COE CST Tenth Annual Technical Meeting

Tasks 323
Structural Health Monitoring (SHM) Framework for Commercial Space Transportation:

Portable electro-mechanical impedance SHM hardware unit development and design of spacecraft data acquisition system as a precursor of future flight recorder

Andrei Zagrai (NMT) & Dale Amon (Immortal Data)

Team Members

- People
  - Andrei Zagrai and Dale Amon

  - Students … in progress of getting visa.., Covid19 impact
- Organizations
- New Mexico Tech and Immortal Data, LLC
  - Both providing matching funds

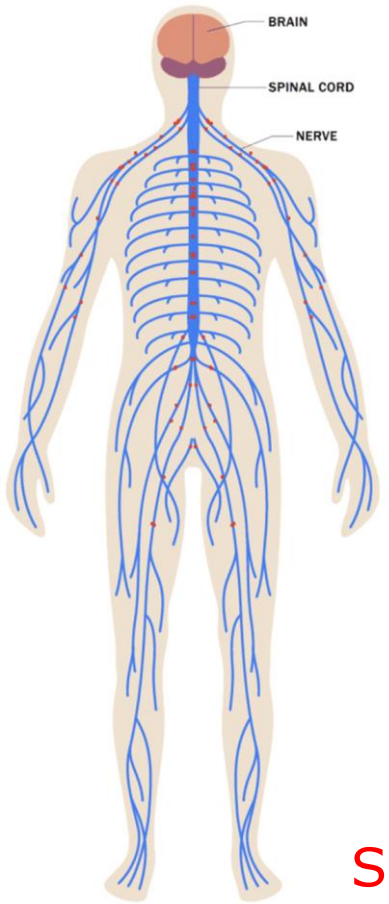
Why?

- Improve safety
- Reduce operation cost
- Structural Health Monitoring (SHM) is seen as one of key technologies that could allow to achieve this goal.

A loose pin prevented one of the parachutes tucked inside Boeing's CST-100 Starliner capsule from deploying during November 4, 2019 crewless abort test in New Mexico.

https://aerospaceamerica.aiaa.org/starliner-descends-one-chute-short-but-nasa-declares-success/ Image credit: NASA

Spaceship that Feels!



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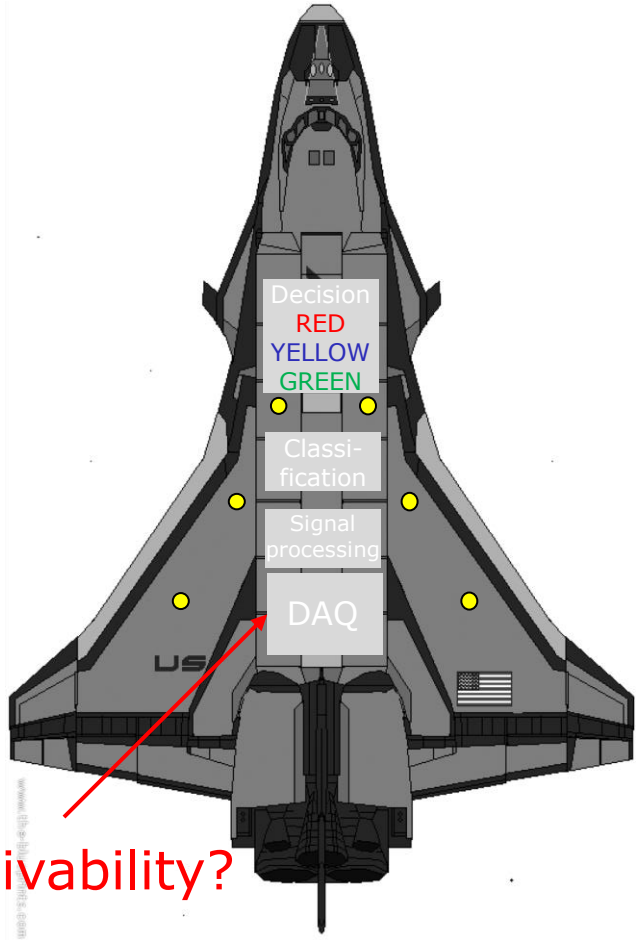


- Passive and active sensors
- Local / global data acquisition
- Signal processing and feature extraction
- Feature classification and automatic decision support (Bayesian, Neural Net)
- Traffic light output
  RED, YELLOW, GREEN

Task Description

- Focus is:
- Development of a portable multi-channel electro-mechanical impedance SHM hardware (NMT lead) and
- Design of spacecraft data acquisition system as a part of SHM framework for CST vehicles, payloads and components. (Immortal Data lead)
- We intend to demonstrate results of development in tests flight(s) on commercial space vehicle(s).

Schedule

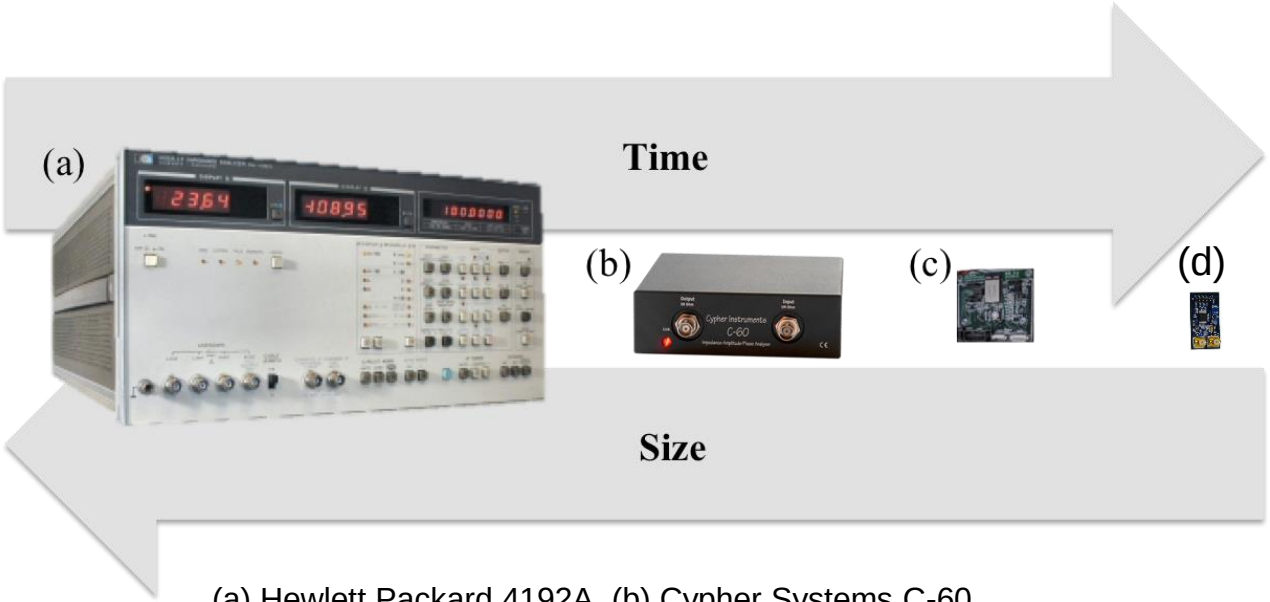
Tasks	2 Years in Months					
	4	8	12	16	20	24
Task 1						
Task 2						

Goals

- Develop a spacecraft data acquisition system which enabled data survivability during catastrophic event
- Develop a small/lightweight electromechanical impedance structural health monitoring (SHM) unit
- Propose integration of SHM and data acquisition system to improve flight safety and reduce flight costs.

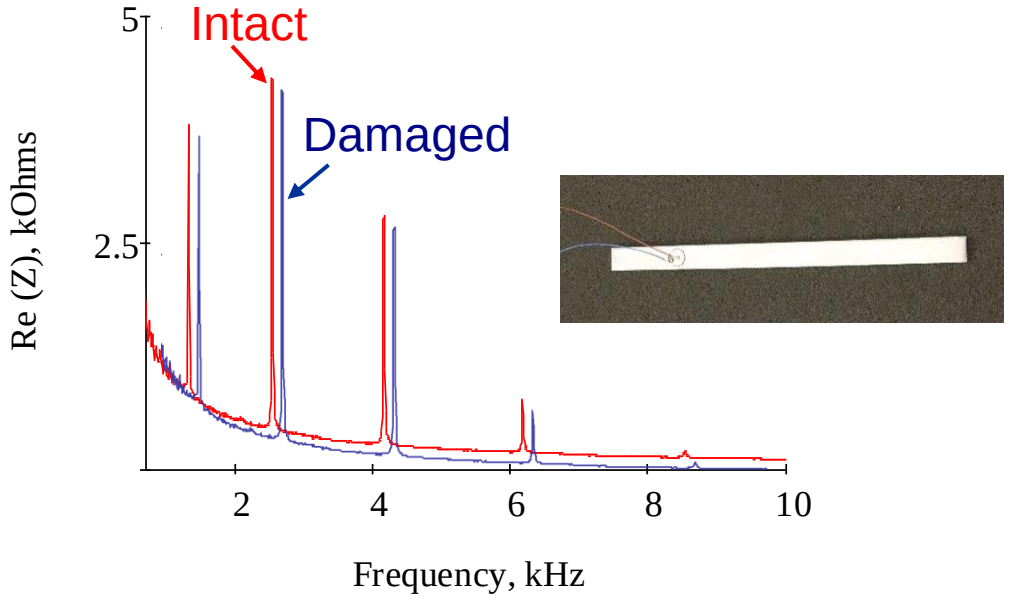
Miniaturization of Impedance Analyzers

- Historically, impedance analyzers were heavy and bulky
  - E.g. HP 4192A impedance analyzer
  - 43 x 24 x 62CM, 19kg

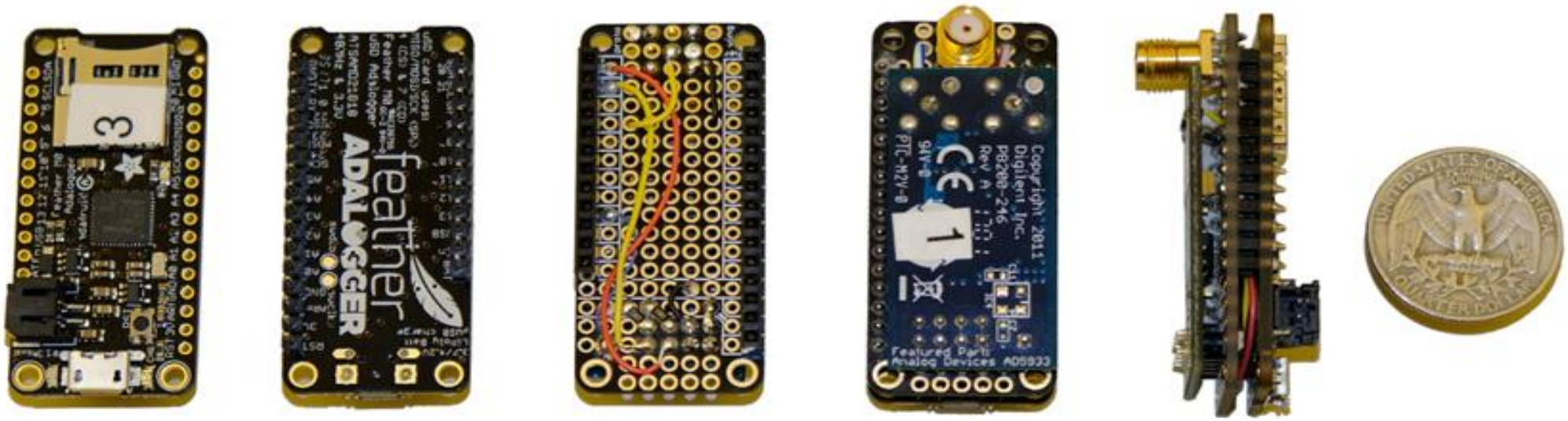


(a) Hewlett Packard 4192A, (b) Cypher Systems C-60
(c) LANL WID3, (d) NMT Canary

- Technological progression
  - PC and DAQ based systems
  - Microcontroller and FPGA based systems.
    - LANL WID system in 2008
    - NMT's Canary 2018



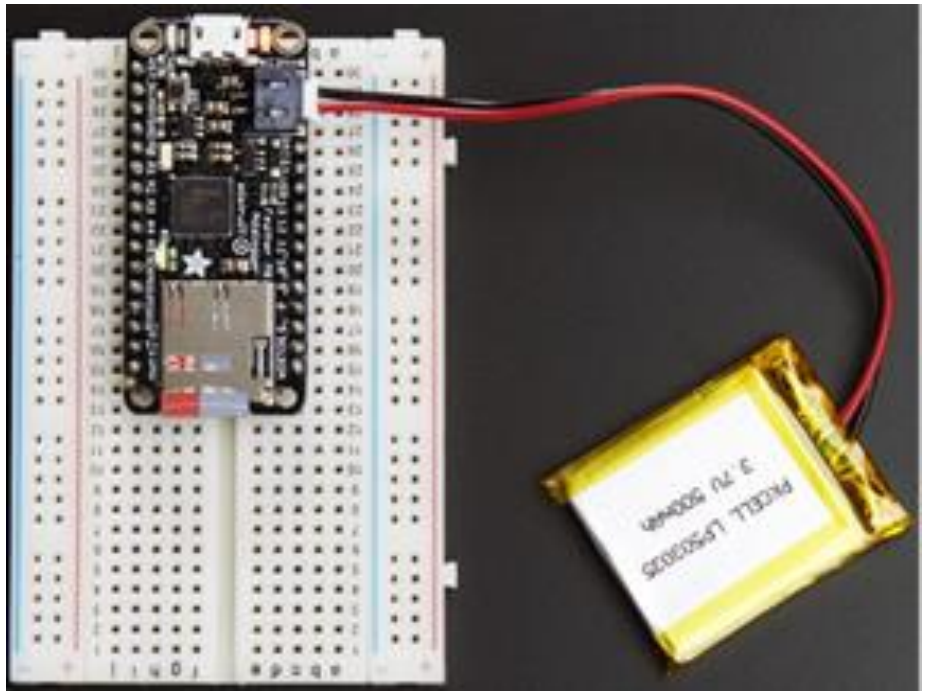
Impedance Measurement Unit - Canary

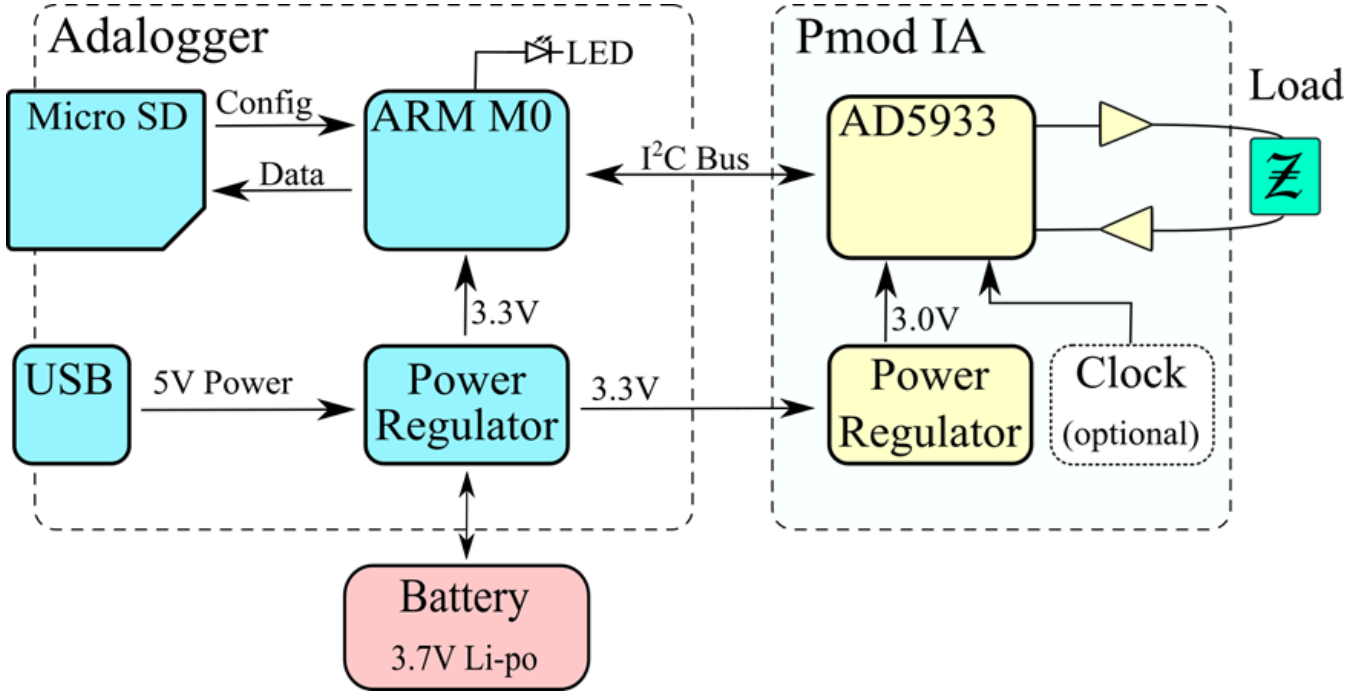


- Full control of AD5933
  - Adjust voltage, gain, and settling time
  - Set frequency in Hz or by frequency code
  - Frequency codes provide 1/32 Hz resolution
- 1kHz to 100kHz specified frequency range
- Save data to micro SD card
- Some post processing of data capability

Battery – powered Unit

- AD5933 + Adalogger = A portable, battery powered, programmable SHM system

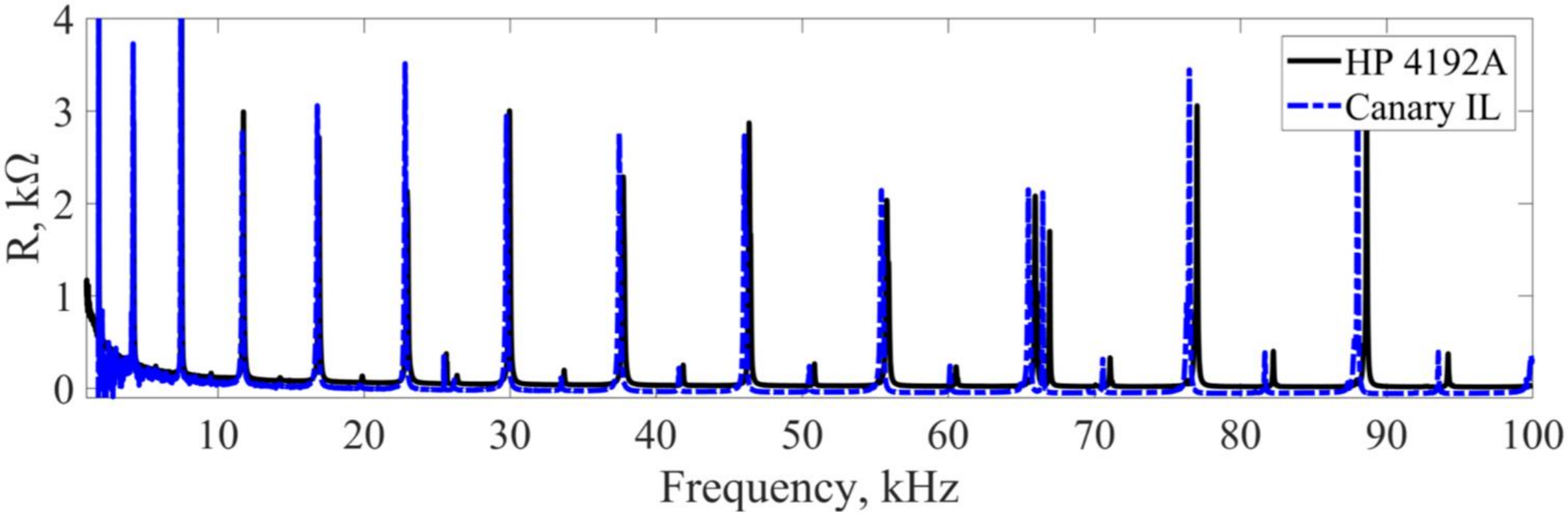




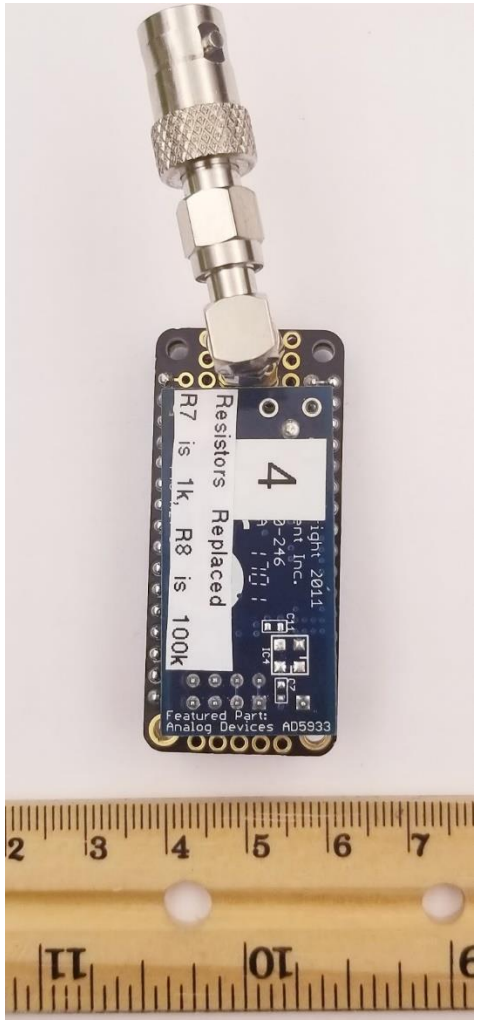
Measures 4cm x 3cm x 0.5cm and weighs 10g

Electromechanical Impedance SHM

Real part of impedance of metallic structure (6061-T6 aluminum circular plate) over broad frequency band



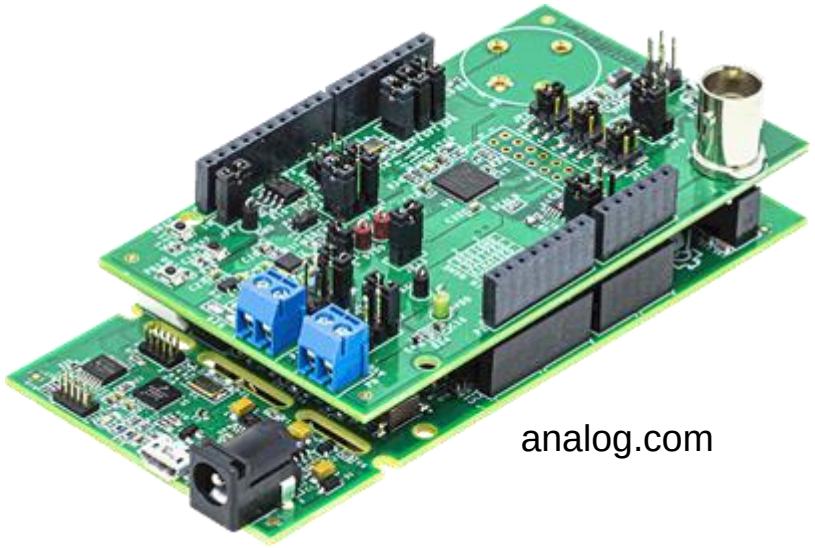
Single-channel unit progress



- Dyllian Powell has provided parts inventory, operation manual and prepared portable computer system to work with Canary.
- We intend to build 3 single-channel Canary units for integration with Immortal Data distributed black box demonstration suborbital flight.
- Ordering of parts for 3 units is in progress

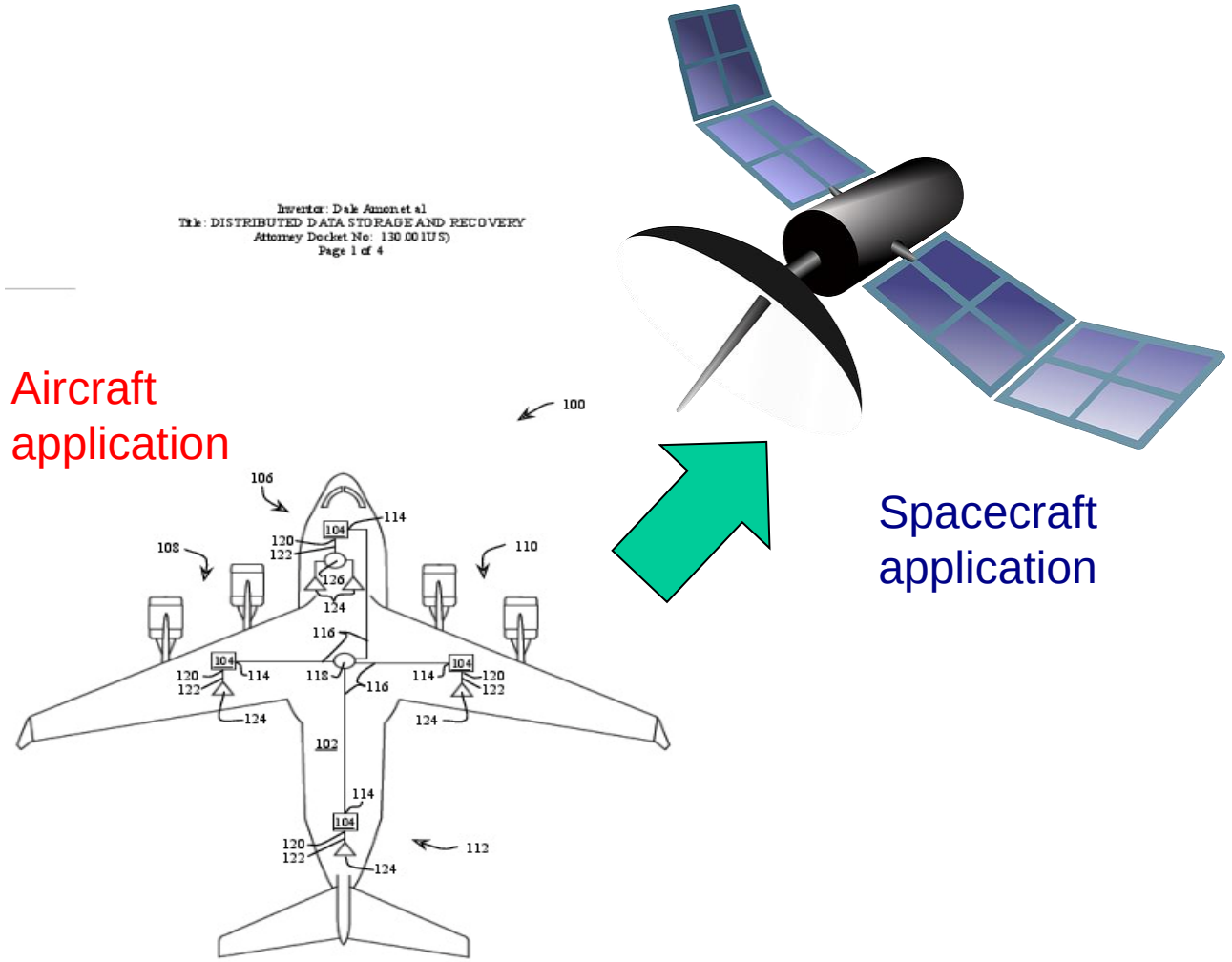
AD5941 New Chip Consideration

- AD5941 is a new generation of chip allowing for impedance measurements.
- Frequency band is improved from 100 kHz to 200 kHz and even possibly 400 kHz.
- Internal clock improvements from 16 MHz to 32 MHz which will allow for improvements of measurement accuracy.
- Improvements in signal-to-noise ratio from 60 dB to 80 dB



analog.com

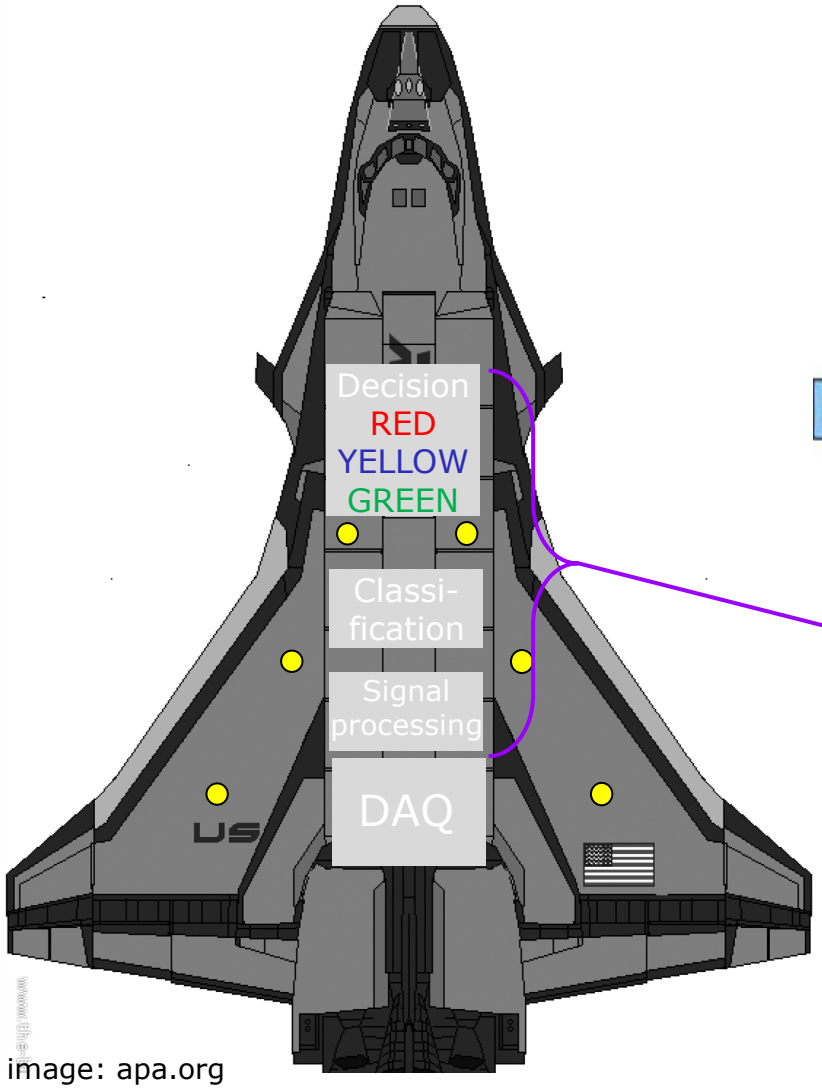
Distributed Black Box™



PATENT #: 9286738 USPTO DN/20150339867

- An Immortal Data patent.
- Numbers works for insects, so why not data? You just can't kill them all.
- Nodes can trade GPS data during the first few seconds after a breakup.
- Every unit knows the trajectory of each of the others.
- Recover any single unit and you have nearly all the data to the last milliseconds.
- Useful in a variety of environments – including aircraft as well as spaceships.

Spaceship SHM and Data Survivability



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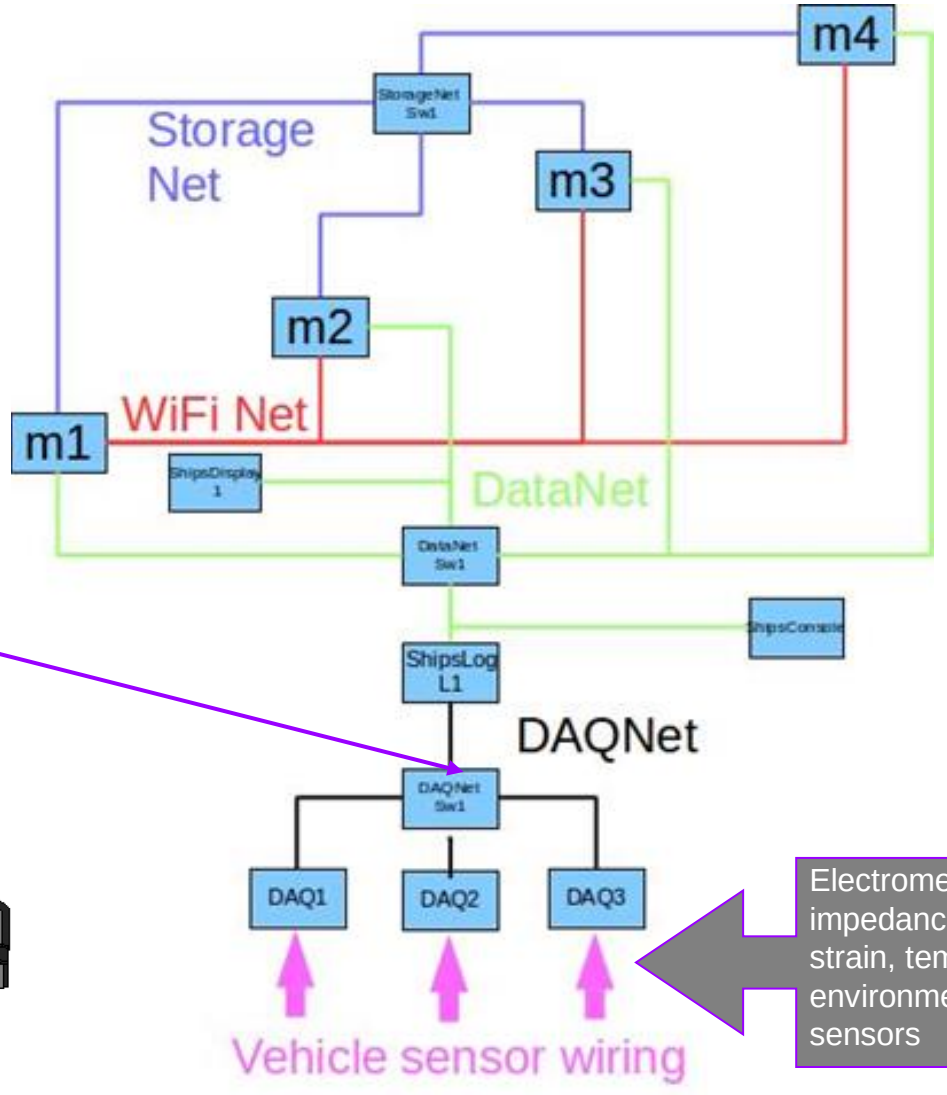


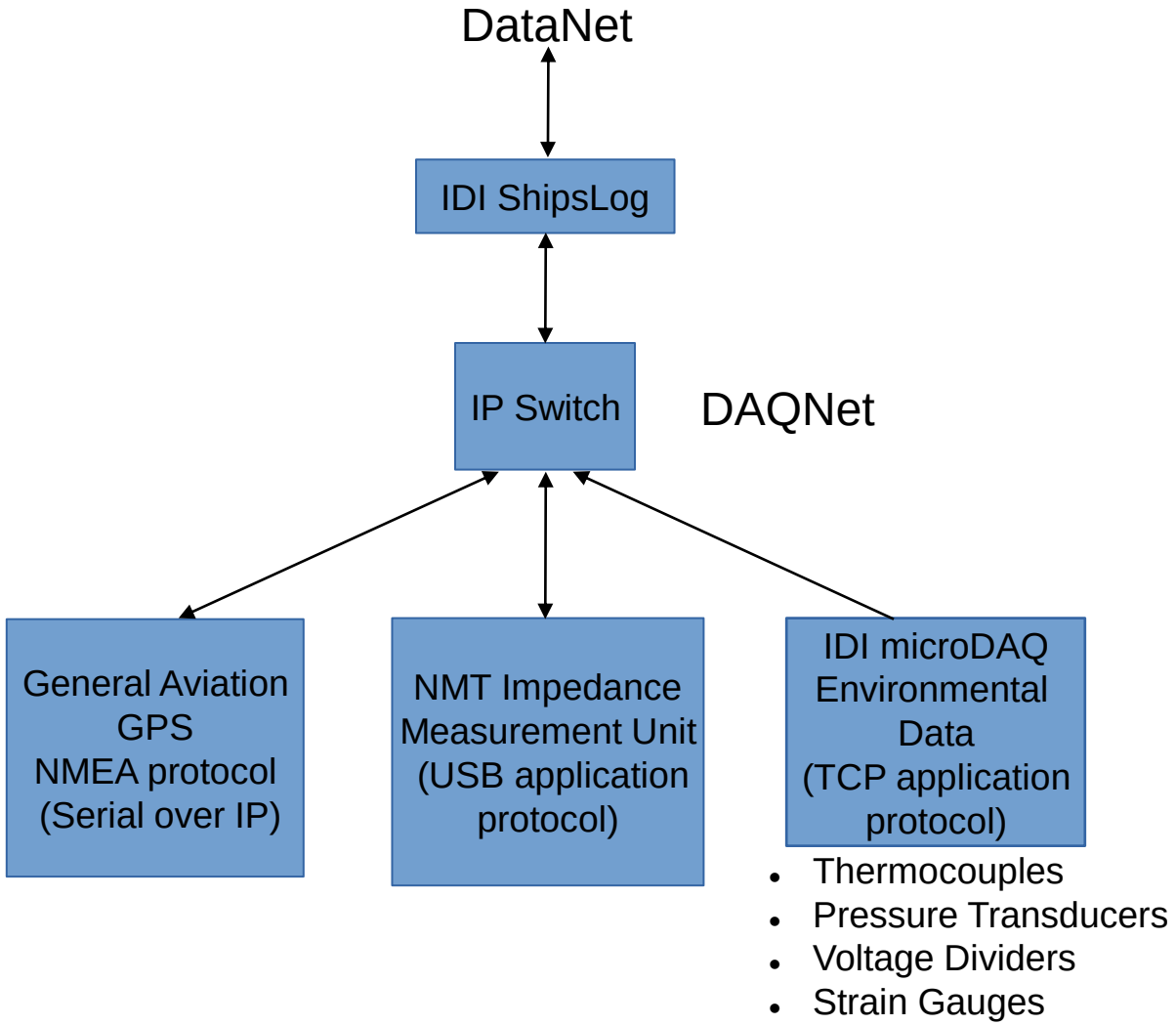
- Redundant path and storage is a key
- ShipsLog™ node polls DAQs on DAQNet
- Data stream is distributed over the DataNet
- Displays, downlink converters, and etc. reside on the DataNet.
- ShipsStore™ can use its private StorageNet and WifiNet to share the data.

Software Design Philosophy

- Hand tooled Real Time loop to collect data, running at a high real time priority in RT Linux.
- Vendor agnostic structure. Only needs a plug in written to interface a new real time data source. We have tested this with a UEI DAQ and an NMEA GPS as data collection peripherals.
- True Real Time is not just optimized use of CPU cycles; it requires traffic on IP networks must be high speed, partitioned, limited to specific uses and traffic tightly controlled to keep sample dropouts at a very low level.
- Standardized low rate / high rate UDP data streaming protocol with only a simple TCP subscription protocol for initial set up.
- Interface to other vendors and other protocol standards is isolated via a translator compute module.

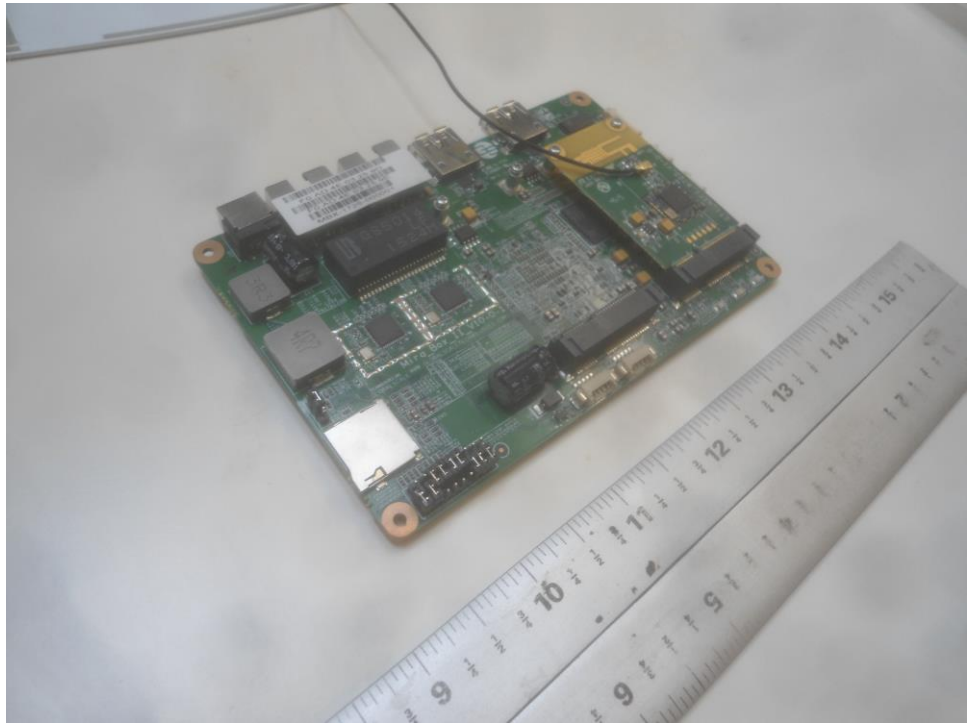
Flight Test Configuration

- ShipsLog coordinates time stamps of disparate devices and stores data frames.
- Each device is polled for single or blocks of sample intervals as appropriate.
- Device agnostic layer allows us to treat all devices as DAQ/Card/Channel, even a Serial NMEA data source.
- NMT needs combination of background environment data as well as the structural signals.
- IDI needs environmental background and proof of concept data.



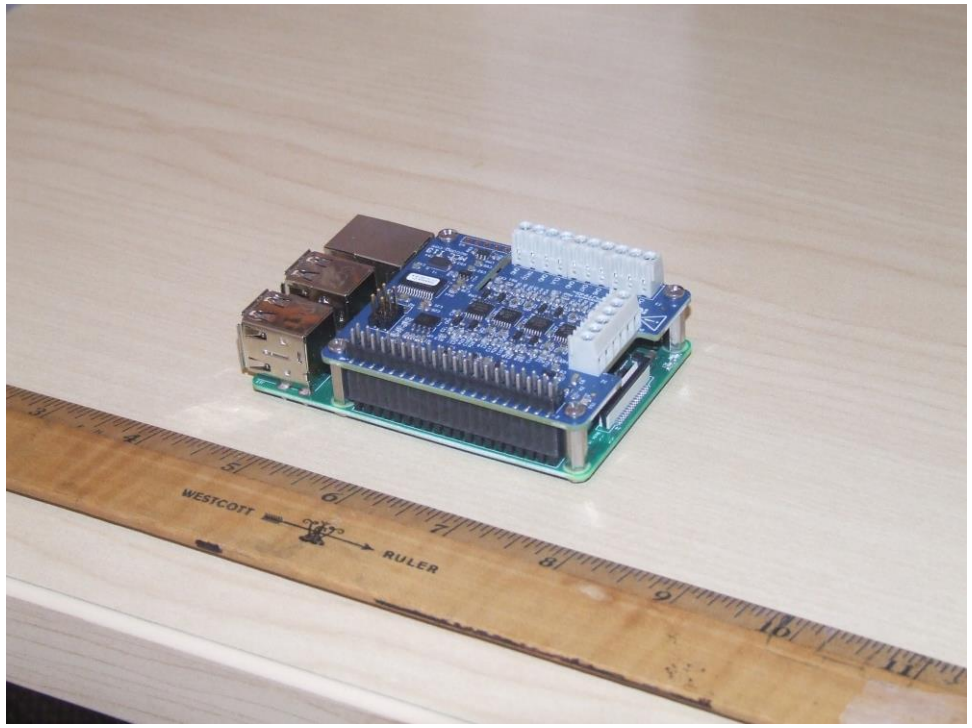
IDI Basic Compute Module

- Prototype unit shown is for ground equipment but with some modifications is good for short term use in LEO.
- Our own compute module for longer term space flight (longer than safe with COTS), will come when we have investment or sufficient internal revenue generation to support it.
- Will have just what is needed for our requirements and no more.
- Module will be common across all of our products (microDAQ, ShipsLog, ShipsStore,etc). These vary at the software and daughter board level.



Standard compute module prototype

Data Acquisition Unit

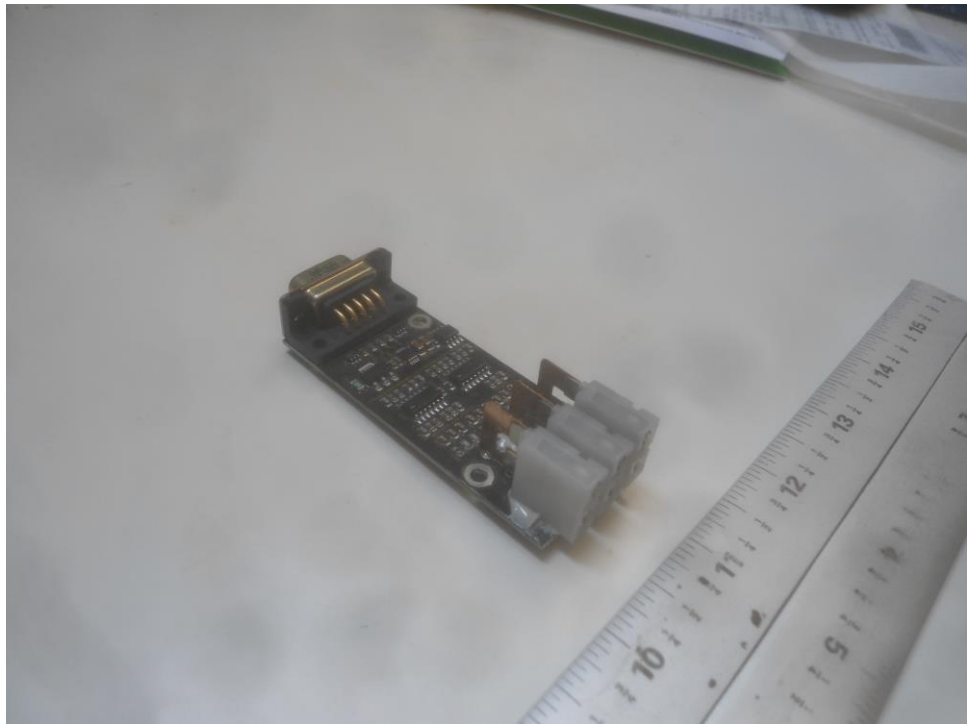


8 port analog microDAQ prototype

- Prototype unit shown is for ground equipment but with some modifications is good for short term use in LEO.
- We are planning our own compute module for long term space flight based on lessons learned.
- Each top hat (1 shown) handles 8 analog inputs; up to 8 are allowed, giving 64 inputs.
- Far cheaper, lower volume and lower mass than Lynx DAQ, although it could handle 124 inputs.

Standardized Sensor Inputs

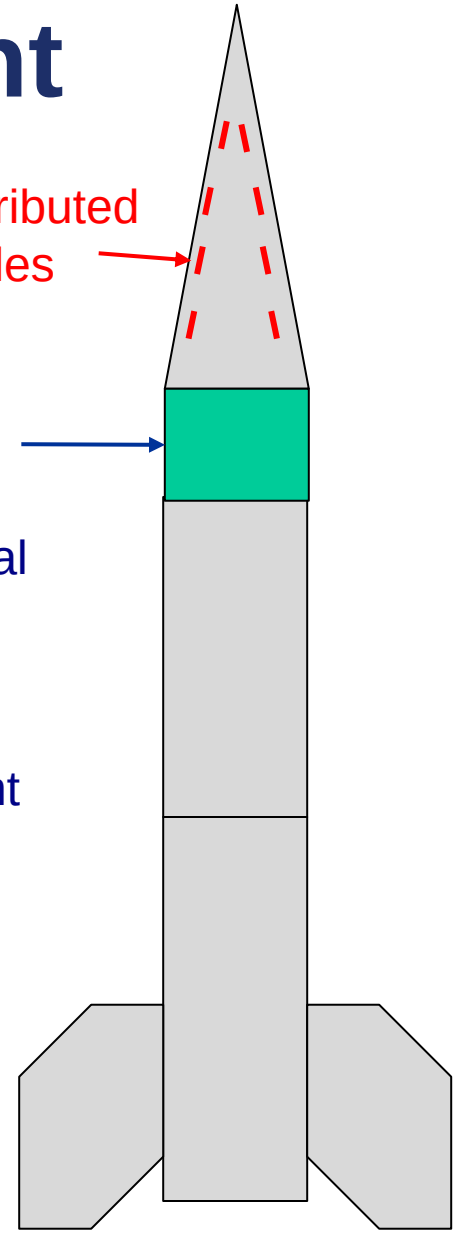
- System supplies power to sensors that require it.
- If sensors require specialized electrical interfaces, we isolate them via instrumentation amplifiers.
- Software loads specialized type objects as needed for conversion of a sensor voltage input to a calibrated engineering unit value.
- Sensors considered:
  - ADXL356 accelerometer 3 axis/ 20g;
  - P51-15-A-B-P pressure transducer;
  - Duplex Insulated K-type thermocouples;
  - 9 additional channels (strain/temperature)



3 Input thermocouple instrumentation amplifier / signal converter

Preparation for Suborbital Test Flight

- Flight will demonstrate
  - Functionality of distributed blackbox in space and reentry environments
  - Operation of NMT's single channel impedance measurement SHM unit
  - Collection and storage of spatially distributed temperature data.



Flight test is anticipated in February 2021

Publications, Presentations, Awards, & Recognitions

PUBLICATIONS

1. Zagrai, A., Campisi, M., Anderson, M., Hunter, D., Sanchez, J.A., Demidovich, N., Kessler, S., (2019) “Structural Diagnostics, Prognostics and Health Management for Future Space Vehicles: Development, Implementation and Testing,” Proceedings of 2019 IEEE Aerospace Conference, Big Sky, MT, USA, March 2-9, 2019, pp. 1-11. doi: 10.1109/AERO.2019.8741659
2. Zagrai, A., Misla, A., Sanchez, J., Powell, D (2020) “Electro-Mechanical Impedance Method for Structural Health Monitoring of Space Structures: from Laboratory Experiments to Measurements during Spaceflight,” Proceedings of the AIAA Propulsion and Energy 2020 Forum, paper AIAA 2020-3529, August 24-28, 2020, Virtual Event, https://doi.org/10.2514/6.2020-3529.
3. Amon, D., (2020) “Design of an Inexpensive Black Box for Commercial Orbital and Suborbital Vehicles,” presentation at Commercial and Government Responsive Access to Space Technology Exchange (CRASTE), June 22, 2020, Virtual Conference.

PRESENTATIONS

1. Zagrai, A., Powell, D., Hunter, D., Anderson, M., Amon, D., Demidovich, D., (2019) “Advances in Electro-Mechanical Impedance Structural Health Monitoring for Space Systems,” presentation at Commercial and Government Responsive Access to Space Technology Exchange (CRASTE), June 24 - 27, 2019, Henderson, NV.

Conclusions and Future Work

- NMT team prepares a single-channel impedance measurement unit for suborbital test flight
- Establishing of specifications and practical realization of spacecraft's distributed data acquisition system is in progress
- Immortal Data did much work on hardware and software for the proposed system. Due to pandemic, NMTs experiences delays in multi-channel unit and software integration.
- Covid19 impacts operation, especially student hiring and work
- Immortal data and NMT are preparing for a suborbital flight test early next year, likely with UPAerospace.