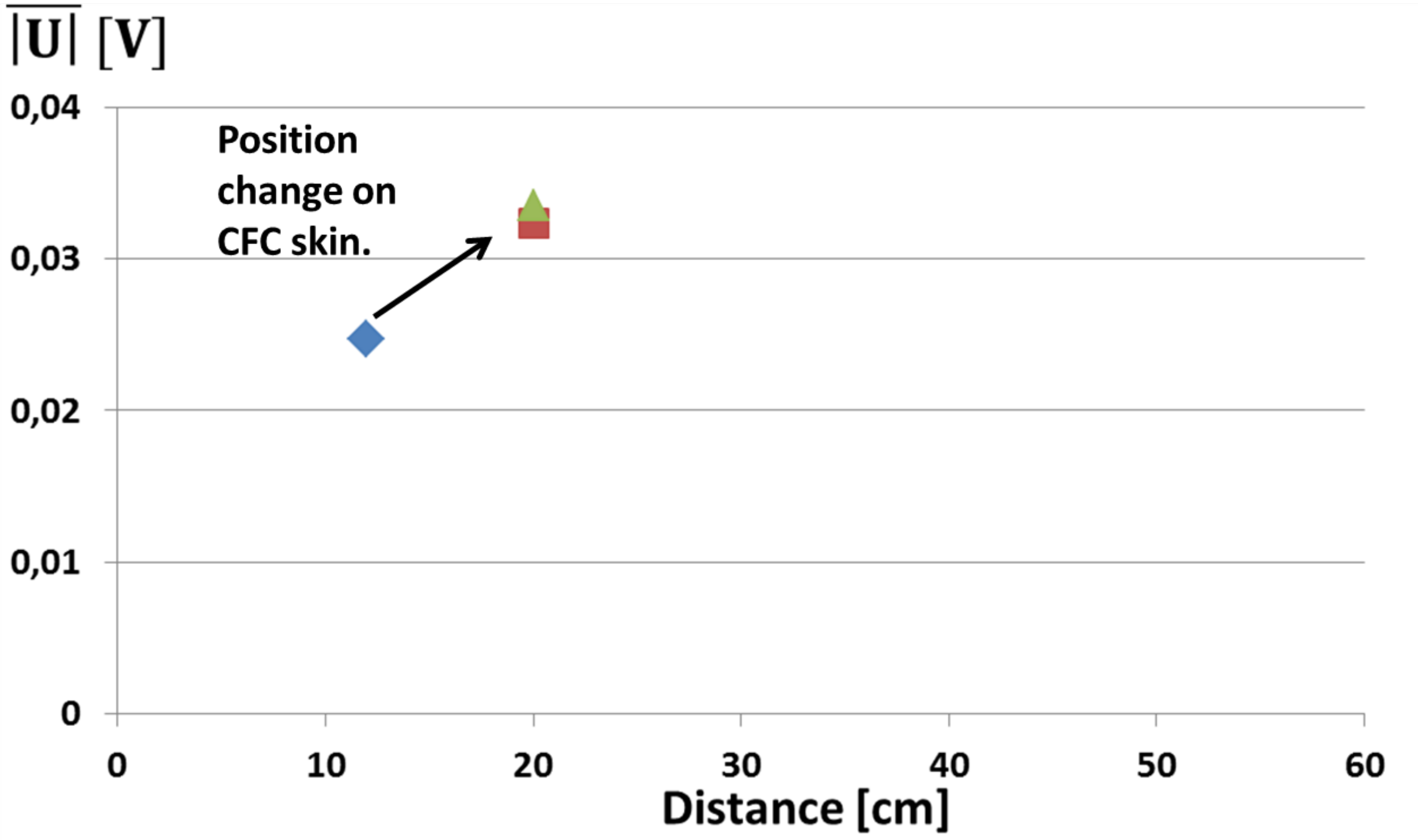


- **not every excited frequency will decrease due to ice build-up!**

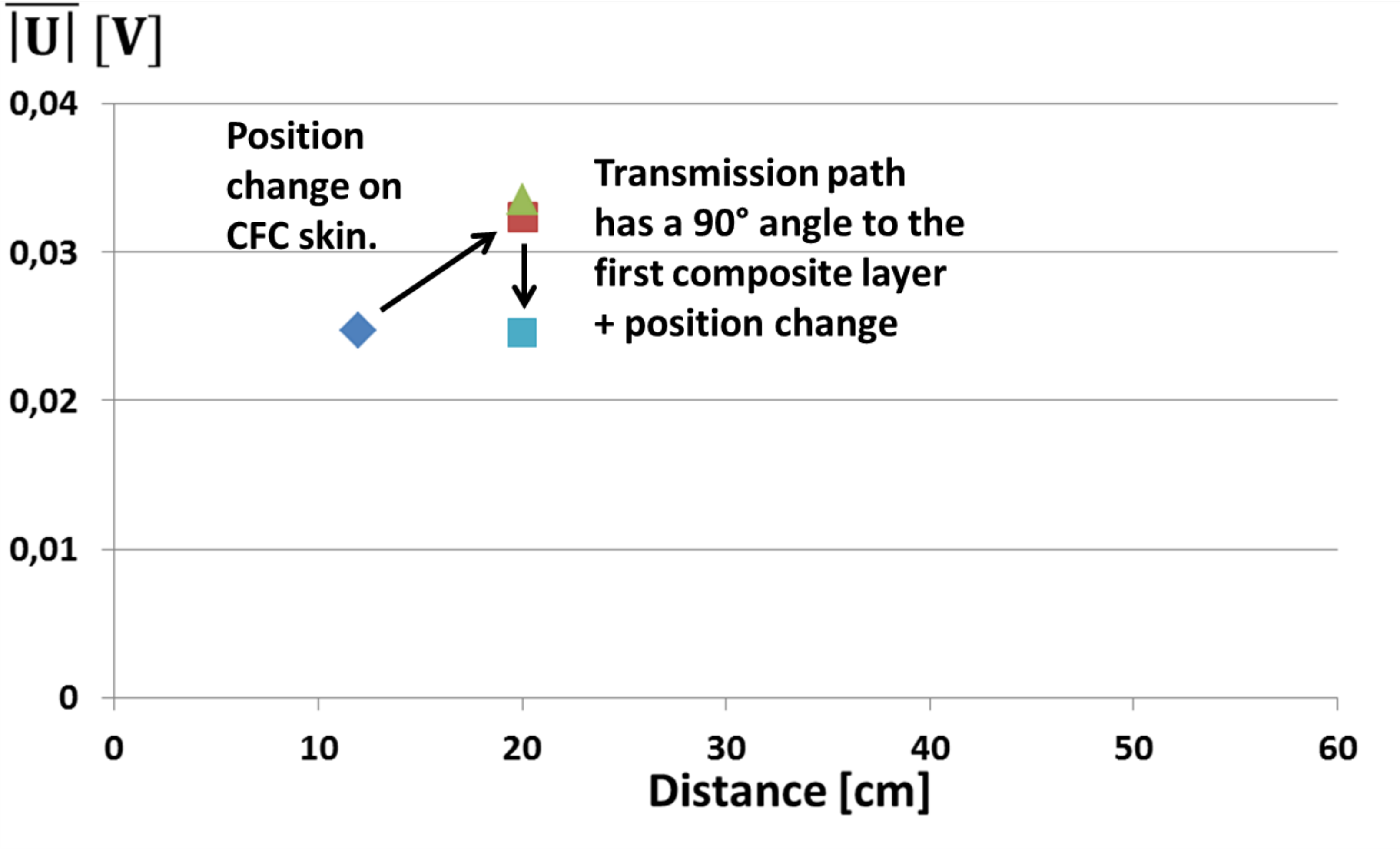
Influence of position and angle between transmission path and fibre



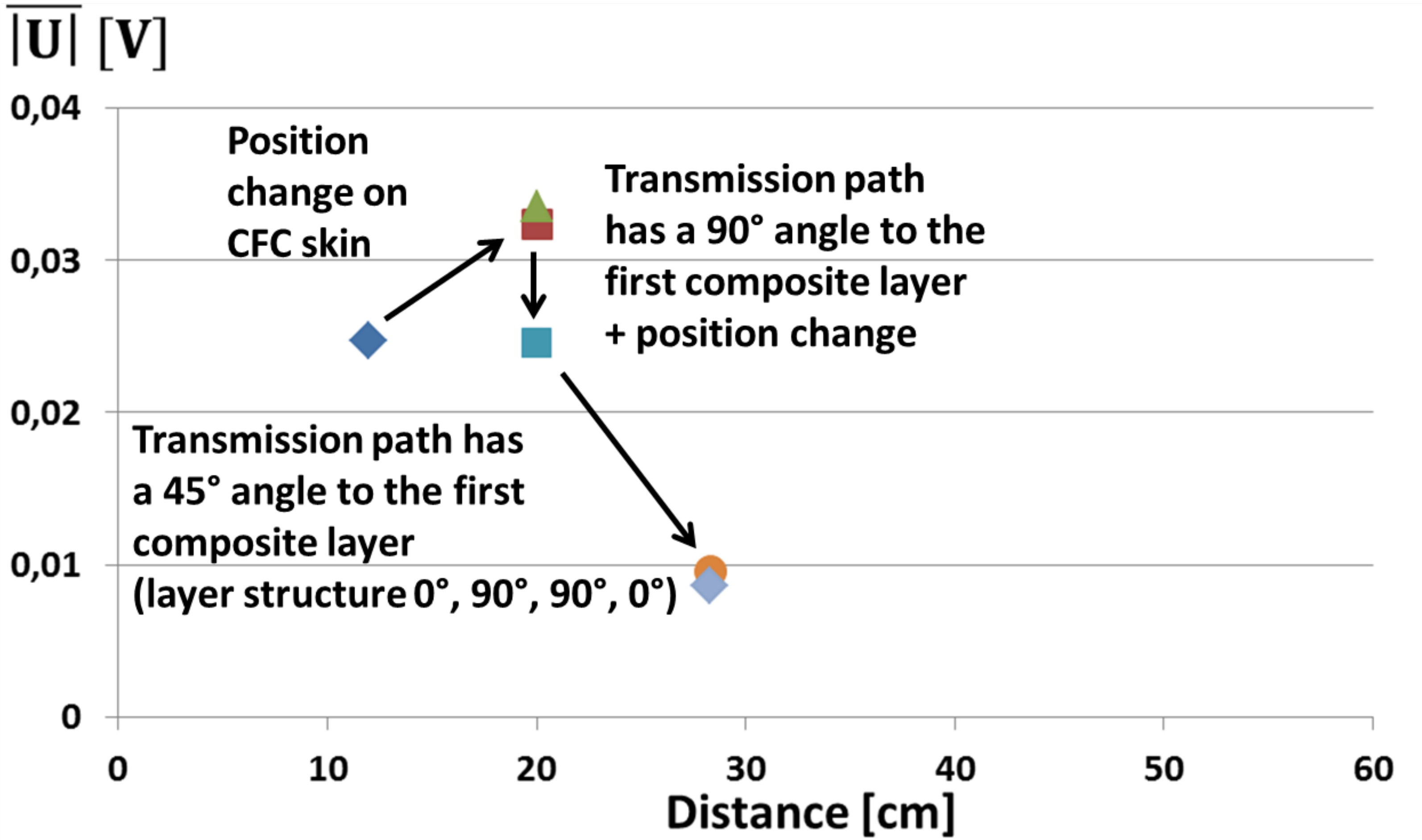
Influence of position and angle between transmission path and fibre



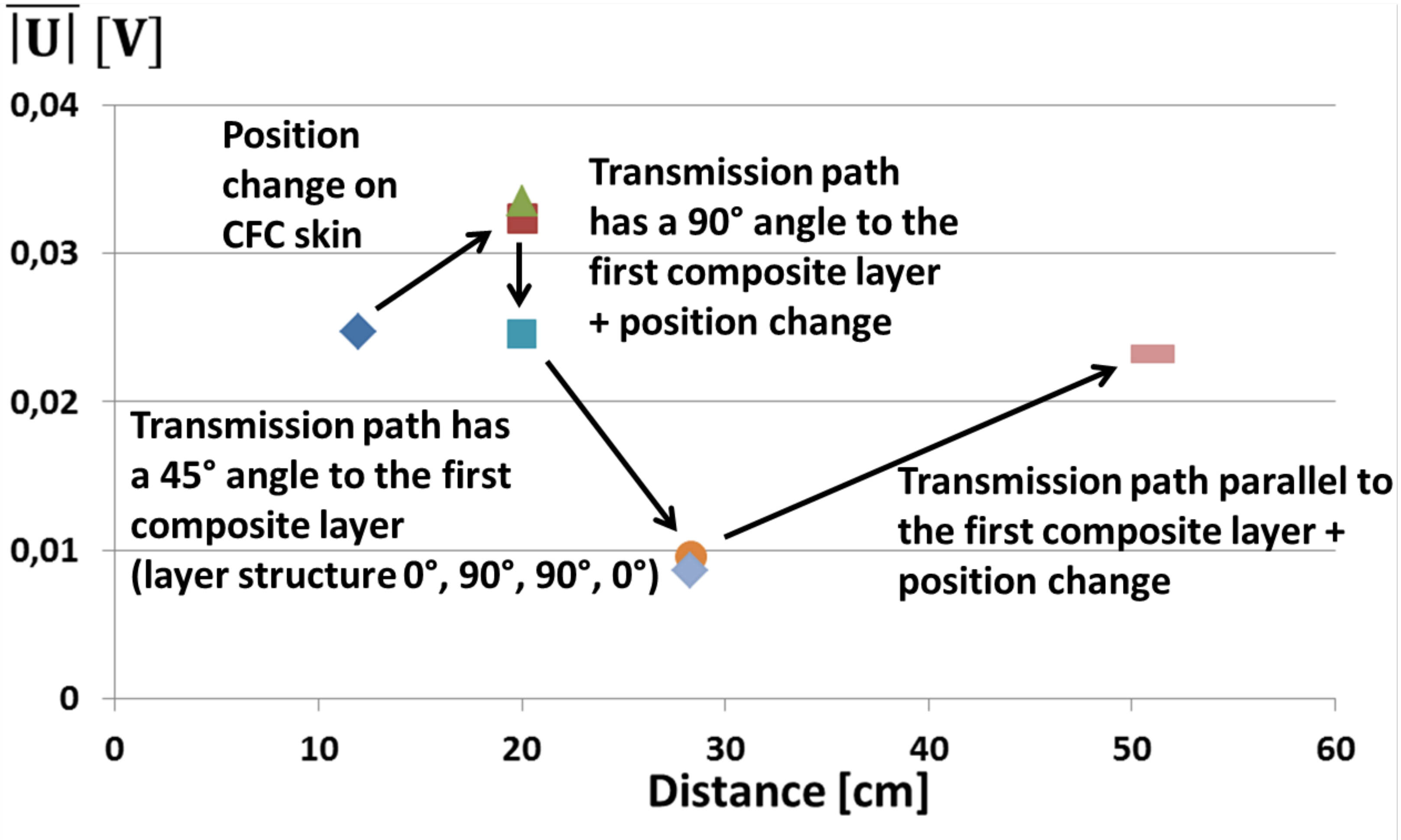
Influence of position and angle between transmission path and fibre



Influence of position and angle between transmission path and fibre



Influence of position and angle between transmission path and fibre



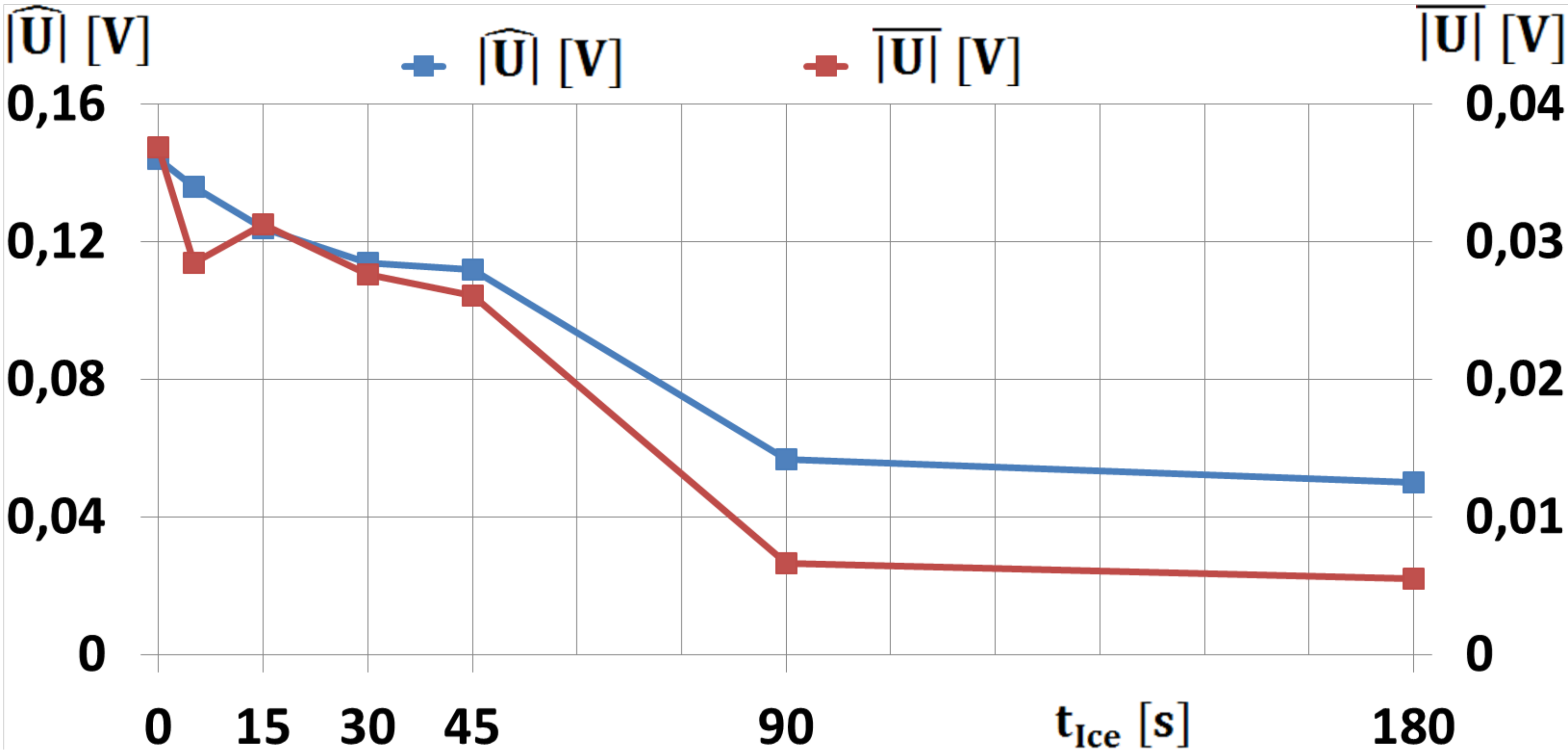
Results for the design

- A manual applied retroactive insulation leads to a significant decrease in signal amplitude!
- Attaching the leading edge to spar and ribs changes the boundary conditions and leads to further decrease in signal amplitude !
- A beforehand encapsulated piecoceramic is preferable to a piezoceramic without enclosure (smaller decrease in amplitude, no failure due to electrical connections between piezoceramic and single carbon fibres)!
- The position on the leading edge and the angle between transmission path and layer structure have even a big influence to the expecting signal amplitude !

→ Ice thickness and ice type are variing over the profil depth

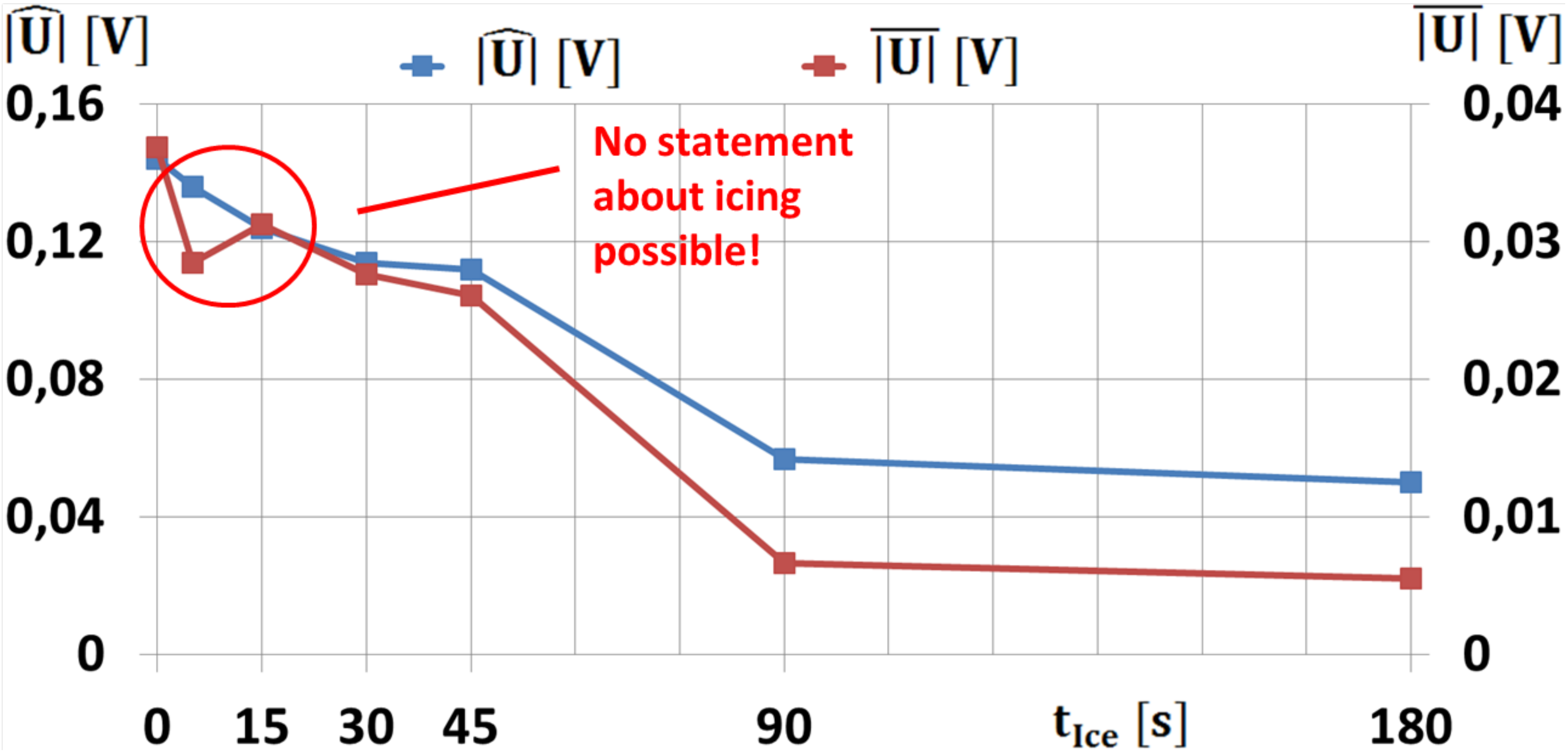
→ Ice thickness is difficult to measure

Measurements for increasing icing time



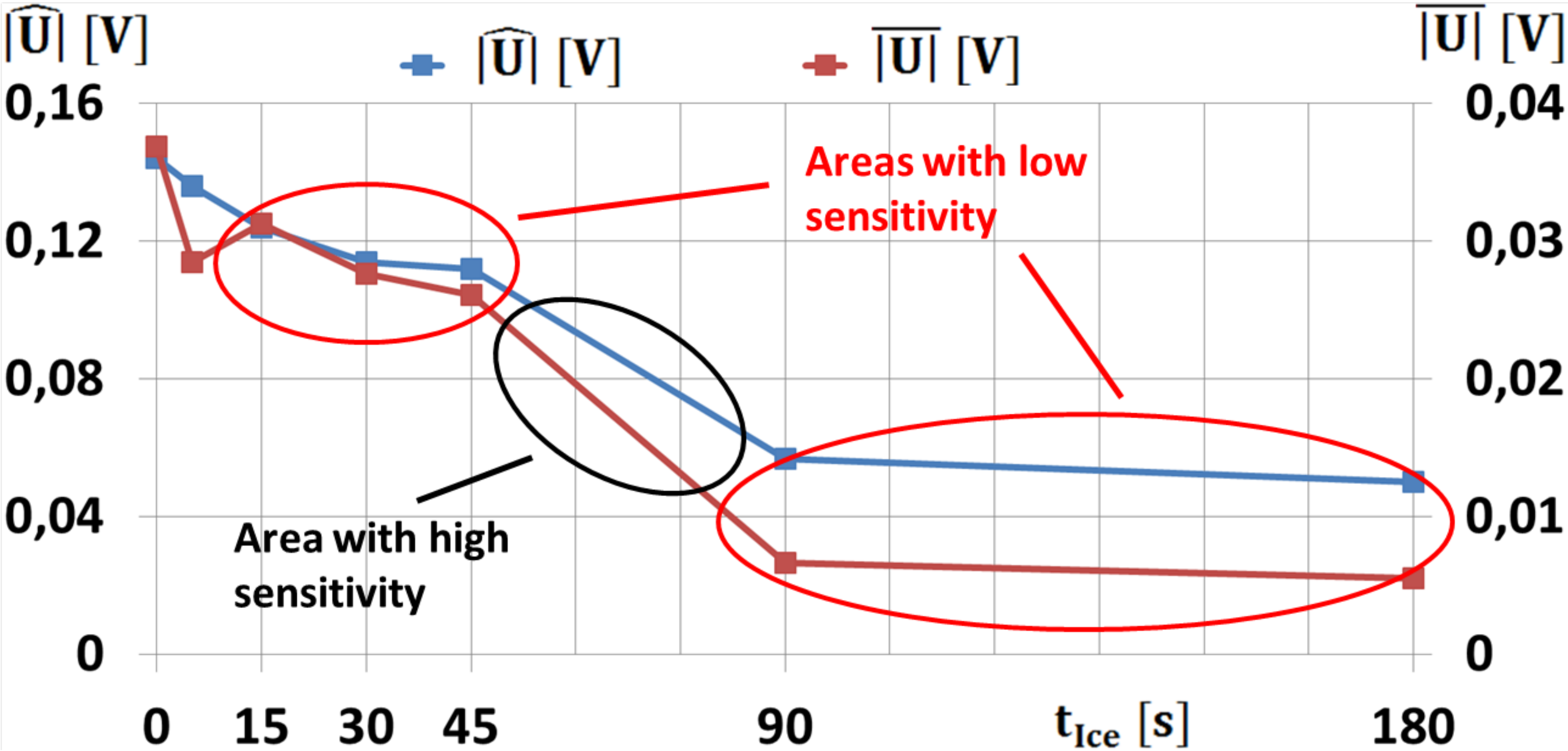
- Influence of temperature change has to be taken into account.
- This influence in turn variies with the position of the piezoceramic and the choosen frequency range for excitation.

Measurements for increasing icing time



- **Reliable operation needs minium ice thickness / ice area**

Measurements for increasing icing time



- **Areas with different sensitivity exist**

Conclusion – Swept sine excitation

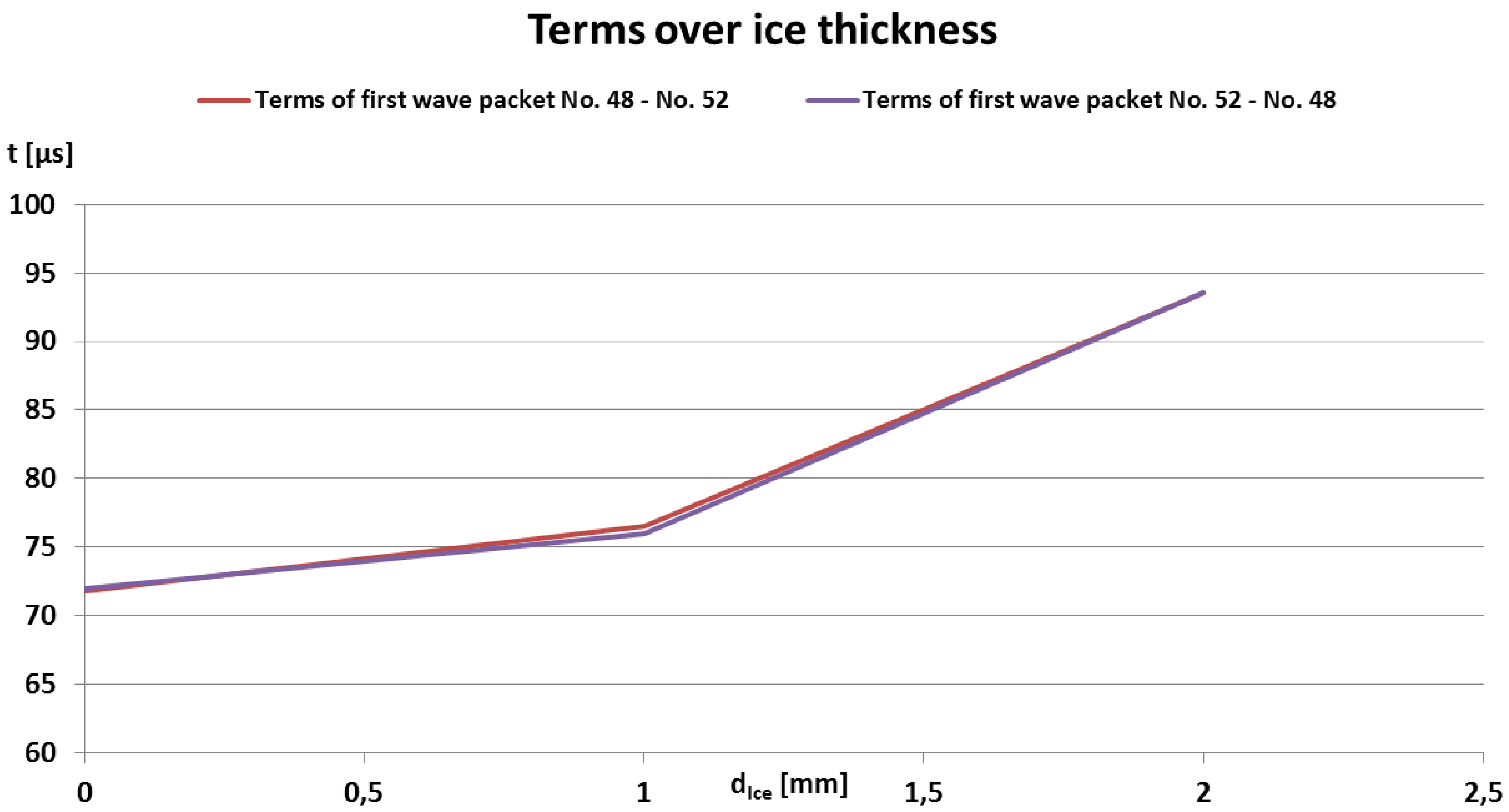
- Detection of ice accretion by analysing $\widehat{|U|}$ and $\overline{|U|}$ is possible
- Low sensitivity of $\widehat{|U|}$ and $\overline{|U|}$ for less amounts of ice
- Small electric power for excitation (1 W) enables sufficient ranges
- For design and interpretation of $\widehat{|U|}$ and $\overline{|U|}$, several influencing parameters have to be considered:
  - Boundary conditions of fixing (spars and ribs)
  - Insulation of piezo ceramics
  - Position of piezo ceramics
  - Angle between transmission path and fibre layers
  - Temperature

Results guided waves – influence of temperature

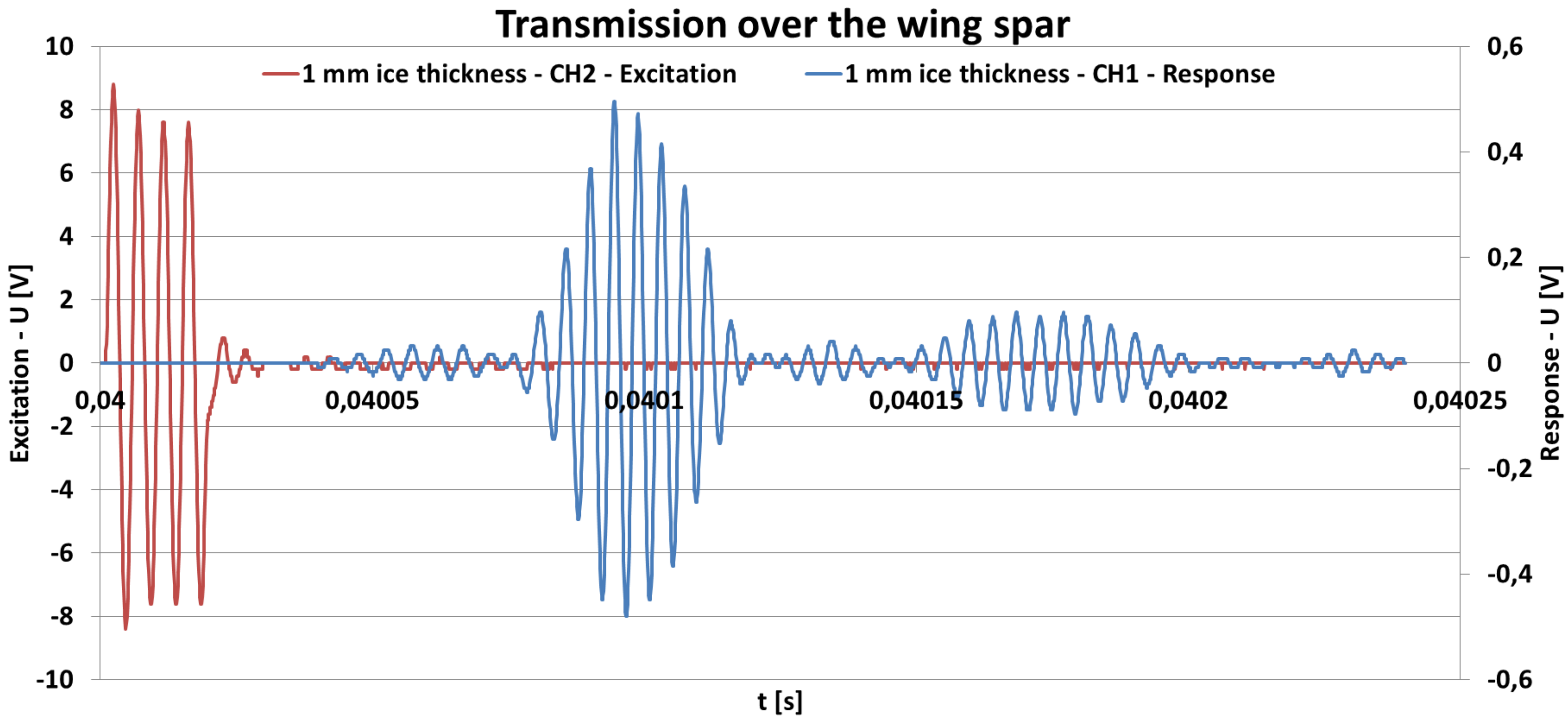
- **Temperature has no influence to term (0 %) and amplitude (< 2 %)**

  (For this setup! Temperature is changing parameters like elastic modulus of the structure and capacity of the piezo ceramics!)

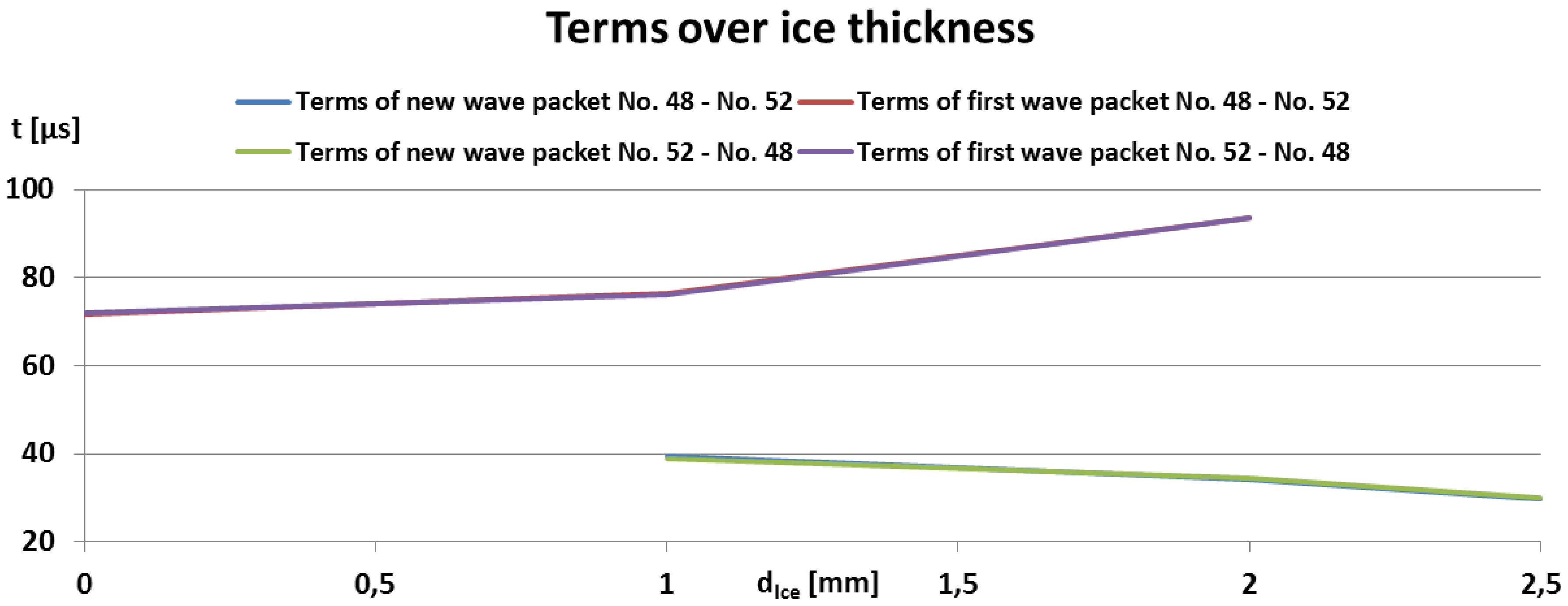
Results of guided waves – Terms



Results of guided waves – New wave package when icing occours

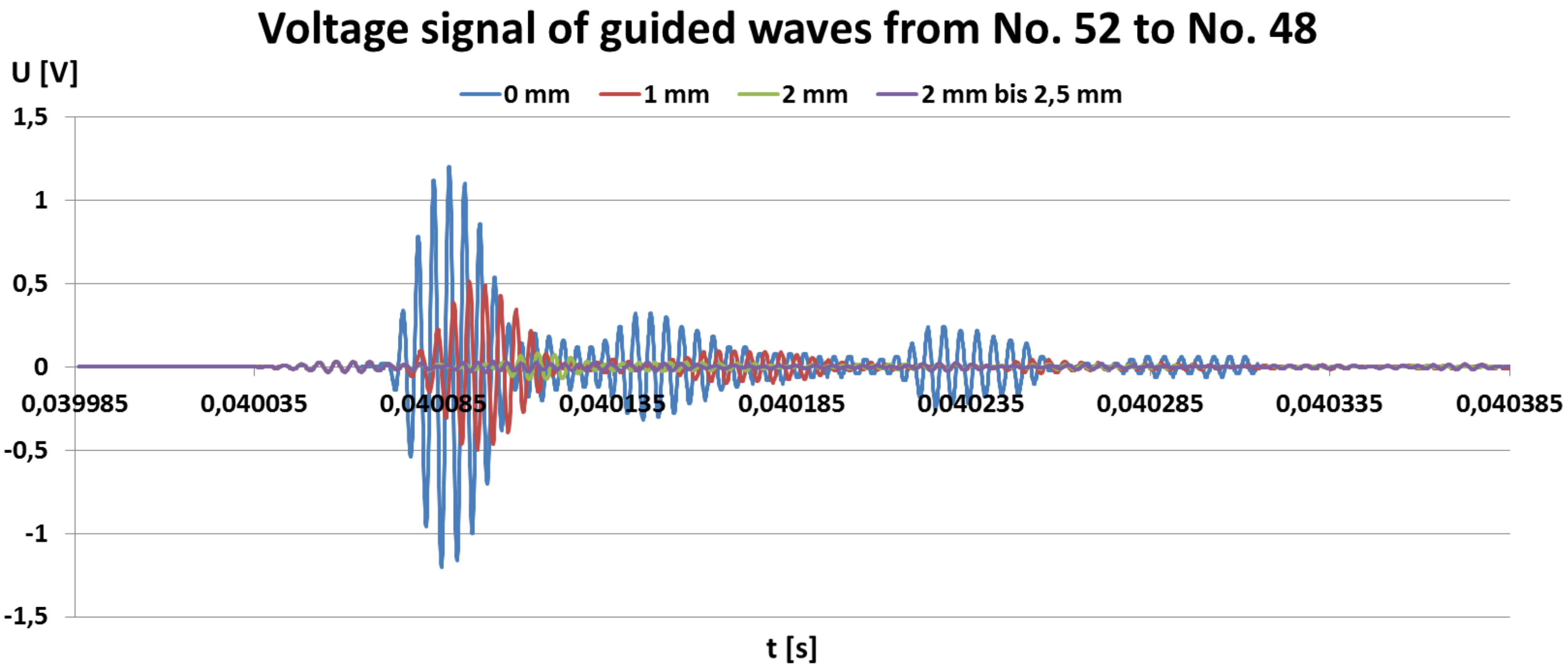


Results of guided waves – Terms of new wave packet



- Term of new wave package is decreasing

Results guided waves – Example of a signal

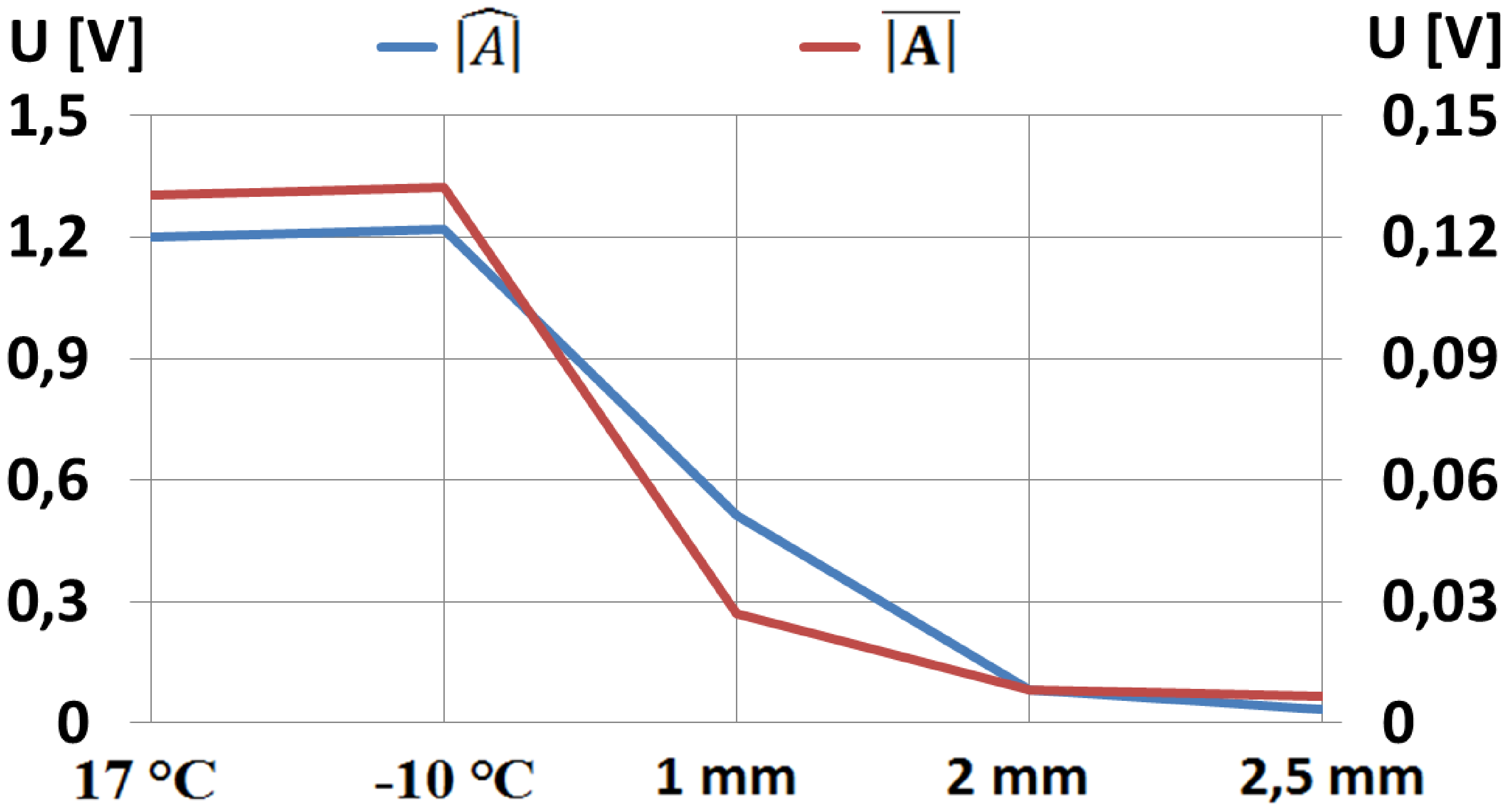


→ Decrease in amplitude with increasing mass / thickness of ice (Iced area difficult to determine)

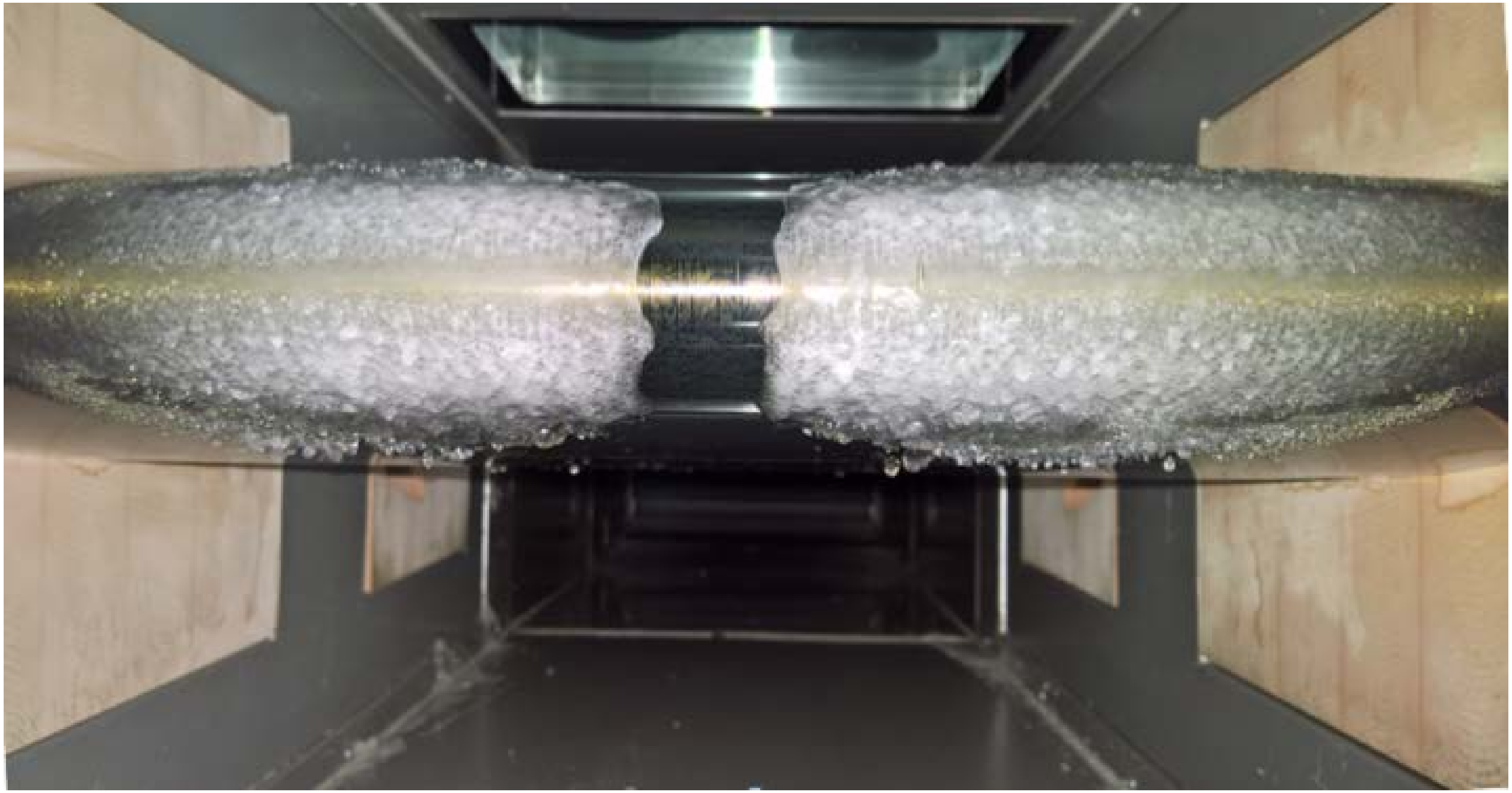
→ Increase in term with increasing mass / thickness of ice

DLR

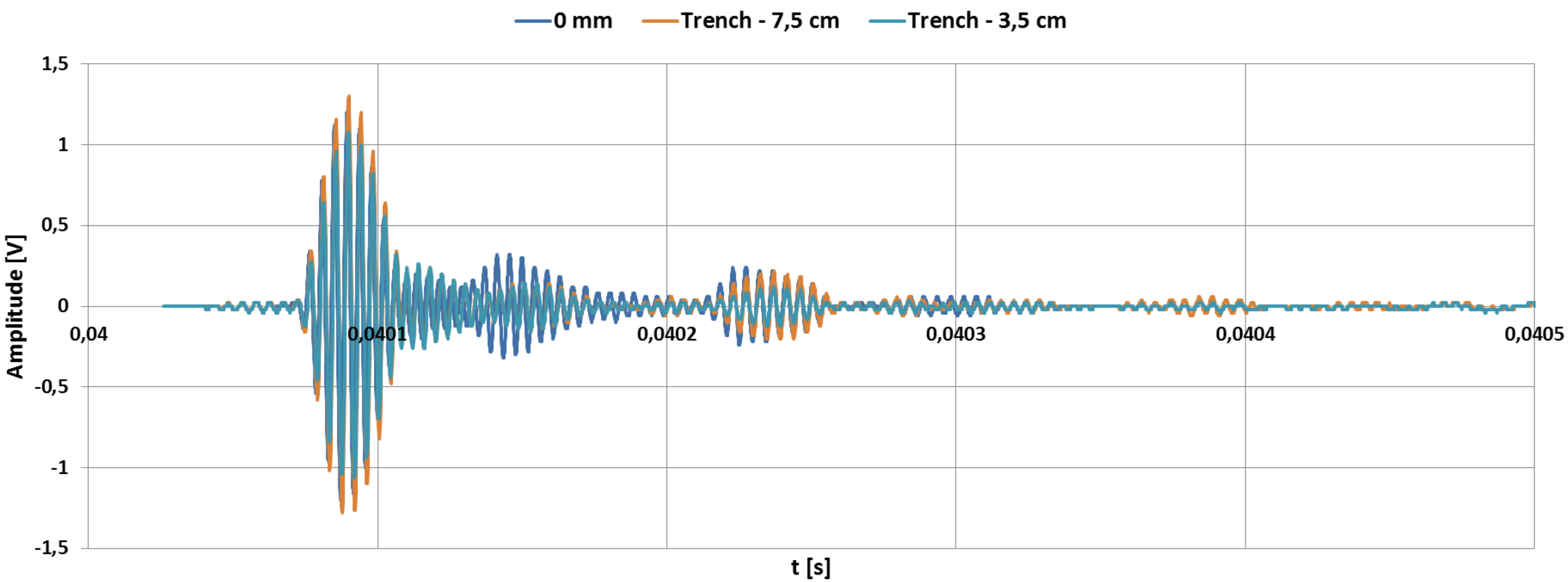
Results guided waves – $|\widehat{U}|$ and $|\overline{U}|$



Ice build-up without ice on the shortes transmission path



DLR



- Regeneration of the first wave package. Lower growth at second and l. third wave package.

→ Different sensitivity of wave packages (modes) to the deiced trench?

Conclusion – Guided waves

- Detection of ice accretion by analysing $|\widehat{U}|$ and $\overline{|U|}$ is possible
- High sensitivity in the area of thin ice thickness for $|\widehat{U}|$ and $\overline{|U|}$
- Increasing sensitivity of the term with increasing ice thickness

→ Combination of both methods for maximum sensitivity possible