Active and passive structural health monitoring system based on arrays of ultrasonic guided waves transducers

L. Capineri, A. Bulletti, M. Calzolai, P. Giannelli, G. Calabrese

Ultrasound and Non Destructive Testing Laboratory
http://www.uscndlab.dinfo.unifi.it/mdswitch.html

In collaborazione con:

ThalesAlenia Space
A Thales / Finmeccanica Company

Structural Health Monitoring (SHM) in space

- **What ?**

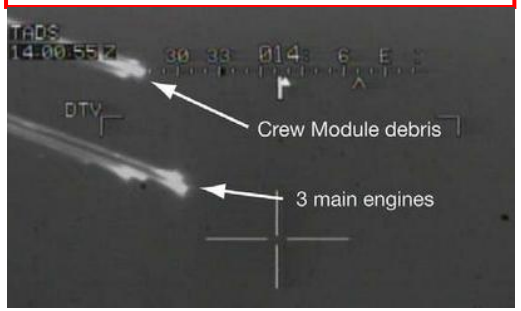
  technology aimed at embedding, into space infrastructures and reusable vehicles, ‘self inspection’ functions for generating real time health diagnostics

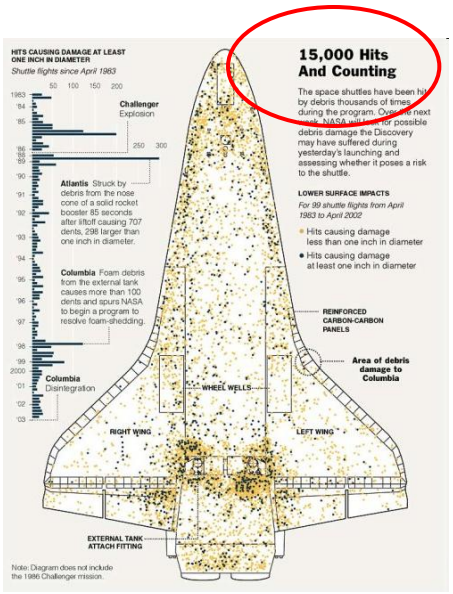
- **SHM – Diagnostics: How ?**

  during past technology development activities performed in TAS-I, experiments on simplified structural component demonstrators were aimed at identifying and selecting not invasive diagnostic technologies able to detect small, remote, not visible damages and their growth under cycling loading. Ceramic broadband PZT ultrasonic transducers were bonded on the tank surface.

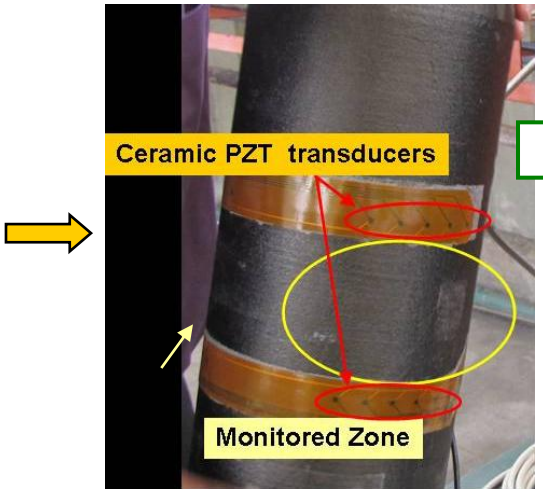
- **Why ?**

Shuttle – Columbia Accident

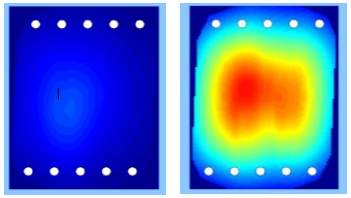




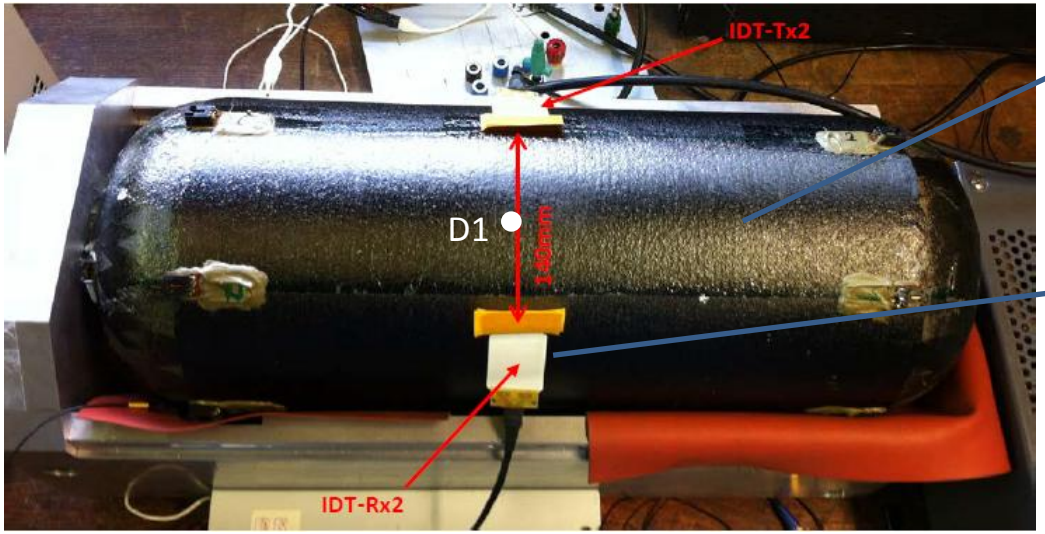
Carbon Overwrapped Pressure Vessel (COPV)



Hidden defect growth, real time monitoring



Interdigital (IDT) piezopolymer transducers for ultrasonic Lamb waves on COPV

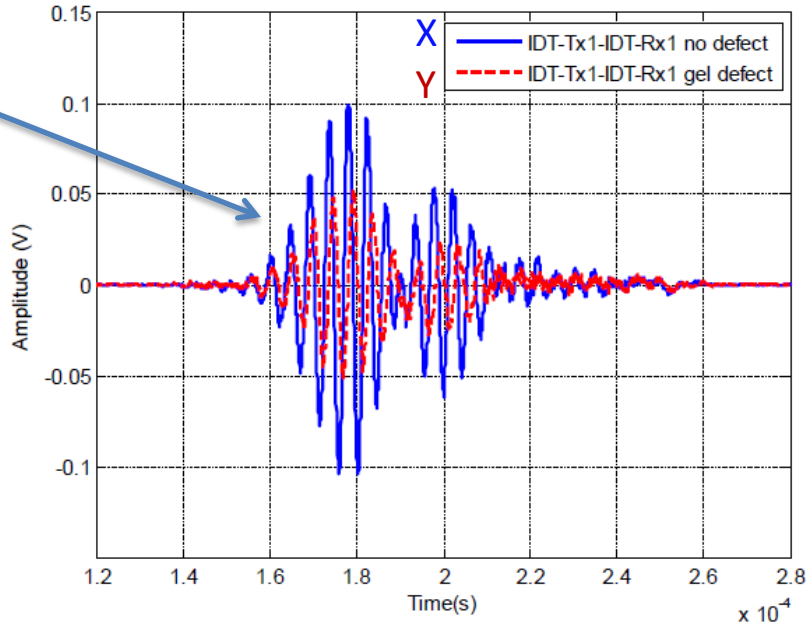


Scale model of a tank COPV, thickness (metal and carbon) about 3 mm

Piezopolymer IDT transducers fabricated by laser ablation (CNR patent), proof of concept *ESA-ITI project 2004*

Propagation velocity 2200m/s

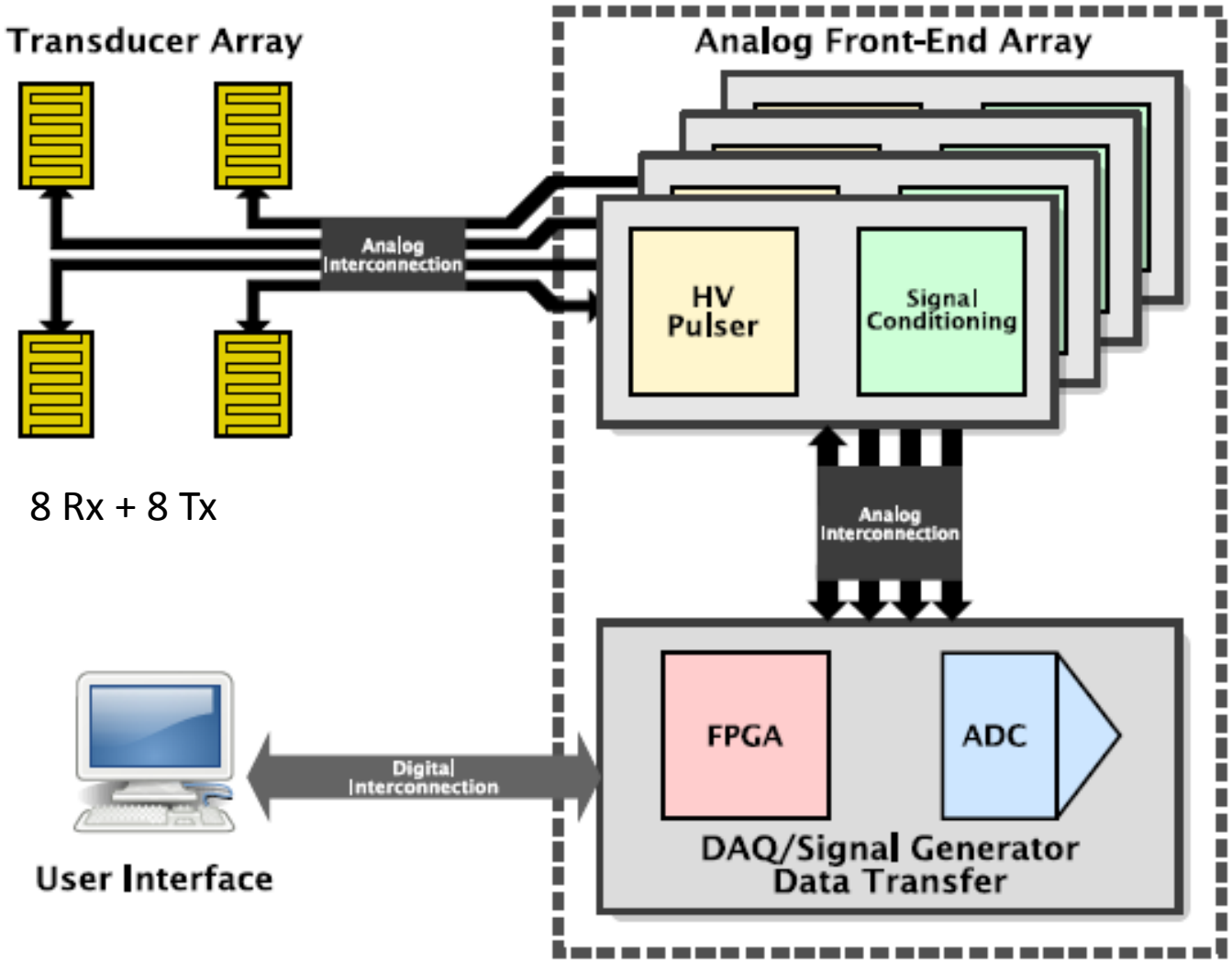
Antisymmetric ultrasonic mode (A_0) using IDTs with λ = 8mm and an excitation frequency of 220kHz



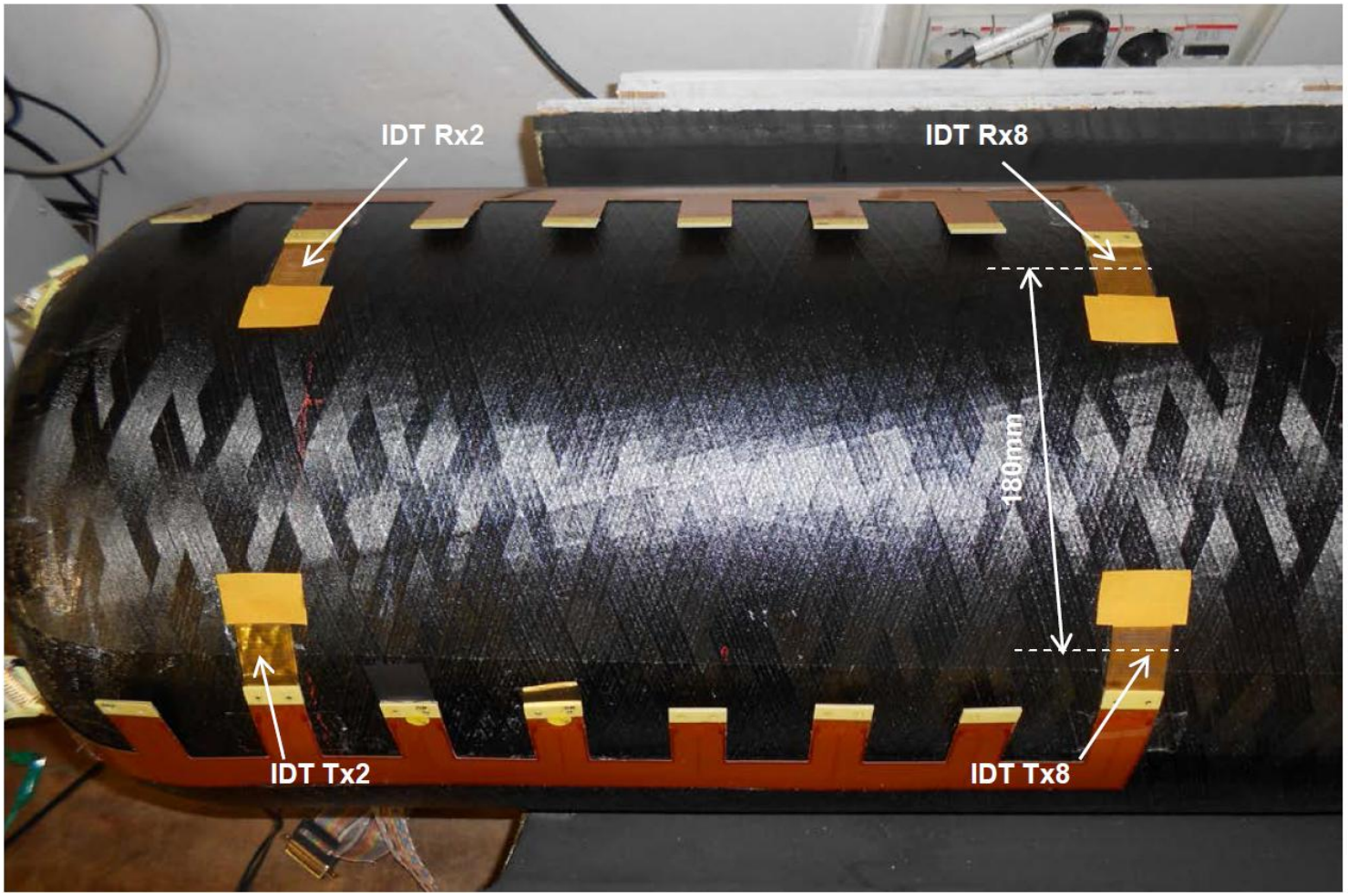
Damage Index *DI* definition:

$$DI = \frac{\sqrt{\left(\sum XY\right)^2}}{\sqrt{\sum X^2 \sum Y^2}} \times \frac{\min\left(\sqrt{\sum X^2}, \sqrt{\sum Y^2}\right)}{\max\left(\sqrt{\sum X^2}, \sqrt{\sum Y^2}\right)}$$

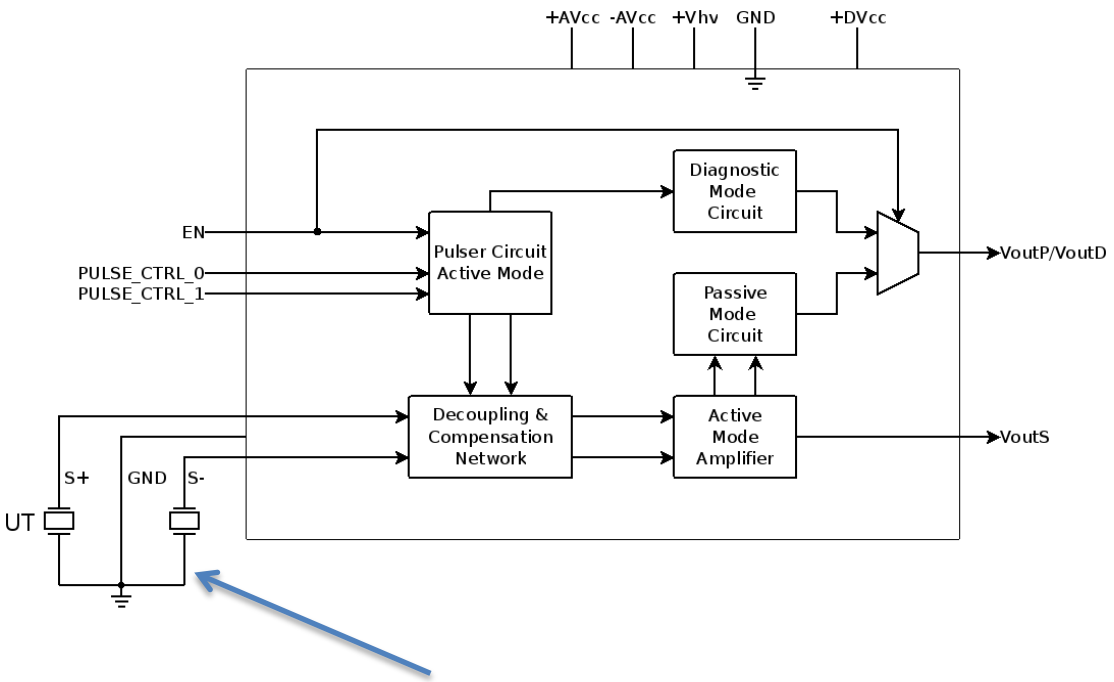
Architecture of the SHM system

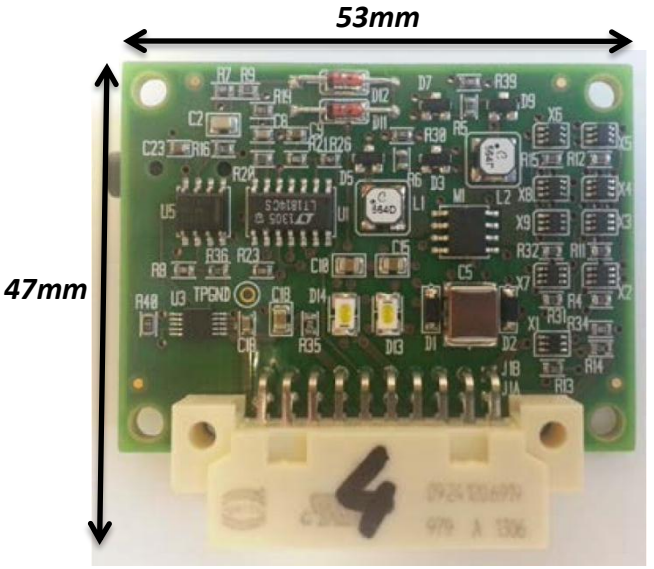


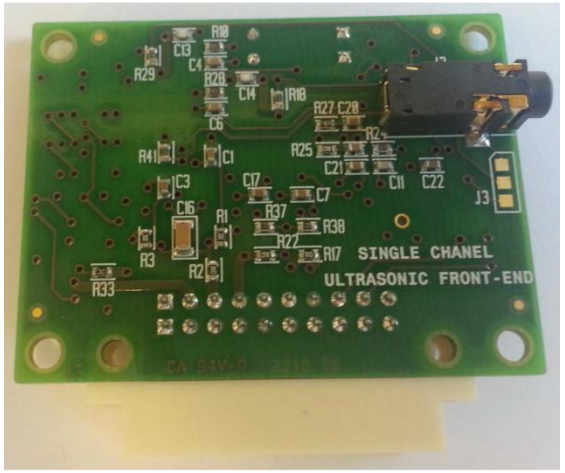
Smart arrays of piezopolymer Lamb wave transducers



Ultrasonic analog front-end



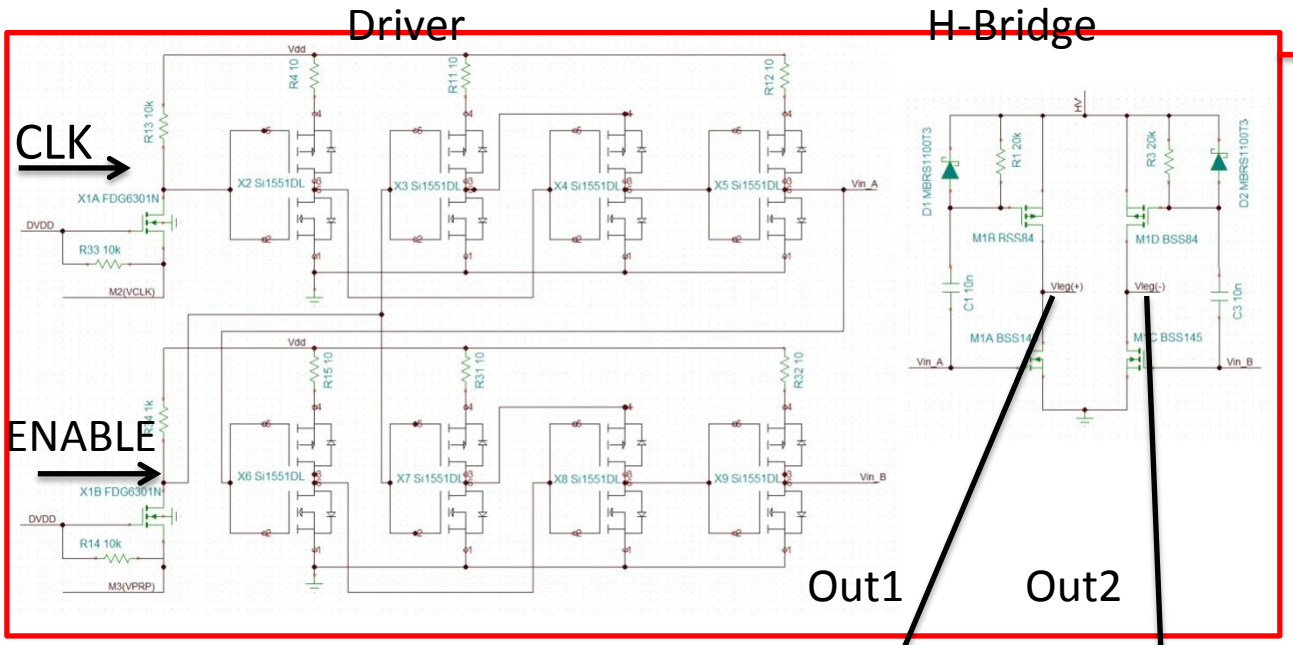


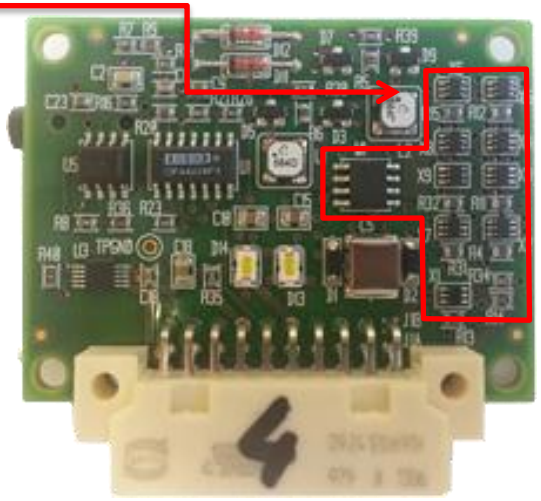


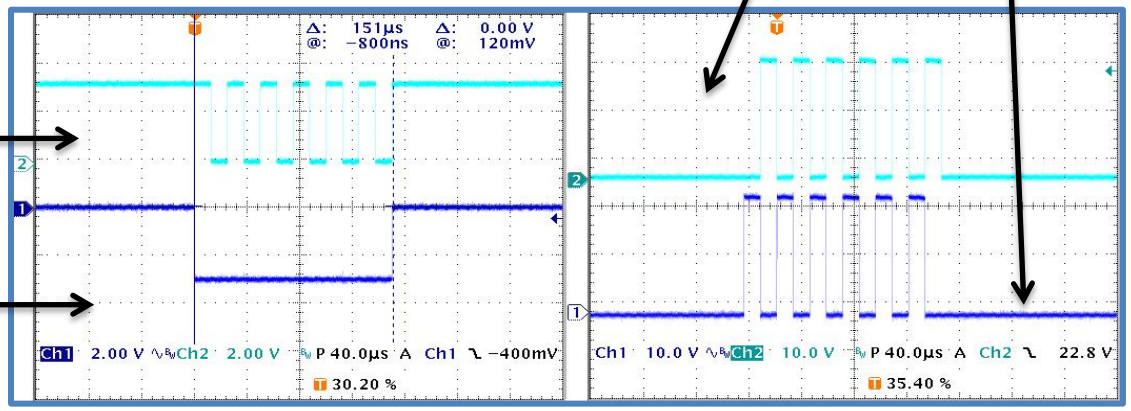
Single channel front-end card

- Operation with IDT piezopolymer (HV) or single ended (LV) piezoceramic transducers
- Selection of diagnostics on transducer current or passive mode for impact detection
- Active mode: up to 100 V , square wave burst at frequency up to 500 kHz

High Voltage pulser circuit



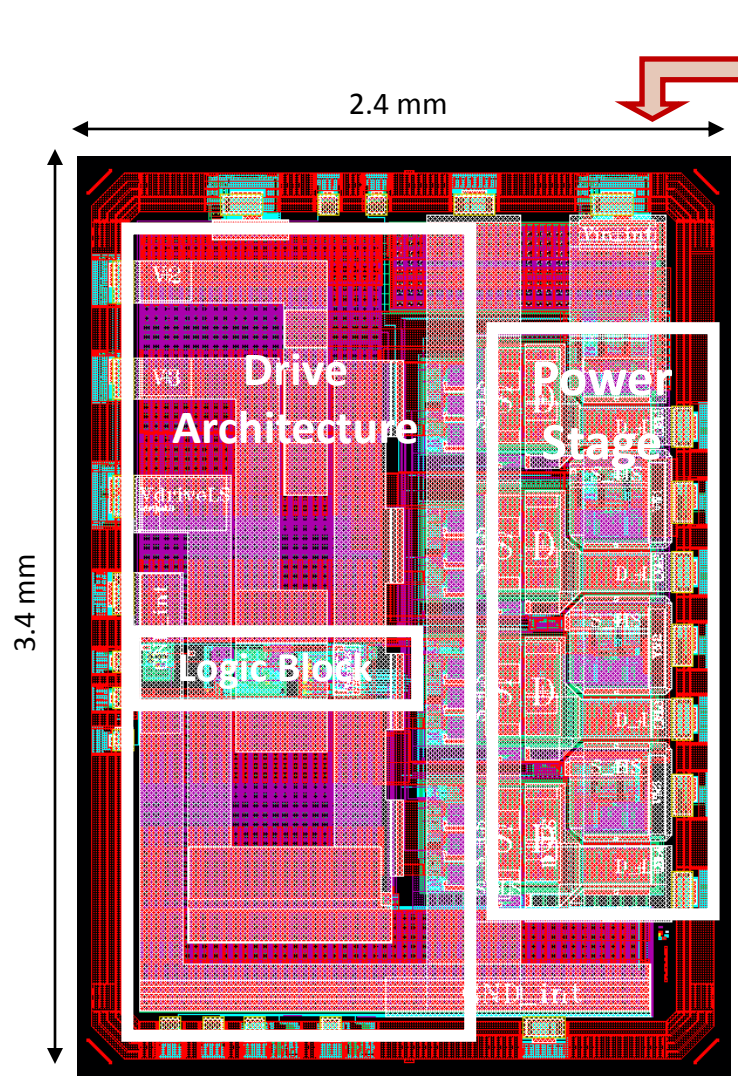


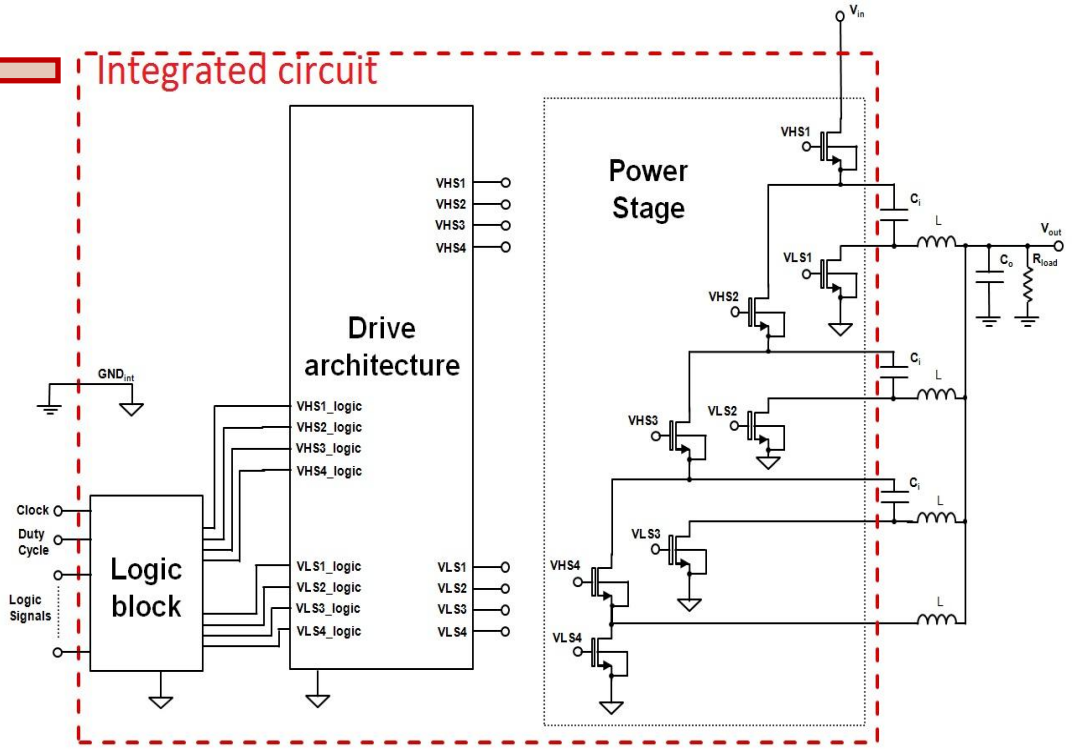


- CLK, ENABLE are 3V3 logic-level signals
- The excitation voltages (Out1,Out2) can be adjusted between 5V and 100V

Integrated power electronics design

HV pulser IC requires skills similar to DC-DC converters design.....

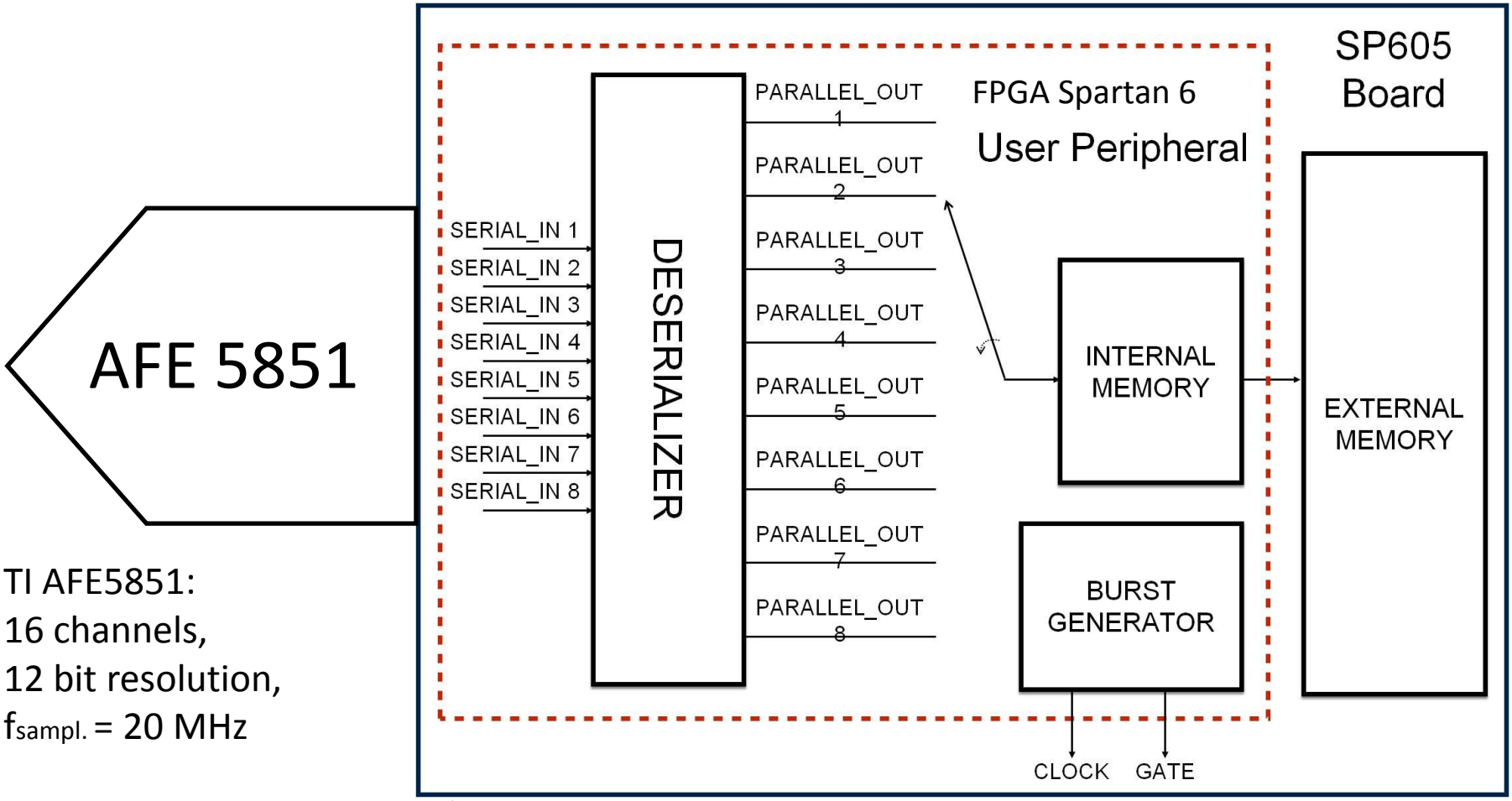




High step-down multiphase buck converter:
Specs: V_{in} = 12 V, V_{out} = 1.2 V, 2A, 10 MHz

Preliminary paper: G. Calabrese, M. Granato, G. Frattini, L. Capineri, "Integrated high step-down multiphase buck converter with high power density," 16th European Conference on Power Electronics and Application, 2014. EPE 2014, 26-28 Aug. 2014

Programmable Data Acquisition system (DAQ)



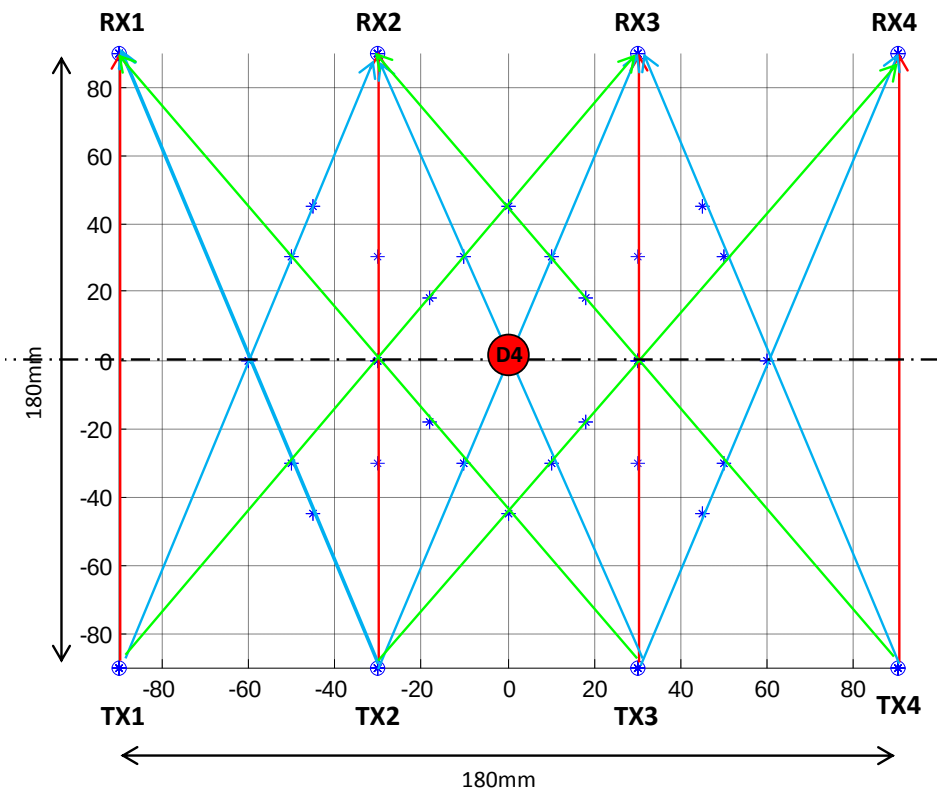
TI AFE5851:
16 channels,
12 bit resolution,
$f_{sampl.}$ = 20 MHz

Programmable active and passive channels with digitized signal length up to 1 Samples

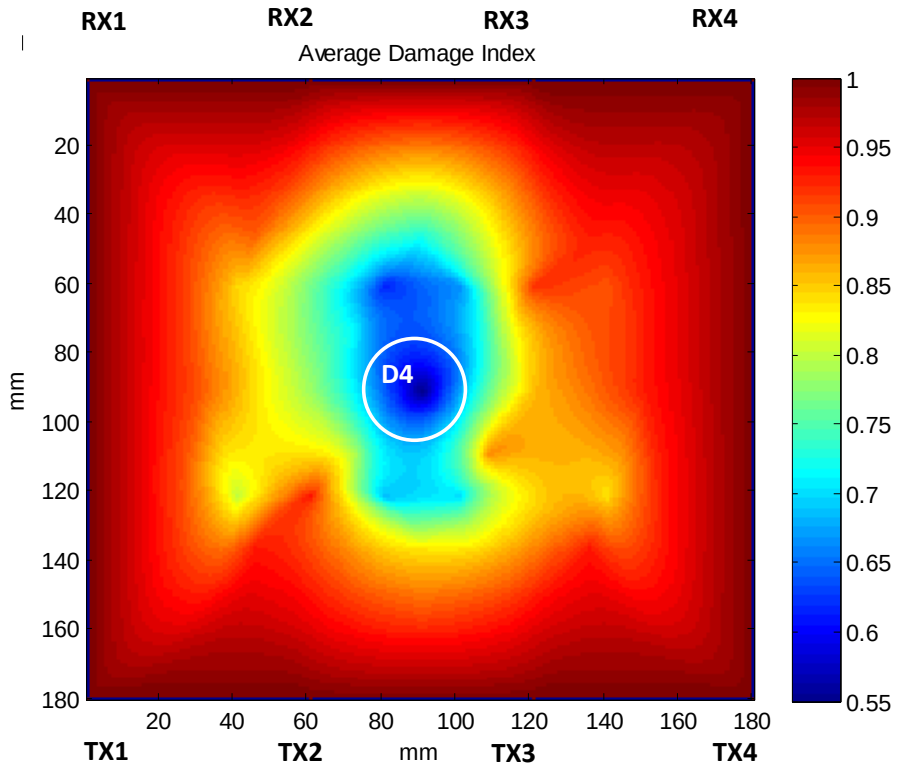
Clock and Gate:
Programmable excitation waveforms for synchronous acquisition

Imaging of a simulated defect D4

Scheme paths with position of defect D4



Colour-map of COPV with defect D4

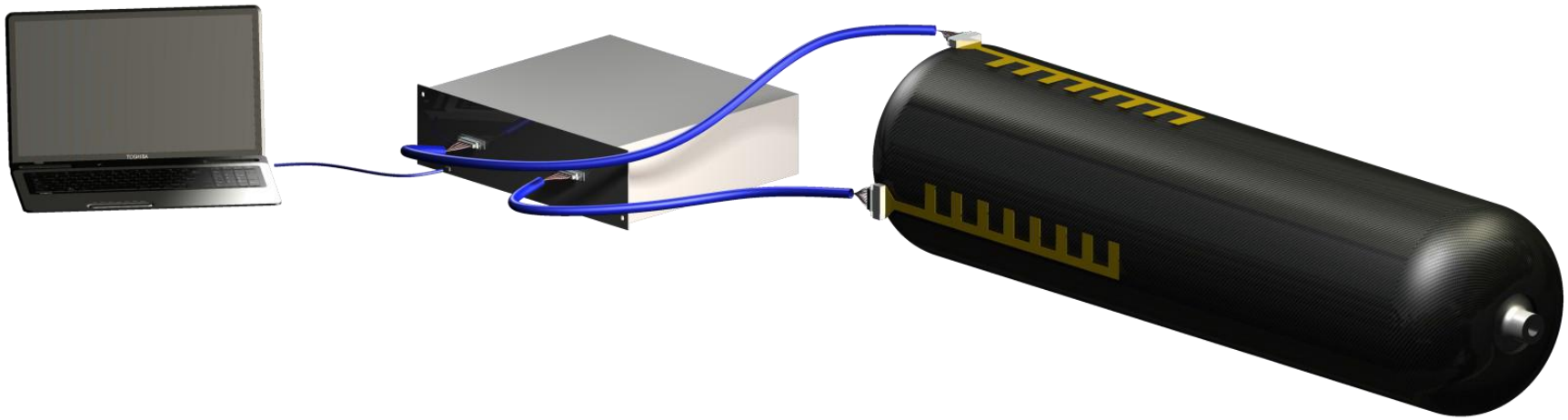


Array configuration with 8 piezopolymer IDTs on COPV

Simulated defect D4:
gel ultrasonic drop with diameter of 20mm

What have we learned from scientific experiments with the SHM system:

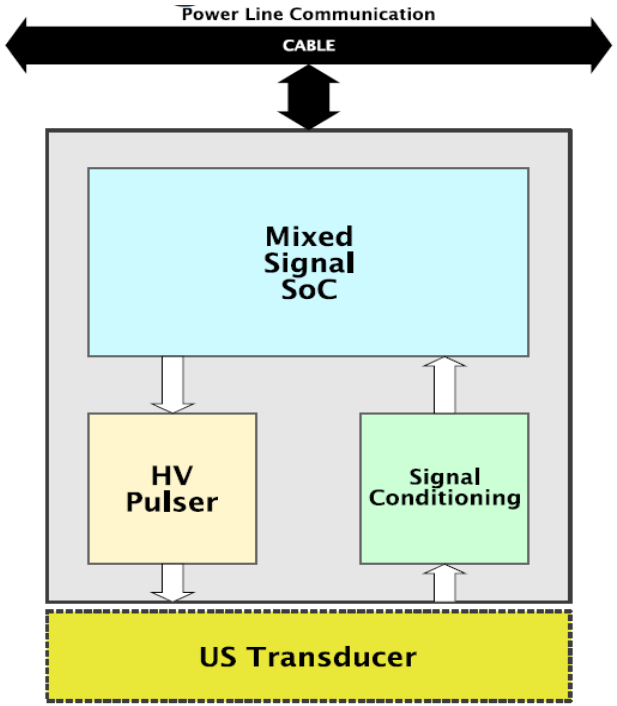
- Multi-pole cables and large dimension of the electronic system limit the versatility
- EMC problem for HV (100V) pulsed signal transmission along the flex circuit tracks
- Very low amplitude analog signals are connected to receivers with long (about 1 m) flex circuit tracks



SHM transducers network

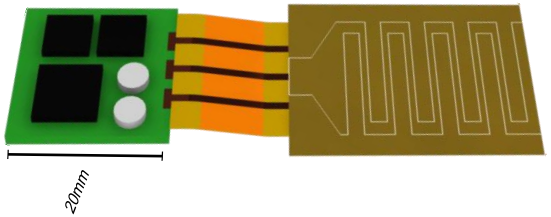
The new goal is to deploy a network of health monitoring nodes over a structure using a reduced amount of wiring:

- Requires the development of highly integrated nodes that can operate one (or more) transducers
- Each node shall provide full DAQ functionalities (pulser, receiver, sampling, digital bus interfacing)
- A base station will process the data acquired by the various nodes and evaluate the health of the structure



Block scheme of a sensor node

Concept design of a sensor node



Conclusions

- New technology for flexible-low profile array with piezopolymer interdigital transducers compatible with space environment requirements
- A damage index has been developed and tested for imaging defects position and size evolution on carbon fibres composite overwrapped vessels (COPV)
- Versatile analog front-end with transducer diagnostic capability and passive mode functioning for impact detection
- A new System on Module has been proposed to innovate this diagnostic method with integrated front-end on each transducer of an array. This step will dramatically improve the applicability of the diagnostic technology to several SHM fields other than space (Aeronautics, Ships, Building, Energy, Automotive...)