Multi-element piezo-composite transducers for structural health monitoring

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Outline

- Short company presentation
- Introduction to structural health monitoring and the AISHA II project
- Lamb waves and array transducers
- Development of piezo-composites
- FEM modelling
- Integration and testing of array transducers
- Conclusions and outlook

Structural health monitoring

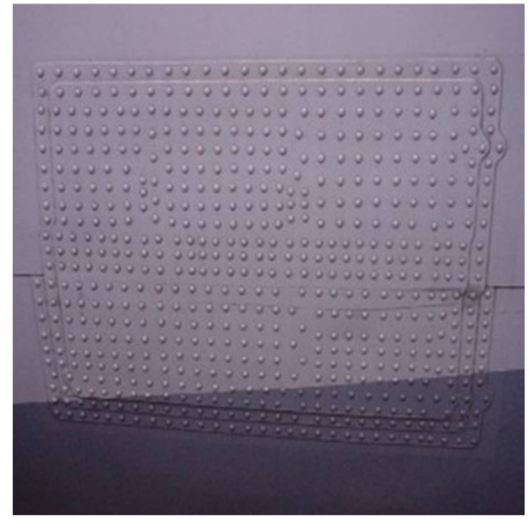
Structural health monitoring

- A collective term for advanced technologies using sensor networks for monitoring of structures of high importance
  - Bridges
  - Buildings
  - Aircraft
- For aircraft, SHM is closely linked to the Maintenance, Repair and Overhaul schedule
  - Light maintenance (A-check, duration < 24 h, interval 2 months)
  - Base maintenance (C- and D-checks, duration 1 – 5 weeks, interval 2 – 10 years)
- Main benefits of SHM:
  - Cost savings by reduction of inspection costs and possible weight reduction in the design phase
  - Enhancement of safety by more frequently applied automated inspections
  - Increase of passenger throughput by reduction of maintenance time and by better maintenance planning

AISHA II project

- **A**ircraft **I**ntegrated **S**tructural **H**ealth **A**ssessment II
- FP7 Theme TRANSPORT (incl. AERONAUTICS)
- 5 full-scale parts selected as cases for SHM:
  - fatigue cracks in slat tracks of Airbus A320 and A380
  - impact damage in the tail boom of the helicopter Eurocopter EC135
  - fatigue cracks in the helicopter tail boom of a MIL Mi-8
  - corrosion in floor beams of Airbus A340
  - fatigue damage in doubler repairs of Airbus A340
- Focus on hot spots
- Examples of sensing technologies:
  - piezoceramic transducers for ultrasonic Lamb waves
  - EMAT sensors for ultrasonic Lamb waves
  - electrochemical sensors
  - optical fibre sensors

AISHA II full-scale parts



AISHA II consortium

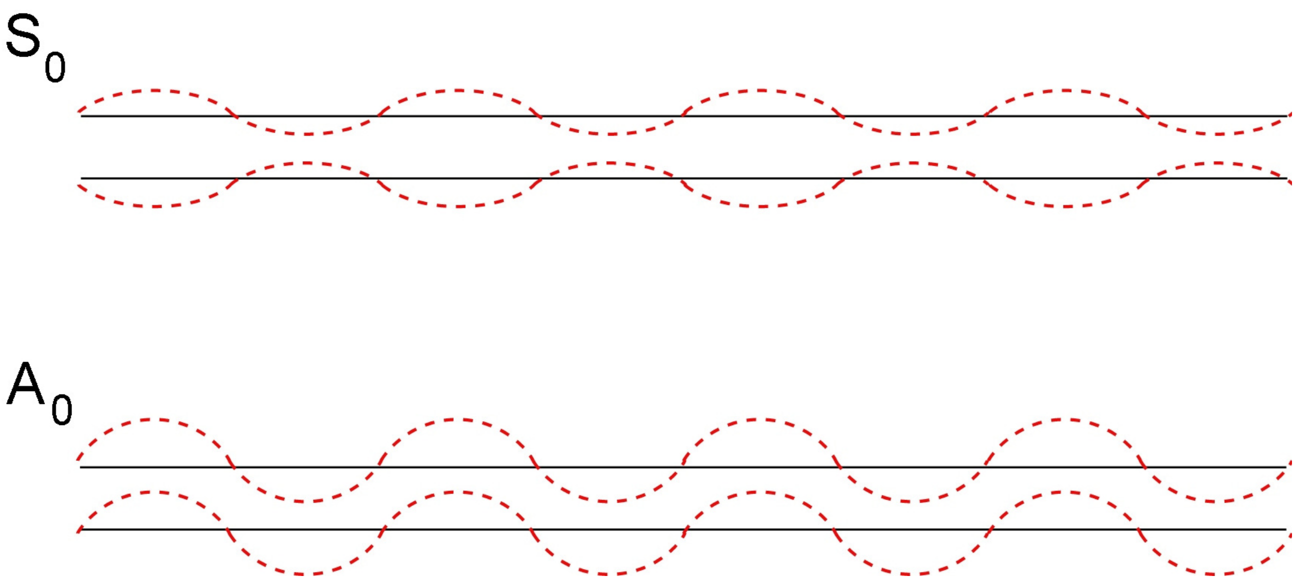
- Katholieke Universiteit Leuven, MTM & ATF (BE)
- METALOGIC nv (BE)
- Deutsches Zentrum für Luft- und Raumfahrt, DLR (DE)
- CEDRAT Technologies SA (FR)
- EUROCOPTER - Marseille (FR)
- Riga Technical University (LV)
- CENTRO DE TECNOLOGIAS AERONAUTICAS, CTA (ES)

- ASCO Industries nv (BE)
- Fraunhofer Institute for Manufacturing Technology and Applied Materials Research, IFAM (DE)
- Universität Leipzig (DE)
- LUFTHANSA Technik (DE)
- Vrije Universiteit Brussel (BE)
- University of the Basque Country (ES)

Lamb waves

Lamb waves

- A type of guided waves also known as plate waves
- For frequencies in the range of a few hundred kilohertz, only the lower-order Lamb waves, S_0 and A_0, will be significant
- S_0 and A_0 are called the symmetric and antisymmetric modes, respectively
- S_0 is the fastest of the two and the one most sensitive to defects



Lamb waves for SHM

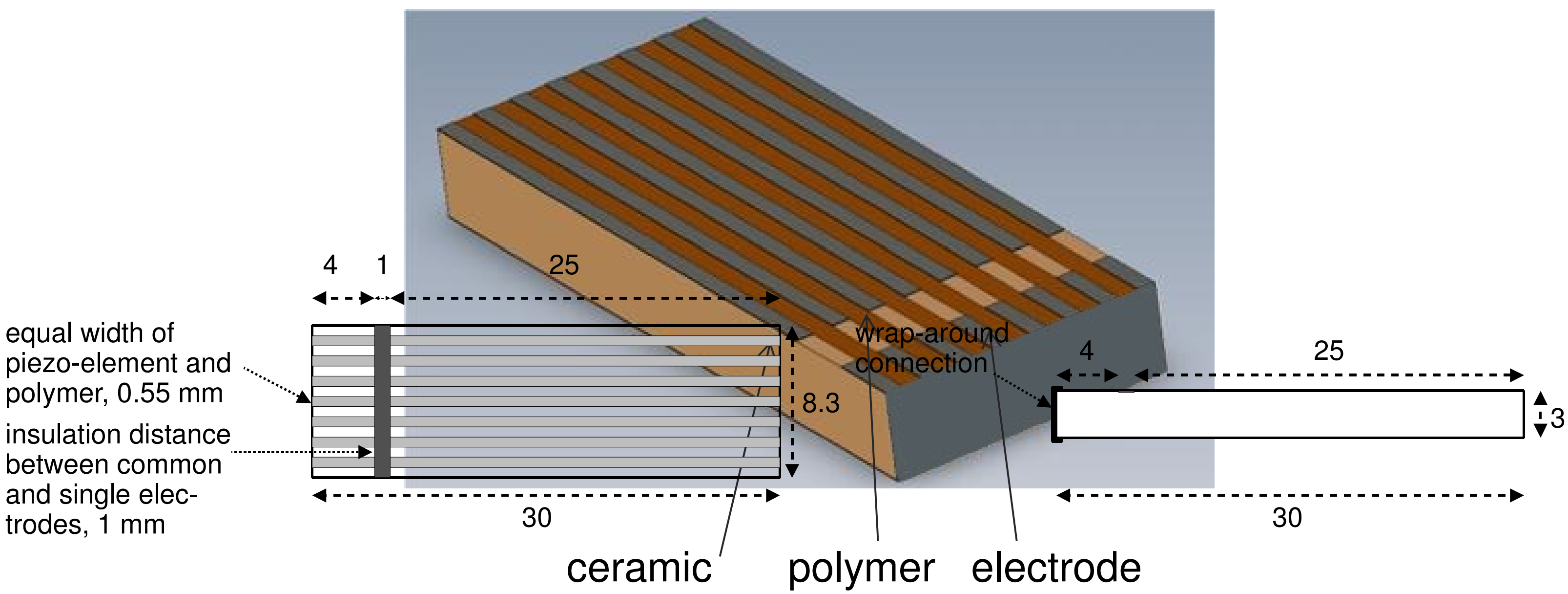
- The main challenge in using Lamb waves for SHM is the multitude of interfering echoes leading to a heavy burden of signal processing
- A convenient solution is to apply mode and direction selectivity by means of a linear array piezoelectric transducer
- In the linear array, the elements are separated by a fixed pitch
- By simple signal processing, waves propagating at different velocities can be distinguished
  - Undesired waves are filtered out by virtually creating destructive interference
  - The interesting wave is amplified by virtually creating constructive interference
- Mode selection delay:

  t_{delay} = pitch/velocity

Piezo-composite transducers

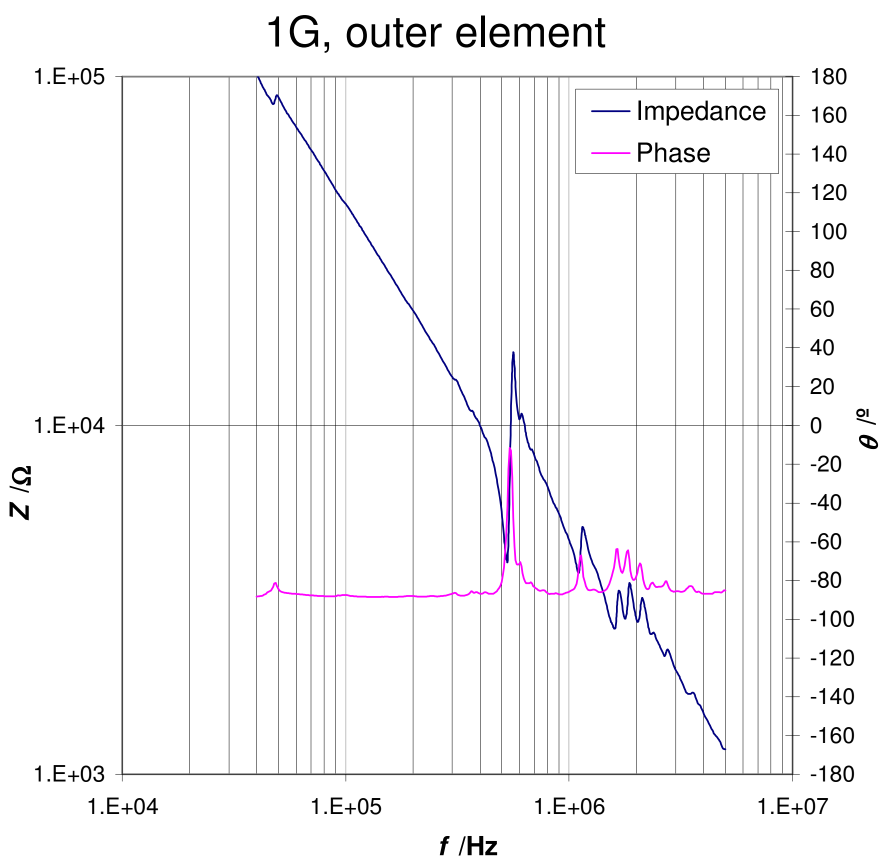
2-2 composites as linear arrays

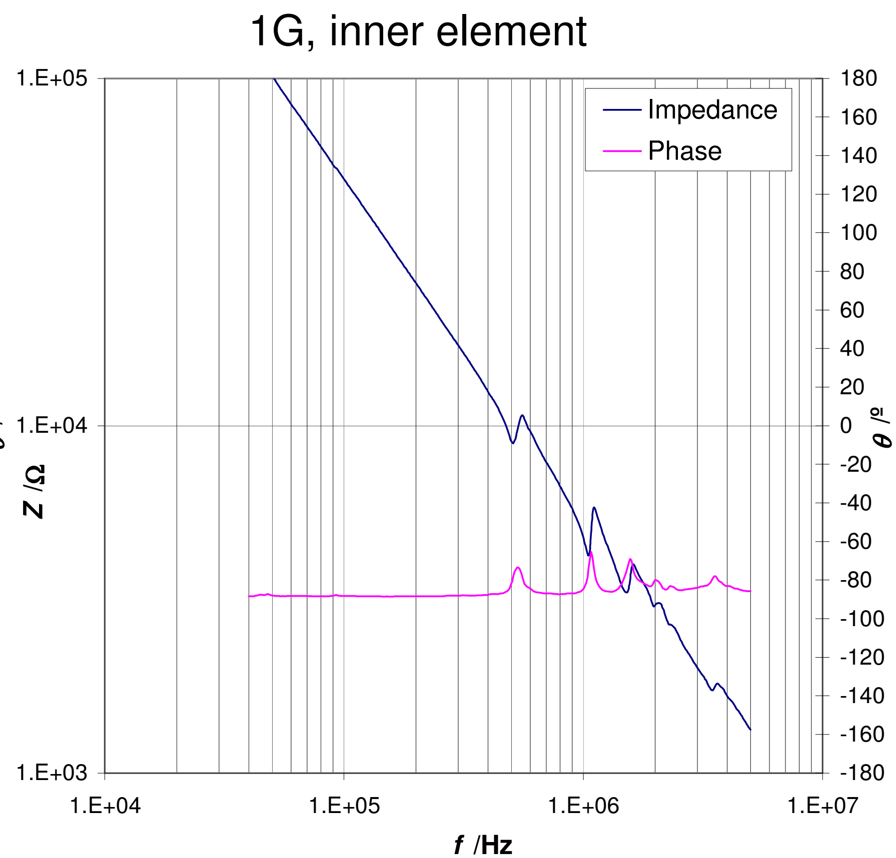
- Composite transducers have very interesting acoustic properties (damping of transverse modes, possibility of electronic scanning, focusing and beam steering)
- 2-2 composites have a multilayer structure (2D connectivity for both the ceramic (active) phase and the polymer (passive) phase)
- Ferroperm soft PZT (Type 100) has been chosen as the piezoceramic



Characterisation of 2-2 composites, 1st generation

- Impedance spectrum shows difference seen between inner and outer elements

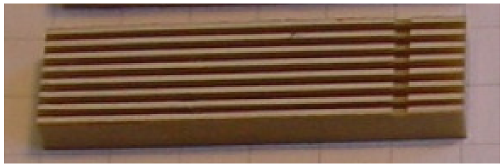




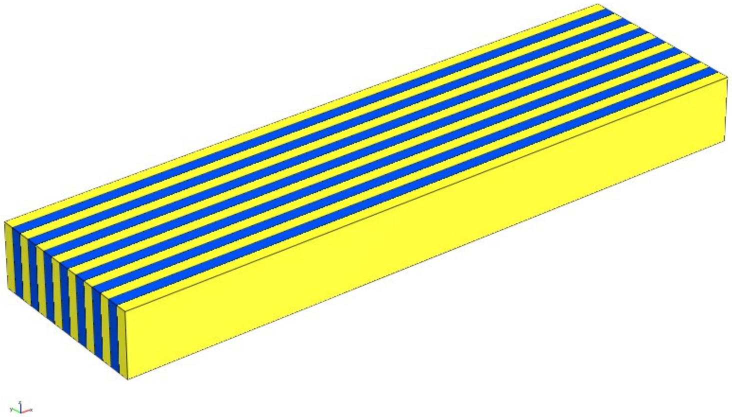
FEM modelling

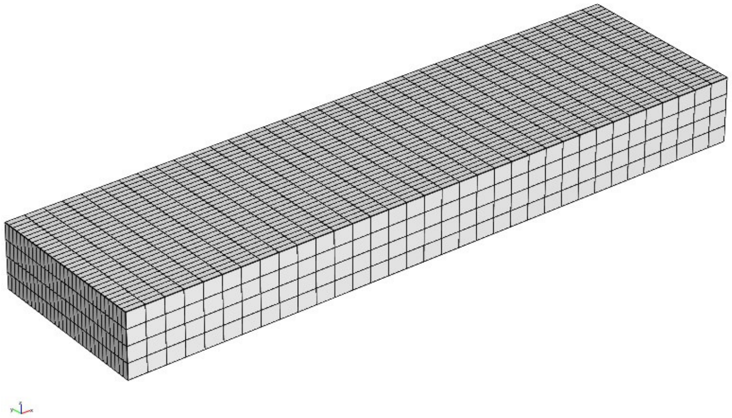
FEM modelling of 2-2 composite

- An FEM model has been set up in COMSOL Multiphysics in order to investigate the uniformity of response over the piezoceramic elements
- Dimensions of composite part:
  - piezoceramic: 8 elements of *L* 30 mm * *W* 0.55 mm * *h* 3 mm
  - polymer: 7 elements of *W* 0.55 mm
  - wrap-around electrode not considered



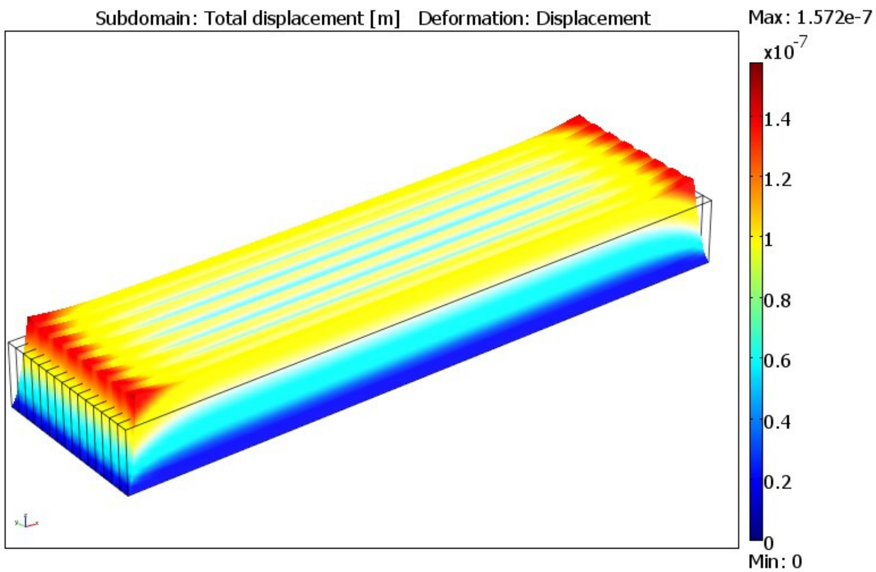
- Model definition and input data (preliminary):
  - piezoceramic: standard soft PZT
  - polymer: density 930 kg/m^3, elastic modulus 1 GPa, Poisson ratio 0.33
  - the part is fixed on the bottom side (~ glue with ideal clamping)
  - rectangular meshing used (34 * 30 * 4 elements)

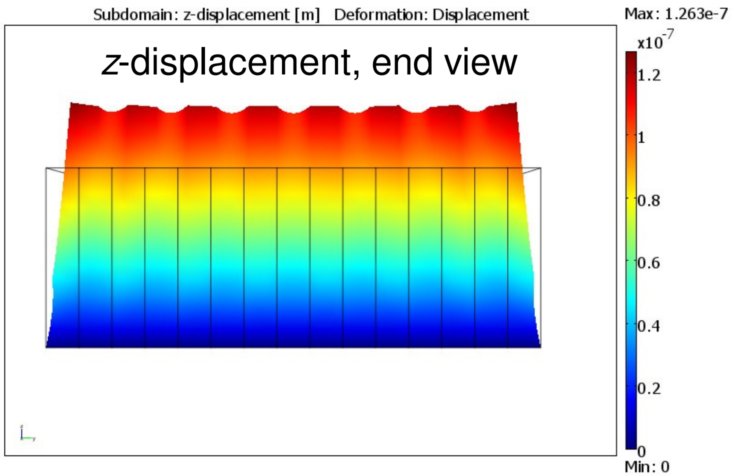


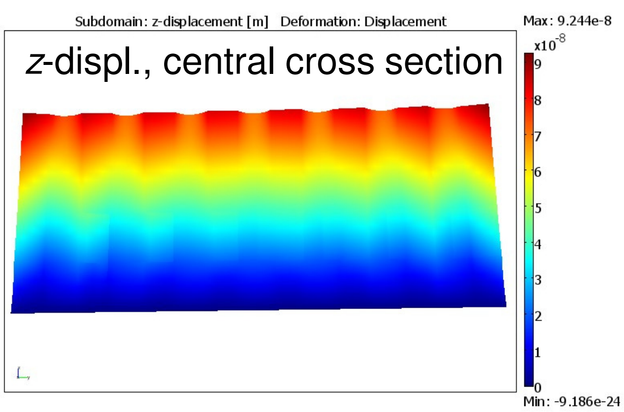


Static displacement

- A plot of the displacement shows higher values at the ends of the element
- Similarly for outer elements (z-displ., end view and central cross section)

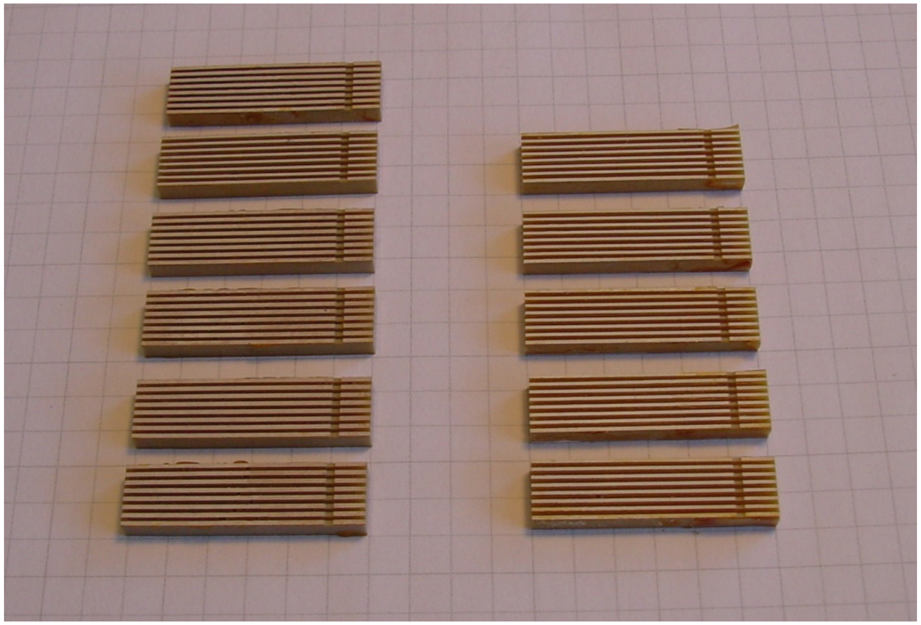






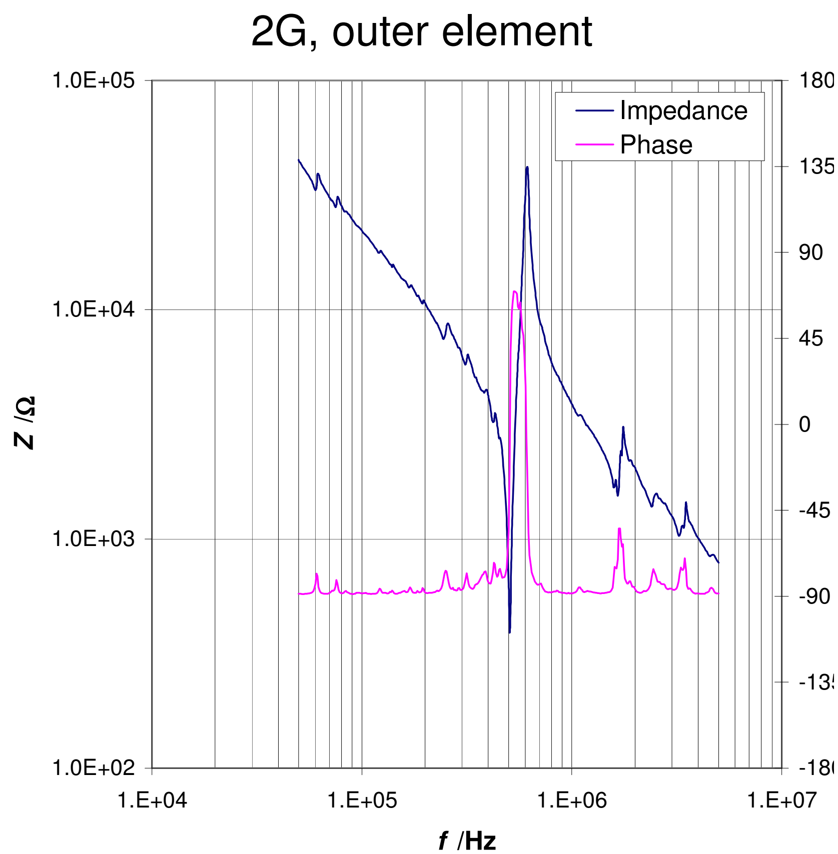
2-2 composites manufactured, 2nd generation

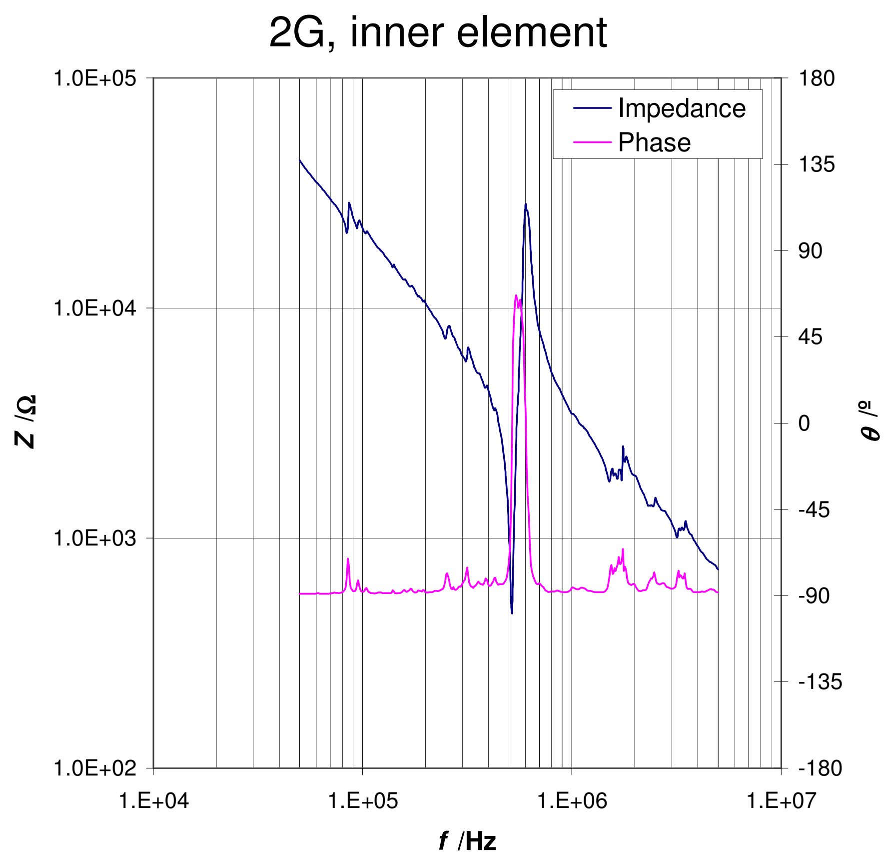
- A different polymer was selected
- A number of improvements were made to the process
- 2nd generation devices show improved quality and uniformity



Characterisation of 2-2 composites

- Impedance spectrum shows enhanced resonance

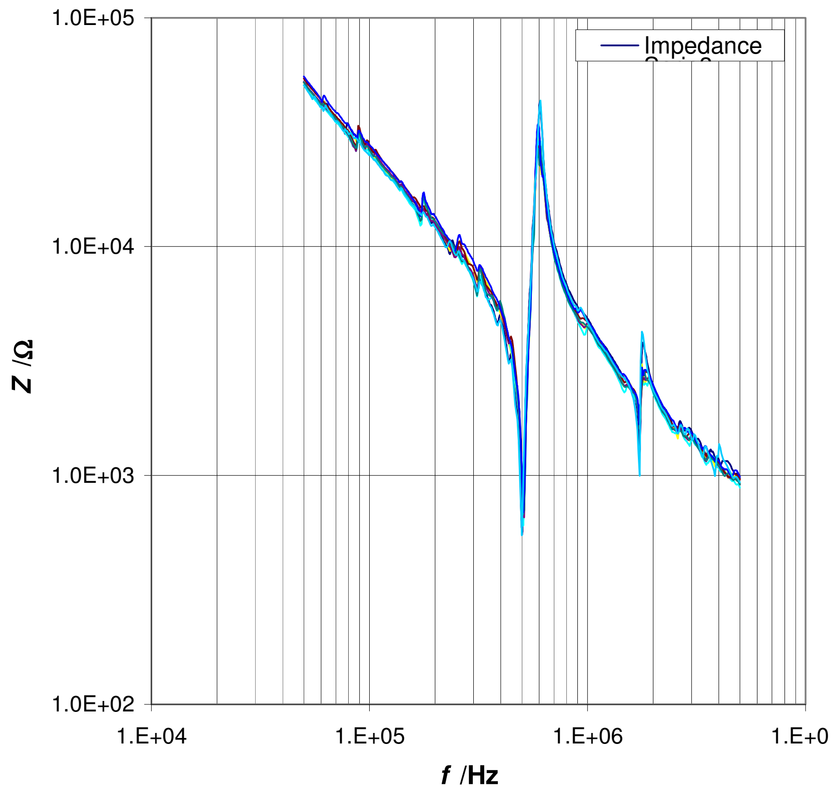




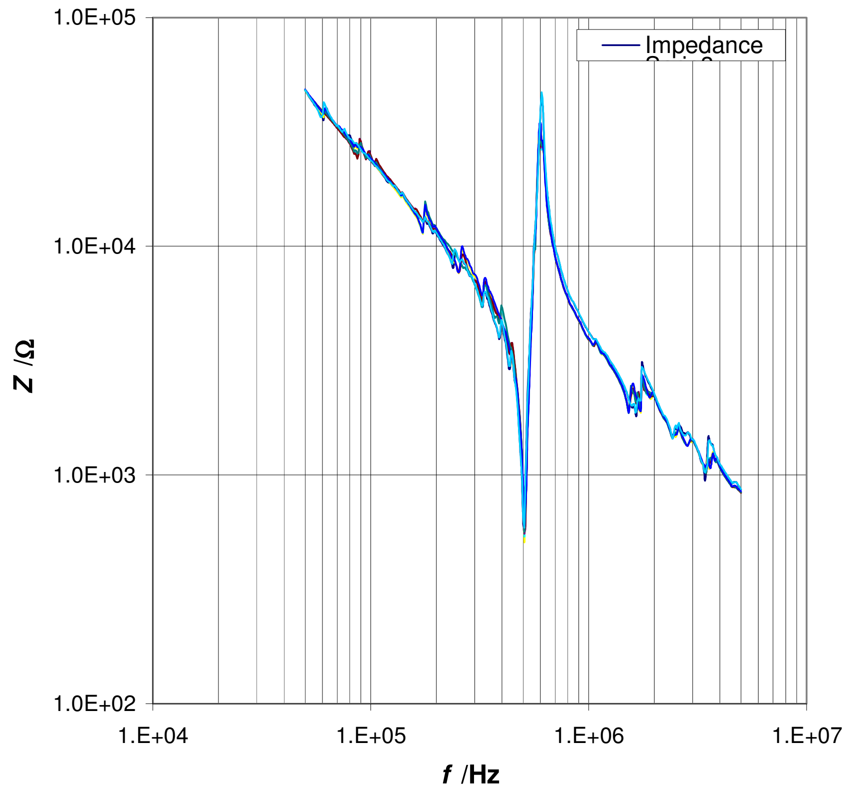
Reproducibility of 2-2 composites

- Resonance very reproducible between elements

3G-14, all elements



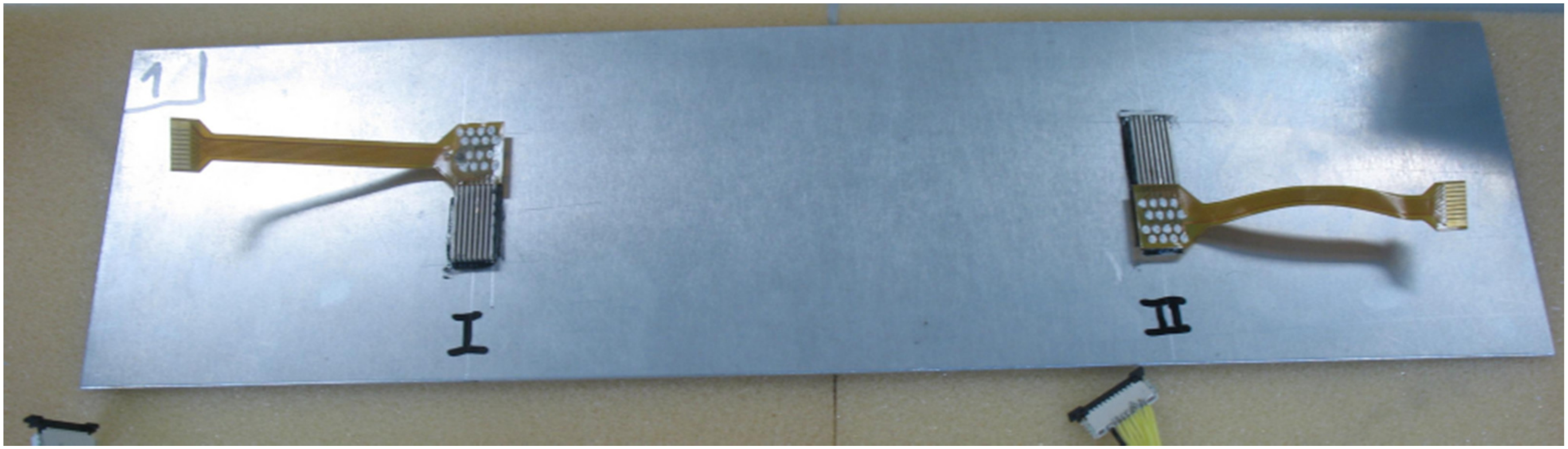
3G-15, all elements



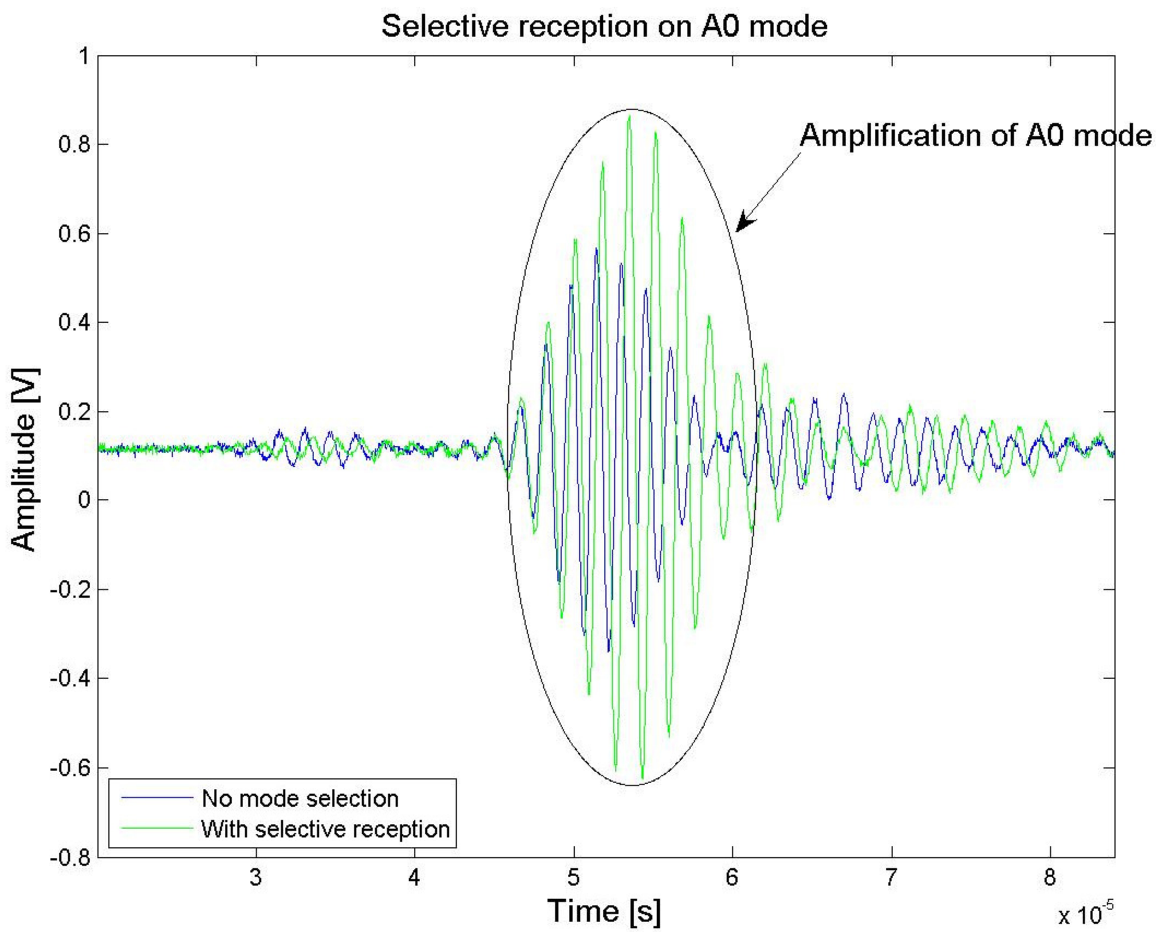
Integration and testing of array transducers

Integration and testing

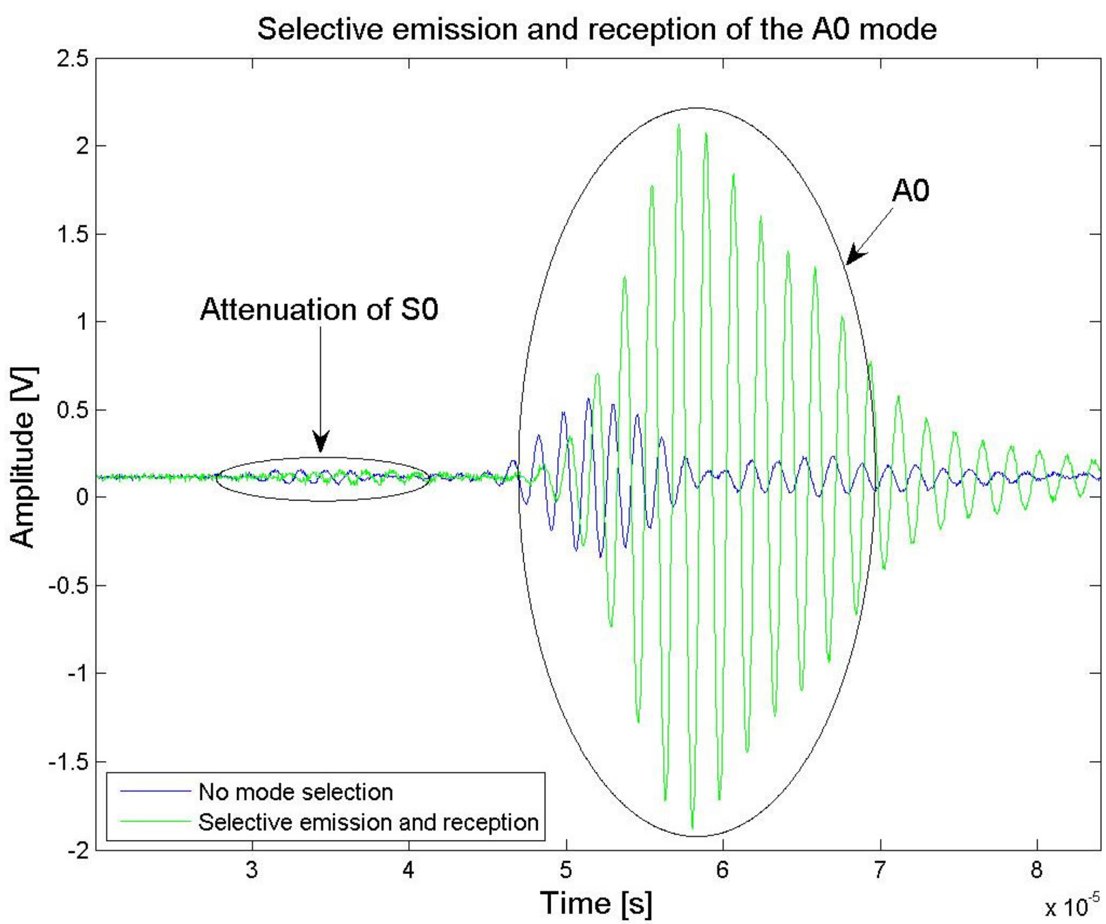
- Arrays mounted with flex PCB by soldering
- Two arrays glued to an aluminium plate
- Both arrays connected to a dedicated SHM electronics module
    - High-frequency excitation (bandwidth up to 2 MHz)
    - PULSECHO functionality (emission and reception on same piezoelectric patch)
    - 4 channels per daughter board



Selective reception



Mode and direction selection



Conclusions and outlook

- Ultrasonic inspection using Lamb waves is an important method for SHM
- By using arrays instead of single patches it is possible to perform mode selection in a very efficient manner
- 8-element linear arrays for SHM have been manufactured successfully in the form of 2-2 composites, obtaining a high degree of reproducibility
- Mode selection in reception of either the S_0 or A_0 mode has been demonstrated
- The selectivity of either mode can be further enhanced by combining selective emission and selective reception
- In the near future, similar 8-element arrays in the form of thick films will be tested

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Aircraft **I**ntegrated **S**tructural **H**ealth **A**ssessment II