High speed Data acquisition using a battery powered cRIO with GPS synchronised wireless data transmission.

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**SCITEK Consultants Ltd

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http://www.scitekconsultants.co.uk

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    - Synchronisation
    - Latency
- Conclusions

SCITEK Rolls-Royce - Businesses

Civil Aerospace	Defence Aerospace	Marine	Energy
			

I n n o v a t i o n

S e r v i c e s

Supply chain units

- Compressors
- Turbines
- Controls
- Instrumentation
- others

Strategic Research Centre

Research & Technology

Group Executive

Corporate Functions, e.g. Logistics, Purchasing, Services

To provide an effective and timely strategic research service to Rolls-Royce

- Identification, evaluation & development of novel technologies
- Providing pro-active advice to the Company's Businesses
- Maintaining awareness of external developments & emerging technologies

Measurement programmes

- Fibre Optics, Imaging and Wireless sensors
- Research and develop low TRL measurement technologies for operational groups across Rolls-Royce

About SCITEK Consultants Ltd

Engineering Services

Fluid Mechanics
CFD, LDA, PIV, Spays

Rig Design
CAD + FEA, Frequency Analysis, Instrumentation

Instrumentation+ Control Systems
Software, Sensors, Signal processing, Test rig infrastructure
LabView certified developer

Image Analysis
X Ray Analysis, Strain gauge Calibration, Neutron Radiography

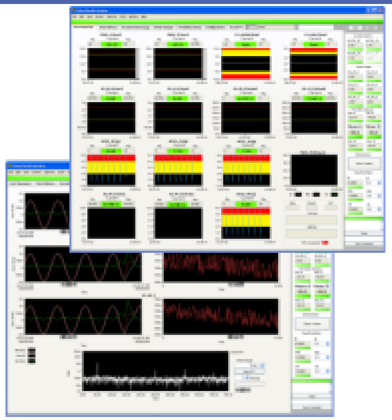
Jet Engine Test Bed
RR Viper 201

Staff : 10 Consultants, 8 Technicians, 2 Administration, + Associates

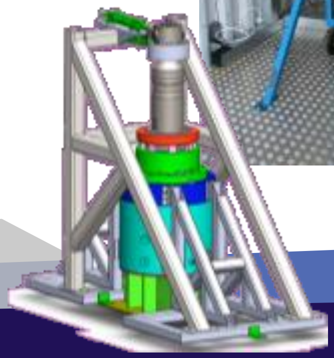
In-house Facilities

Workshop, Optics Lab, Test Rig area, Electronics Lab.
Vibration and bearing test rigs, PCM Bearing Test Rig

SCITEK Capabilities:

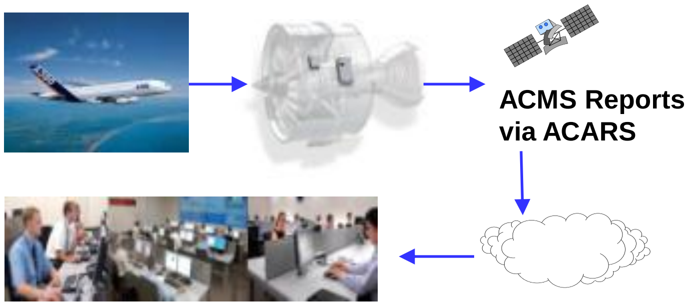


- Design, manufacture and instrumentation of R&D rigs
- FEA, Thermal and Frequency analysis
- Vibration and Noise measurement
- Experimental and Computational Fluid Dynamics
- Image analysis for engineering applications
- Data acquisition and Control systems
- Software Development for control, data acquisition and signal processing
- Programming in LabView (National Instruments Alliance member – 2 LabView Certified developers)
- Integrator of University developed technology to industry.

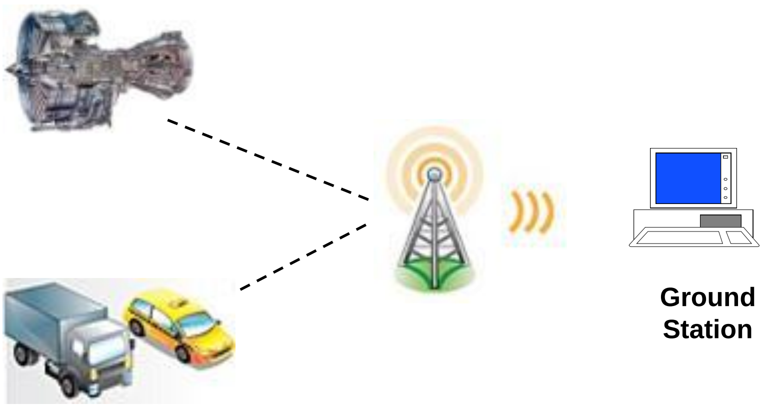


Wireless sensor applications in RR

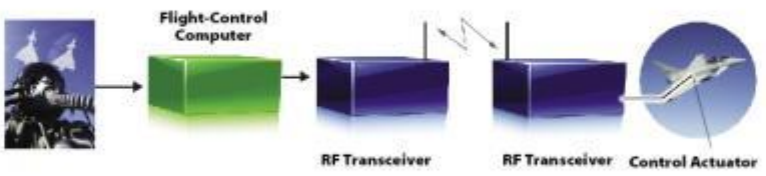
Test & Measurement



Equipment Health Monitoring



Asset Management & RTLS



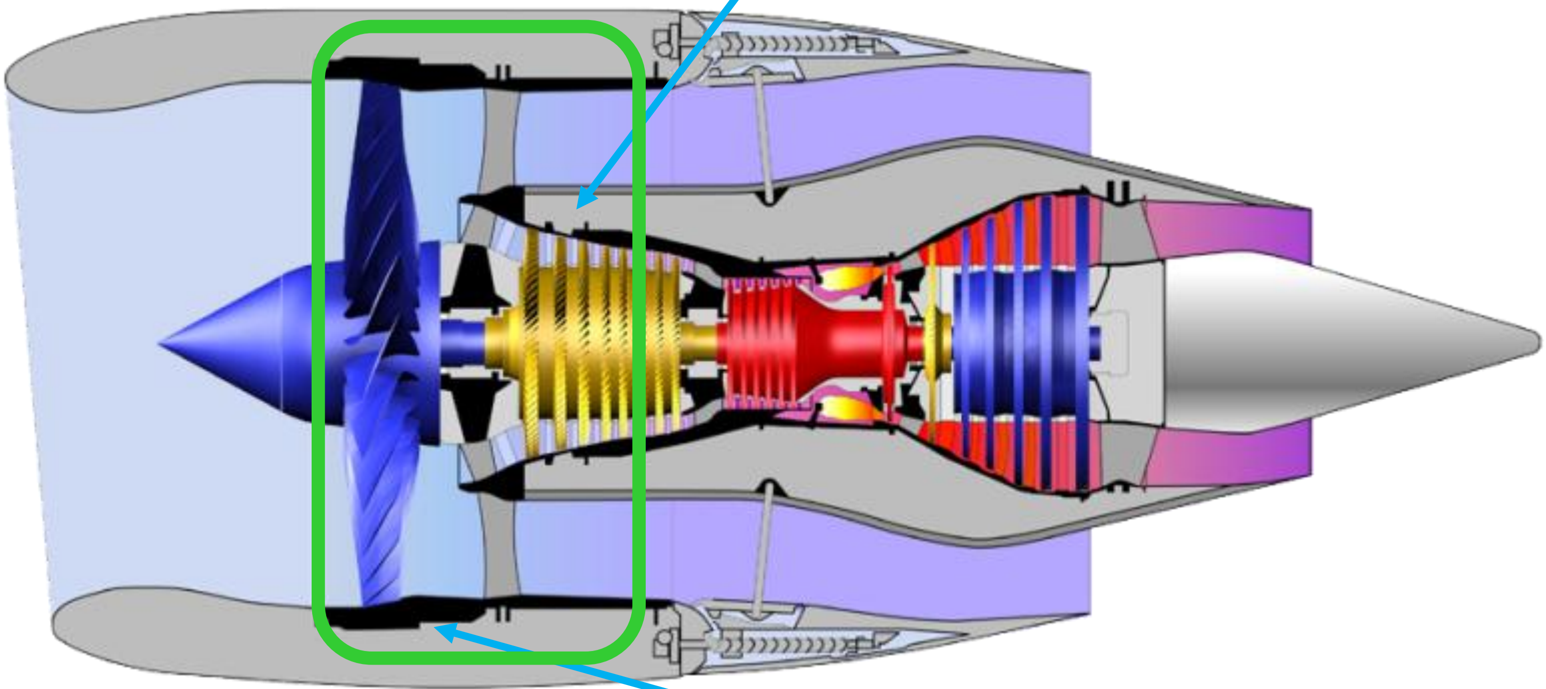
Wireless control

Wireless sensor overview

Wireless Sensors for development engines

- **Active**
  - Data concentrator
    - Low temperature
    - Processor
    - g, T, p, e
    - Battery powered / energy harvesting
    - High data throughput possible
    - Larger size
    - Real time data streaming
  - Sensor node
    - Low temperature
    - Processor
    - g, T, p, e
    - Battery powered / energy harvesting
    - Moderate data throughput
    - Small size
- **Passive**
  - Sensor node
    - Higher temperature
    - No processor
    - g, T, p, e
    - No battery
    - Moderate data throughput
    - Small size

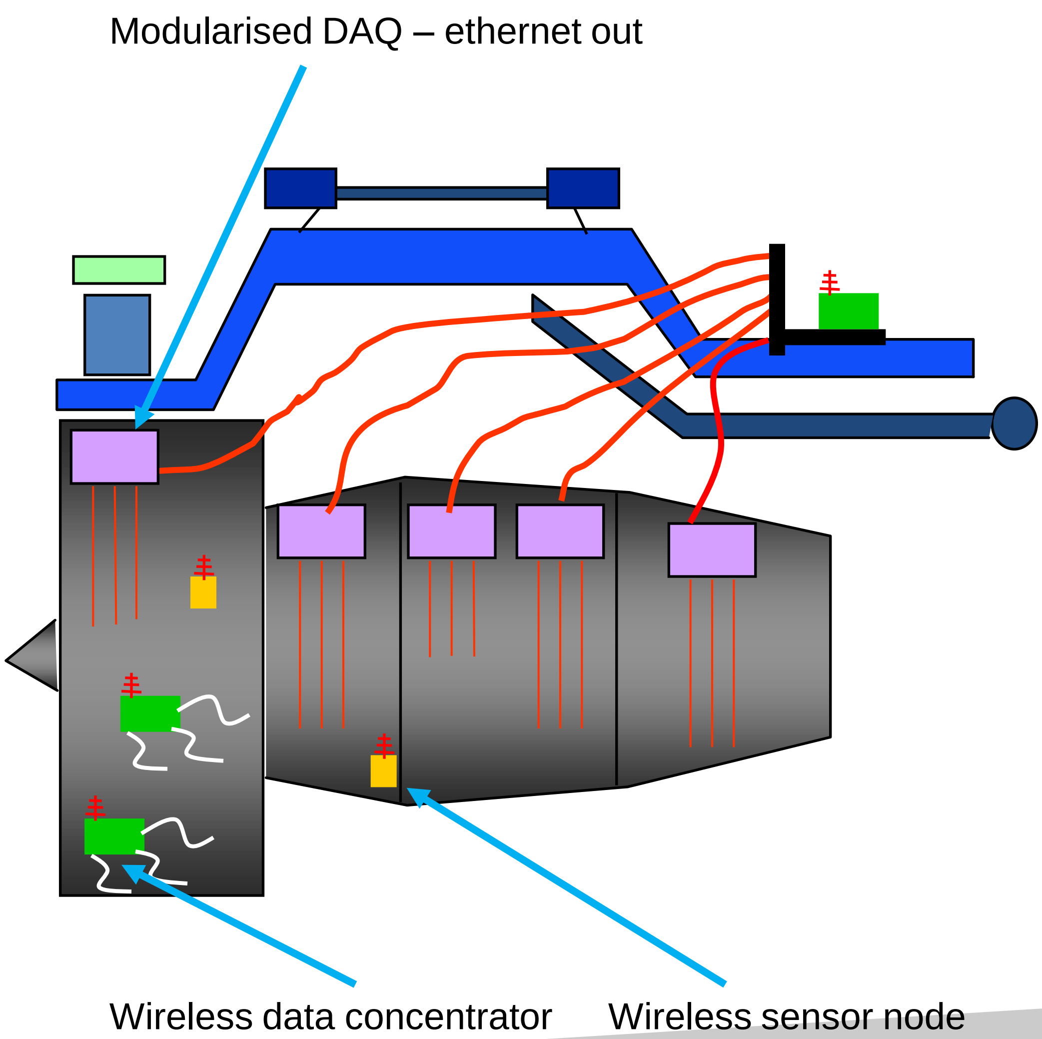
Development engine – low temperature zone



Development engine – state of the art

- 3000+ parameters measured on development engine
  - Every transducer led out to pylon
- Cables tie engine modules together
  - difficult to dismantle engine in case of problem
- Risks inherent with cables
  - Connector faults
  - Incorrect connection
  - ⇒ Cost

Wireless sensor benefits

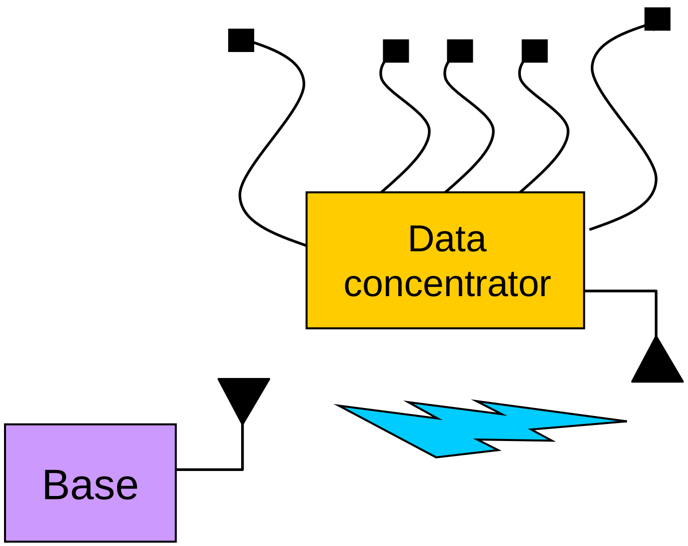


- Additional data concentrators for quick, ad hoc measurements – no cable replacement
- Re-measurement for affirmation without extensive re-rigging
- Simplification
- Reduction of connection faults and failures
- More reliable measurements lead to significant cost savings

Requirements spec

Parameter	typ. value
Signal bandwidth	15 kHz
Resolution	16 bit
Latency	0.1 s
Synchronisation	< 1 ms
Battery charge cycle	10 h
Channel #	12
Internal temp channels	3

Data concentrator



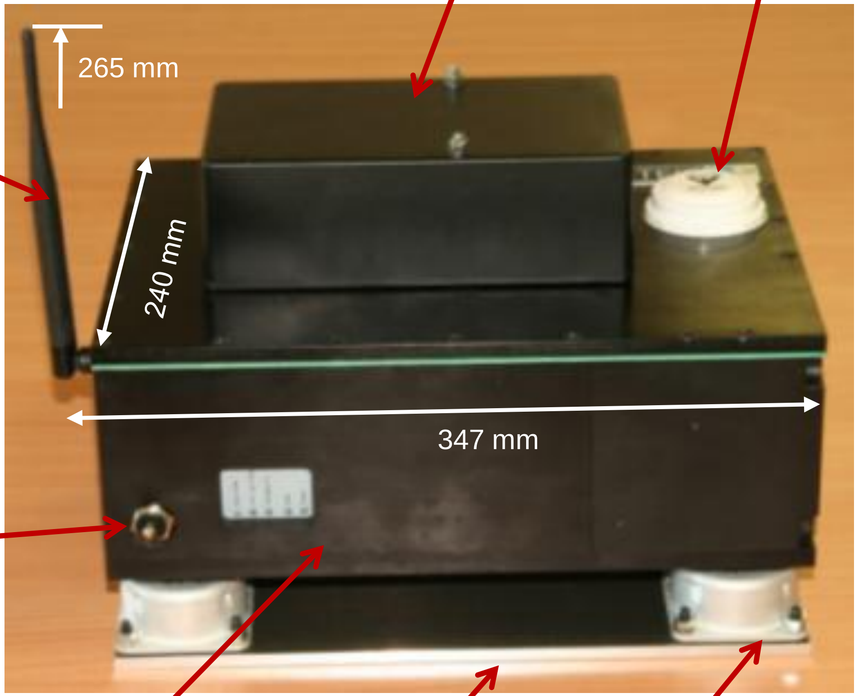
Test bed application
- COTS transducers: g, T, p (+)
- Multiple channels (+)
- High data rate radio (+)
- Higher power consumption (-)
- Bulky packaging (-)

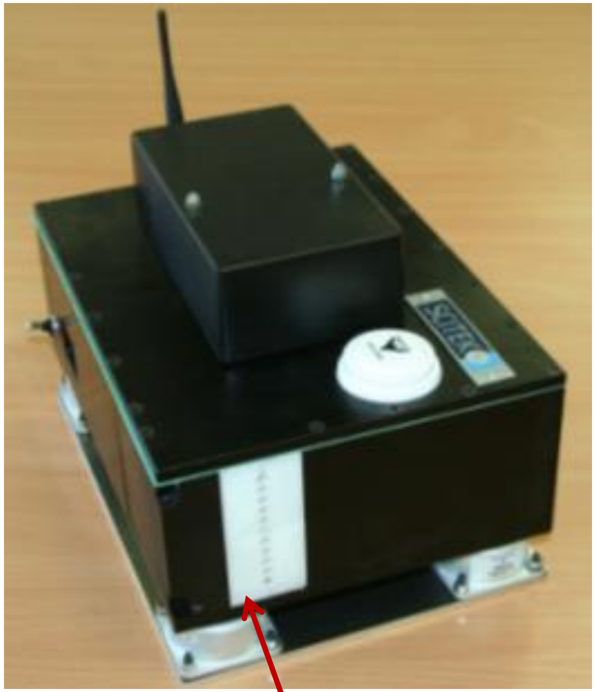
System Overview

Removable Battery pack

GPS Receiver Antenna

Wireless Antenna for transmitting Data





Waterproof Power Switch

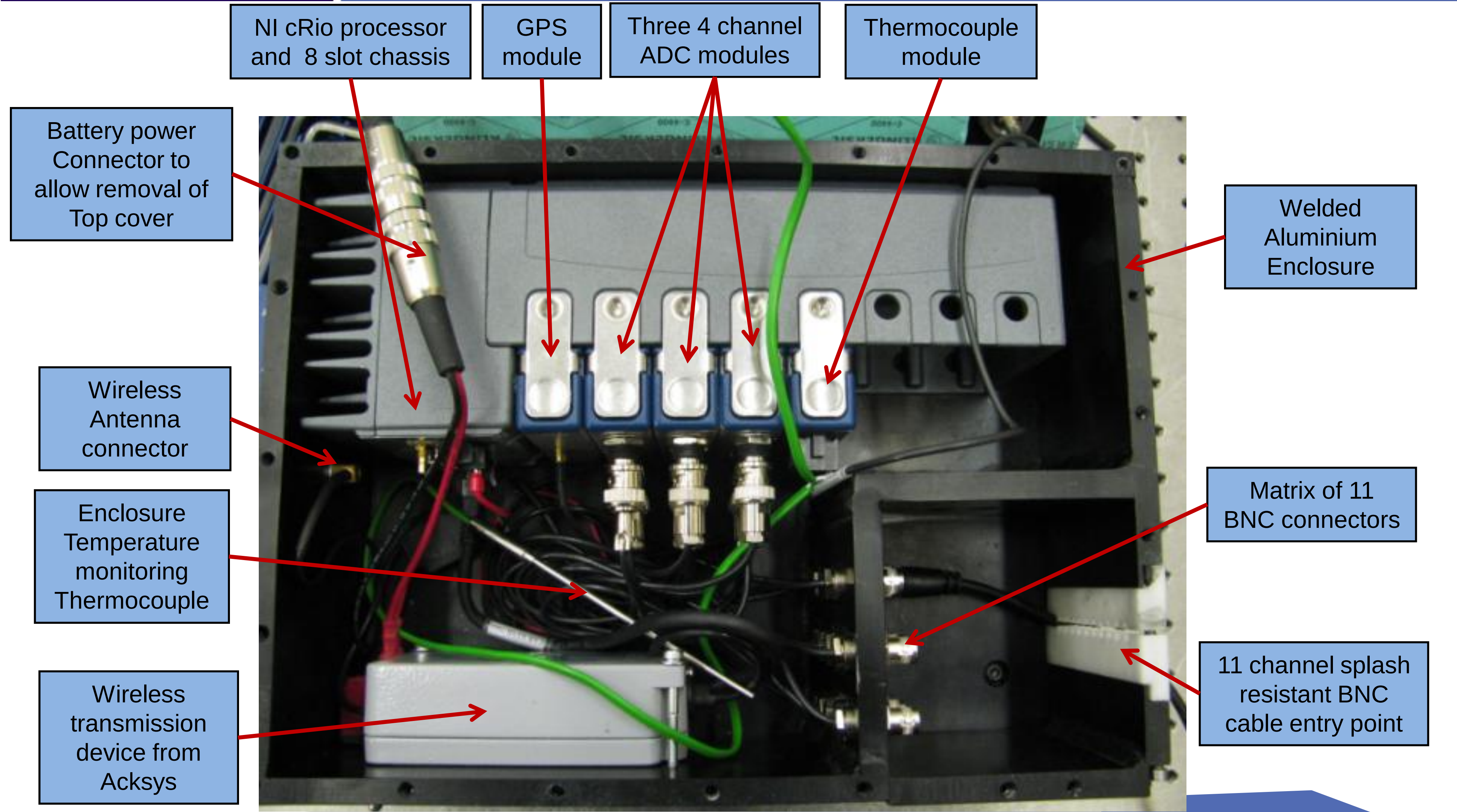
Wireless transmission indicator LEDs

Aluminium Mounting Base

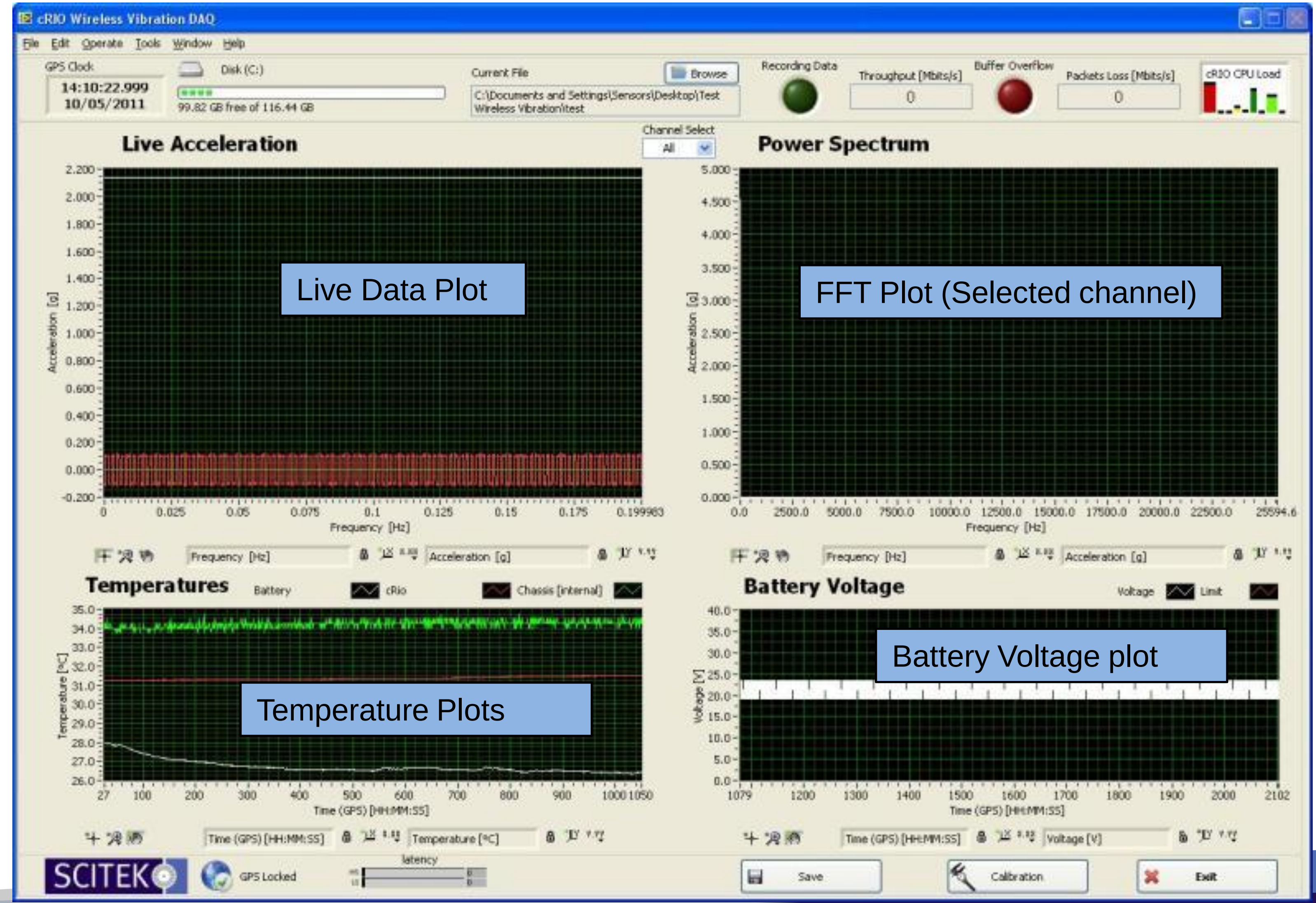
Vibration Isolation mounts

11 channel splash resistant BNC cable entry point

Internal Components



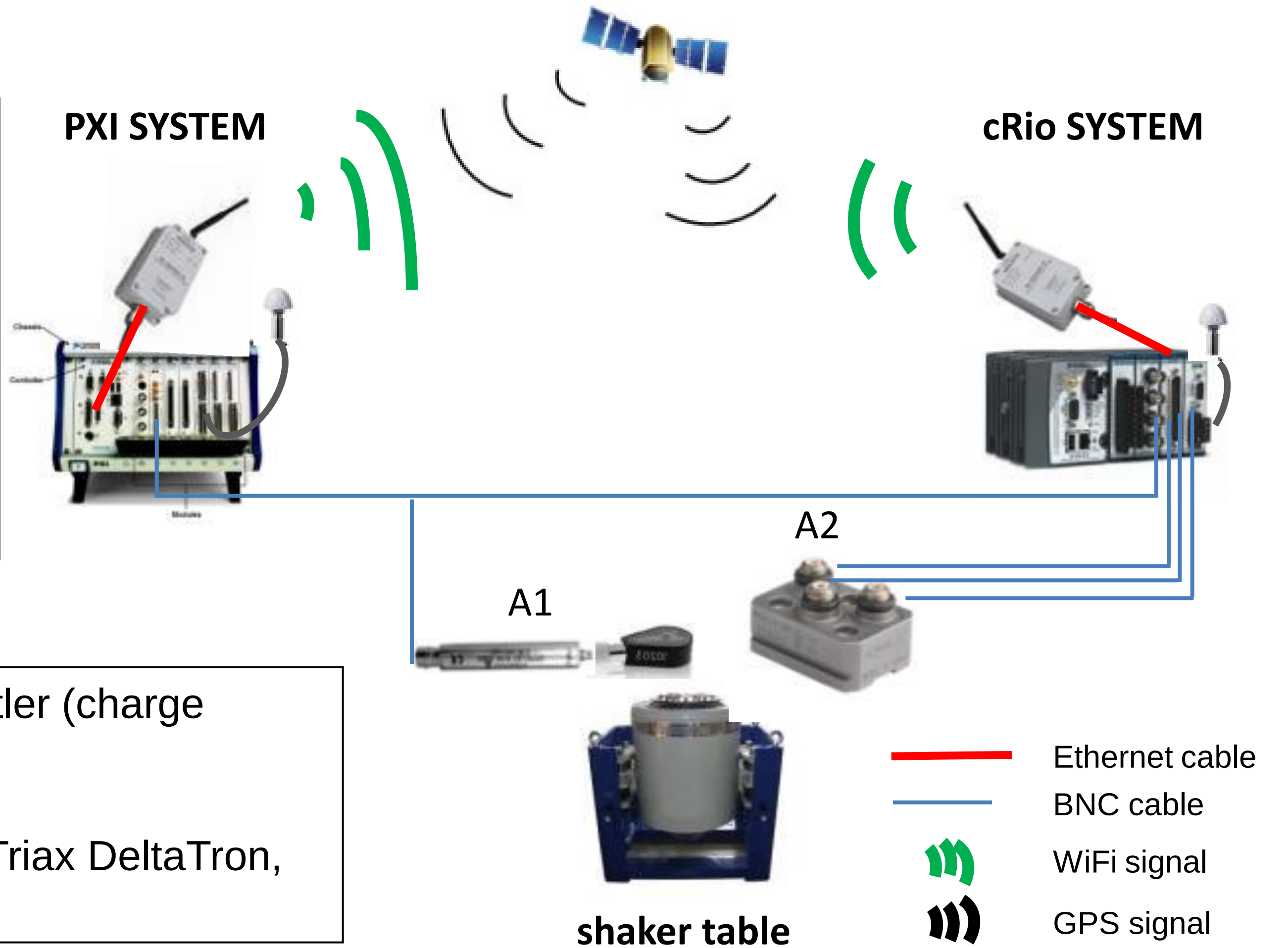
Software User Interface



cRio CPU loading

Experimental set up

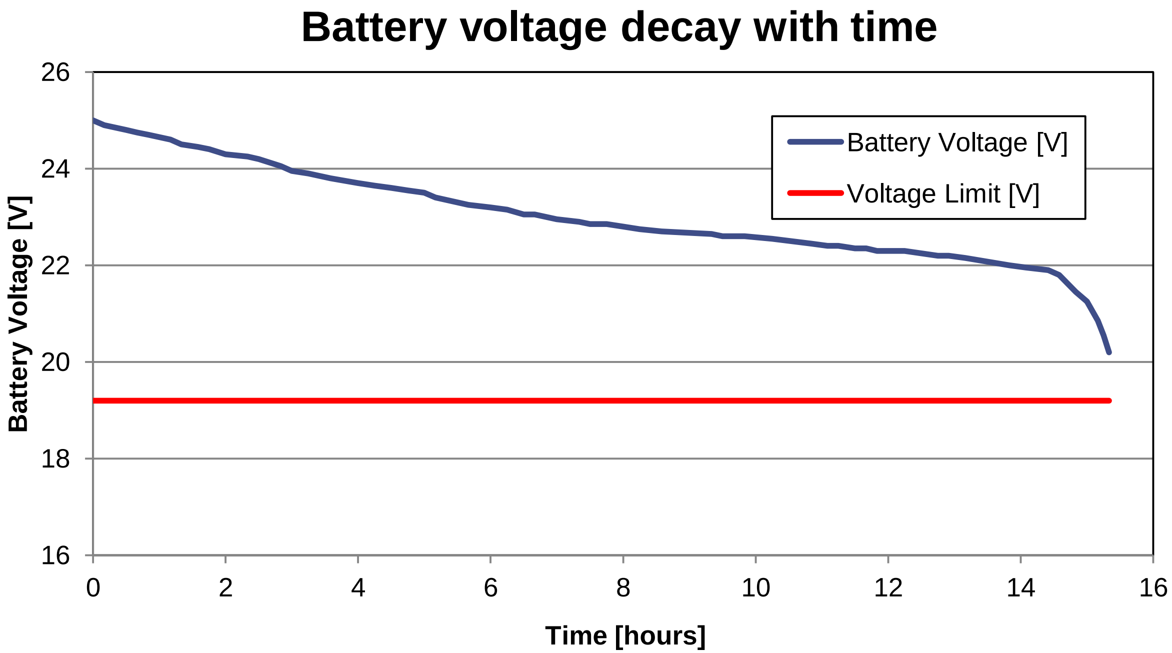
- Wi-Fi, 802.11a ch 44
- 20 Mbits/s
- cRIO 12 channels
- 51.2 kSps per channel
- Power
    - Battery: 5.8 Ah
    - System : 0.405 Ah
    - 14.3 hours



A1 : Endevco 2220D with Kistler (charge amplifier), Sensitivity 20 g/V

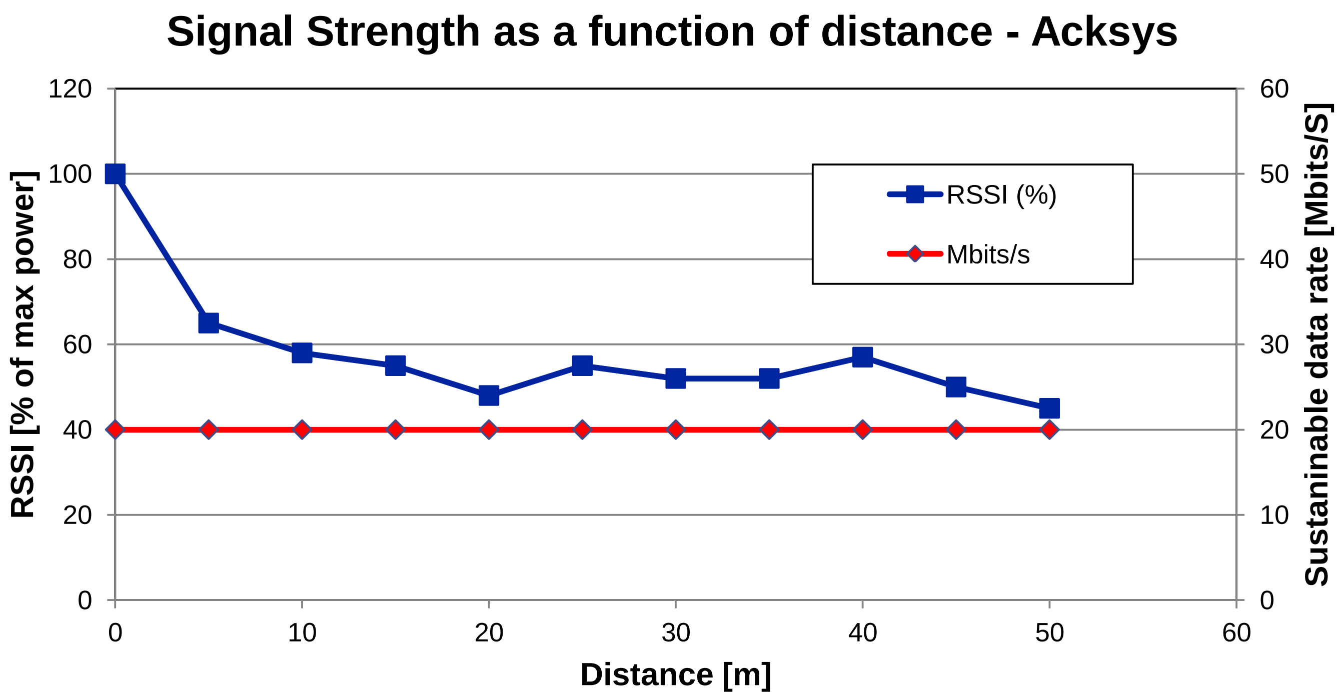
A2 : Bruel&Kjaer 4504 IEPE Triax DeltaTron, Sensitivity 100 g/V ±20%

Power Consumption - Tests



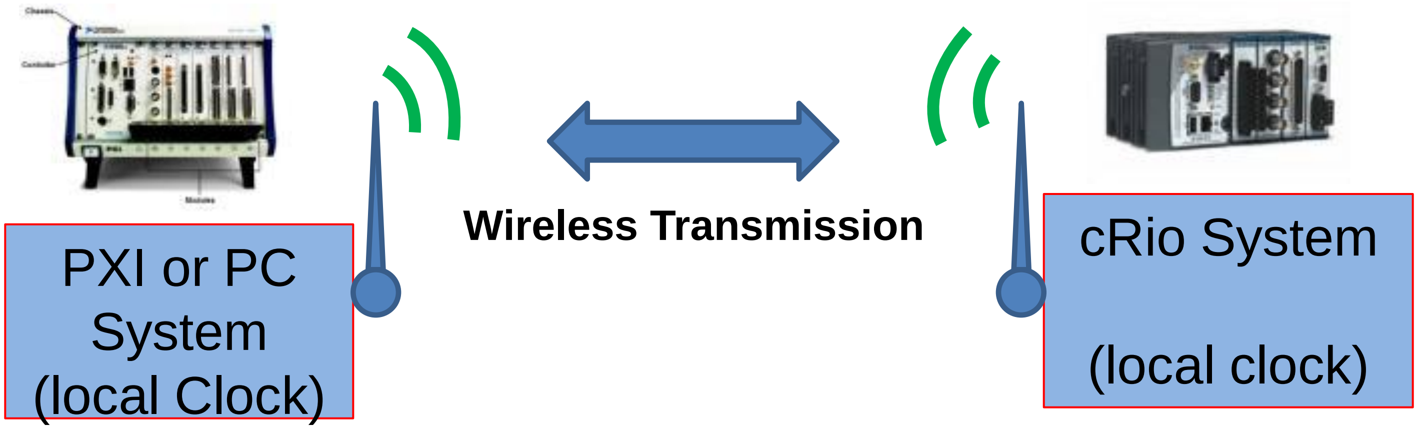
- **Test was carried out with system recording at 51.2 kHz on all 12 channels and transmitting the data through the Acksys wireless device to a PC**
- **Use of system on one battery for up to 14 hours**
- **System can be used continuously for up to 10 hours replacing the battery with a freshly charged one at the end of the 8 hour shift with plenty of reserve power.**

Range and Data Throughput Tests



- **Data rate is unaffected by distance between device and test bed hub**

Synchronisation Background



Clocks on each system will drift (slightly) due to environmental conditions.
Observed variations from 3ms to 3s.
Thus Clock synchronisation needs to be done at regular intervals.
The satellites of the Global Positioning System (GPS) broadcast radio signals to enable GPS receivers to synchronize time on Earth’s surface.
Therefore two independent systems can be synchronised with high accuracy using GPS receivers.

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Synchronisation Challenge

- **cRIO FPGA clock is 40MHz (25ns/cycle) with stated accuracy of 100ppm (possible drift of 100µs per second). Actual frequency drifts primarily with temperature.**
- **Data Acquisition (NI 9234 module) clock accuracy of 50ppm – still not good enough!**
- **Cannot synchronise the sample clocks of data acquisition modules without a wired connection.**

Synchronisation Possibility

- **A good GPS signal provides accurate time information to within 100ns of UTC (Coordinated Universal Time)**

- **Possible Solution - S.E.A. GPS module claims 100ns accuracy on the “Pulse Per Second” output that is continually updated and aligned with UTC.**

- **Caveats:**
  - **S.E.A. did not provide definitive figures for accuracy.**
  - **The time code message is read from the proprietary GPS microprocessor serially and is non-deterministic.**
  - **At the present time the S.E.A. solution is the only one available on the cRIO platform.**
  - **National Instruments, however, are working hard on a wireless synchronisation solution and are also working hard to find out how we did it!**

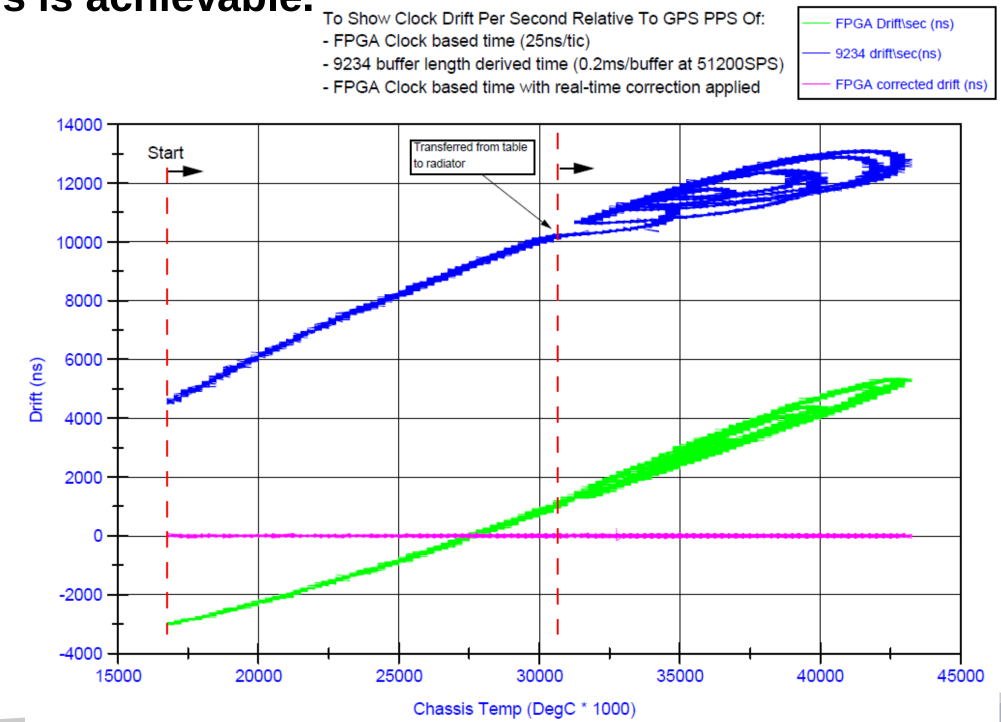
Synchronisation Solution

- Compare GPS "Pulse Per Second" (PPS) and cRIO FPGA clock.
- Implement nanosecond counter based on FPGA clock ticks per PPS.
- Use non-deterministic time data to provide the time to 1 second resolution.
- Use nanosecond counter based on FPGA clock to timestamp every data sample.

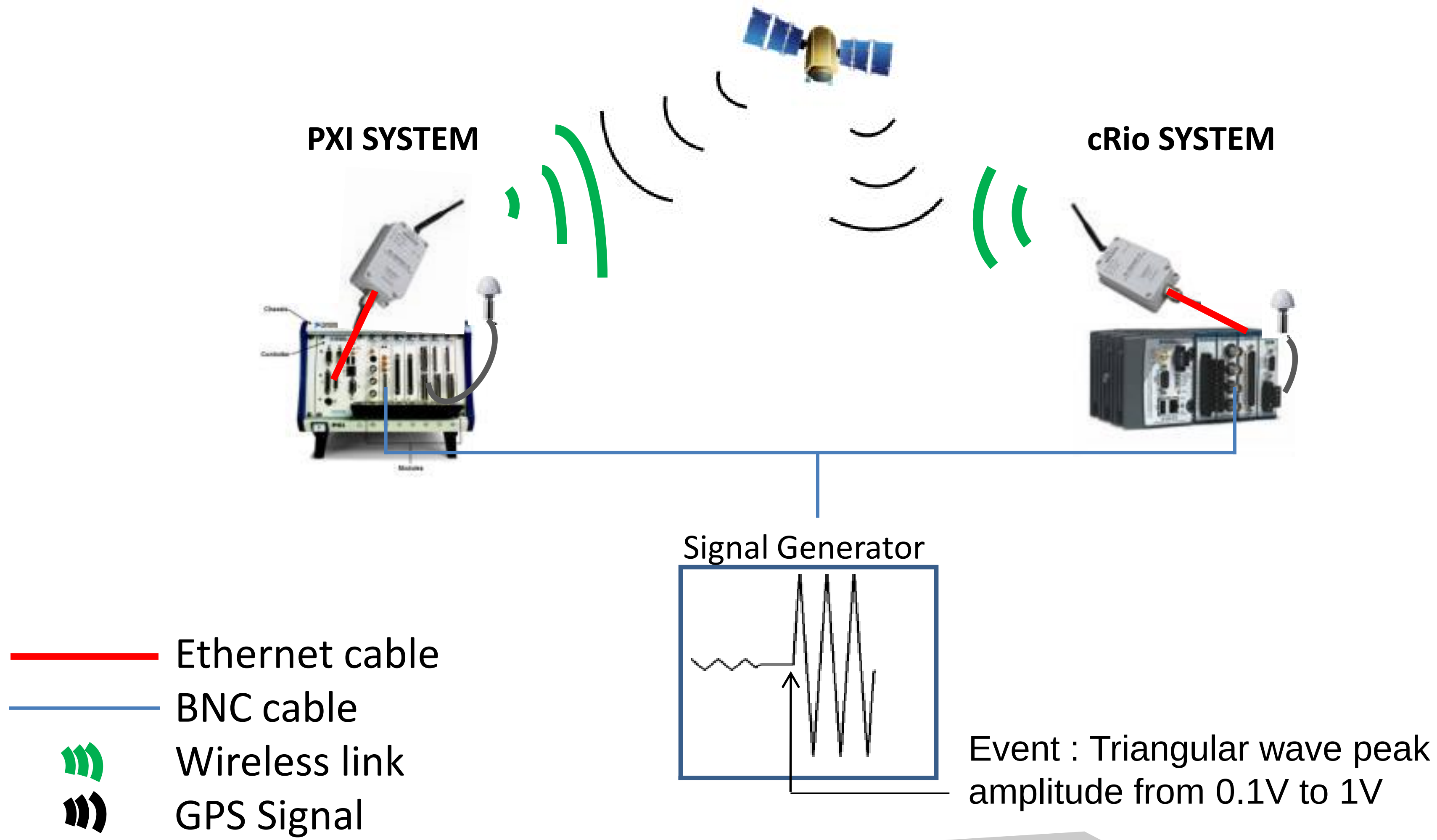
- Depends on accuracy of PPS
- Depends on agreement between wireless units on the start of the second
- Actual sample times between units will remain unsynchronised, but each sample can be accurately timestamped to within a microsecond.

Corrective Timestamp Algorithm Test

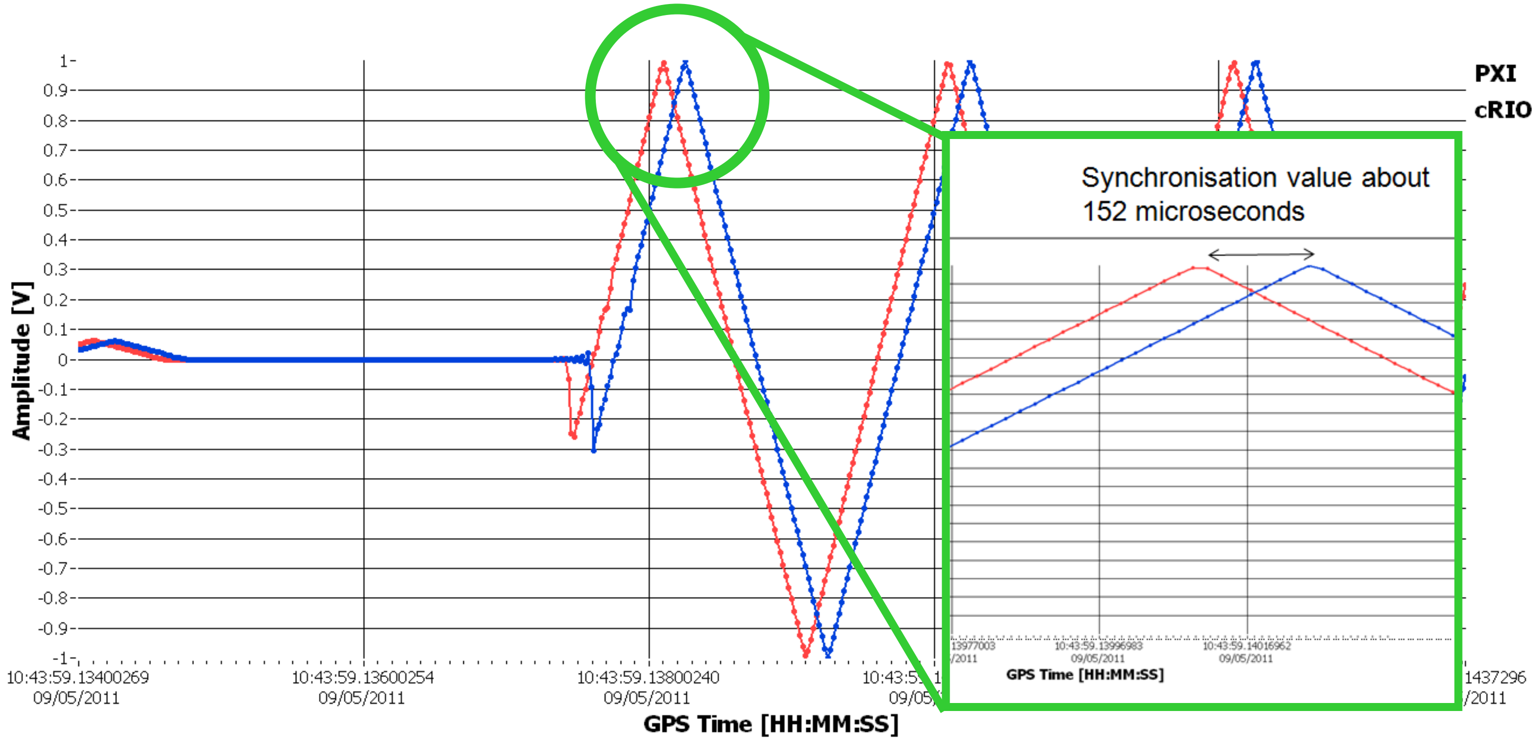
- **Testing on a single cRIO was carried out using temperature changes to force the clock rates of the FPGA and data acquisition module to drift.**
- **The FPGA backplane has a temperature sensor with a 0.25 C resolution.**
- **The correction algorithm was seen to deviate from the PPS by less than 200ns**
- **Assuming a sufficiently stable PPS between wireless units, synchronisation to within 1µs is achievable.**



Synchronisation / latency Test

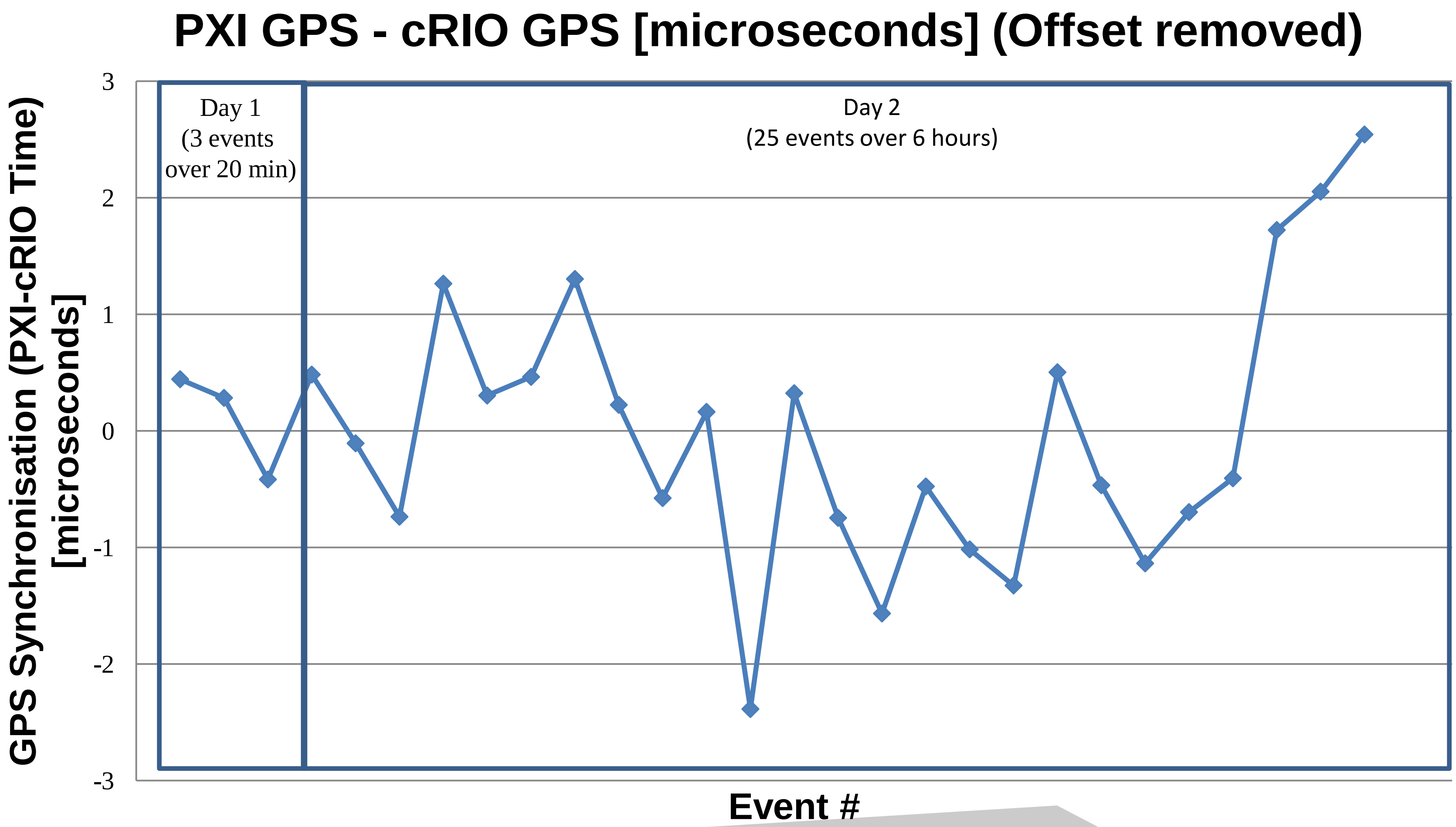


User Generated Event



- **User generated event by changing scale of signal generator**
  - ❑ **Creates amplitude step**
  - ❑ **Helps to identify onset of event**
- **25 events over six hours**

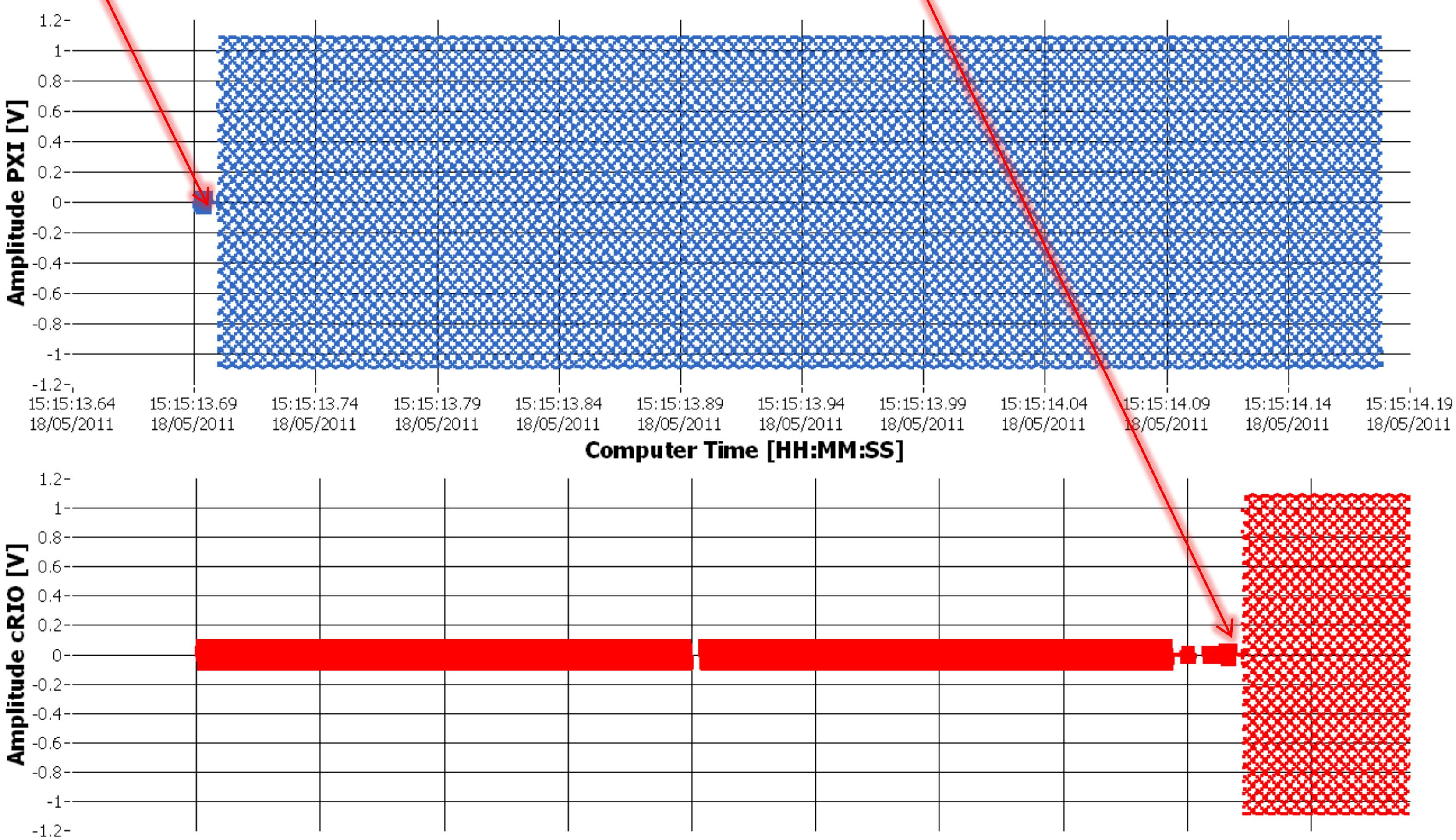
Synchronisation Time History – 6 Hours



Latency Test – User Generated Event

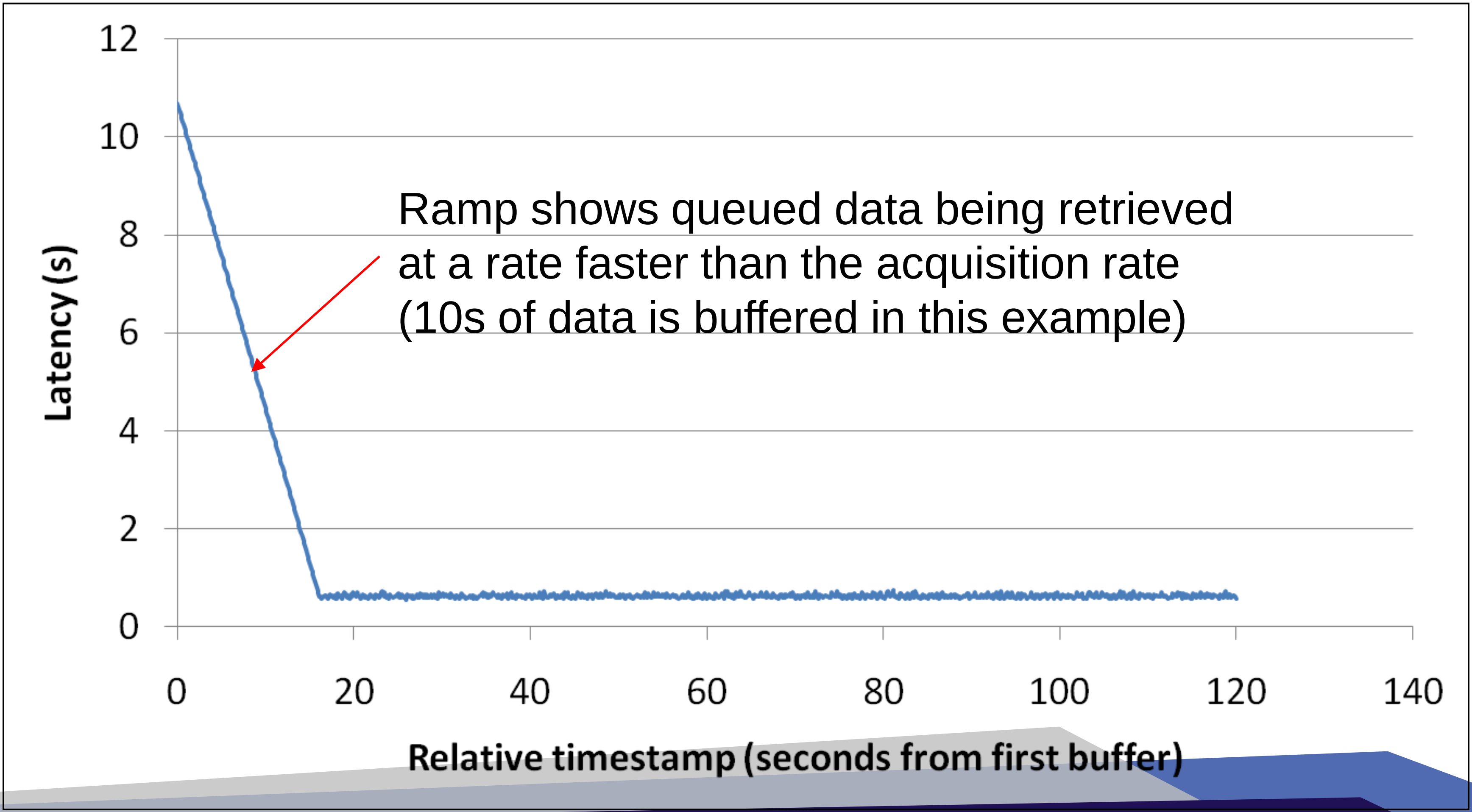
Event detected by PXI

Same Event detected by cRIO. Appears on screen 0.4s later

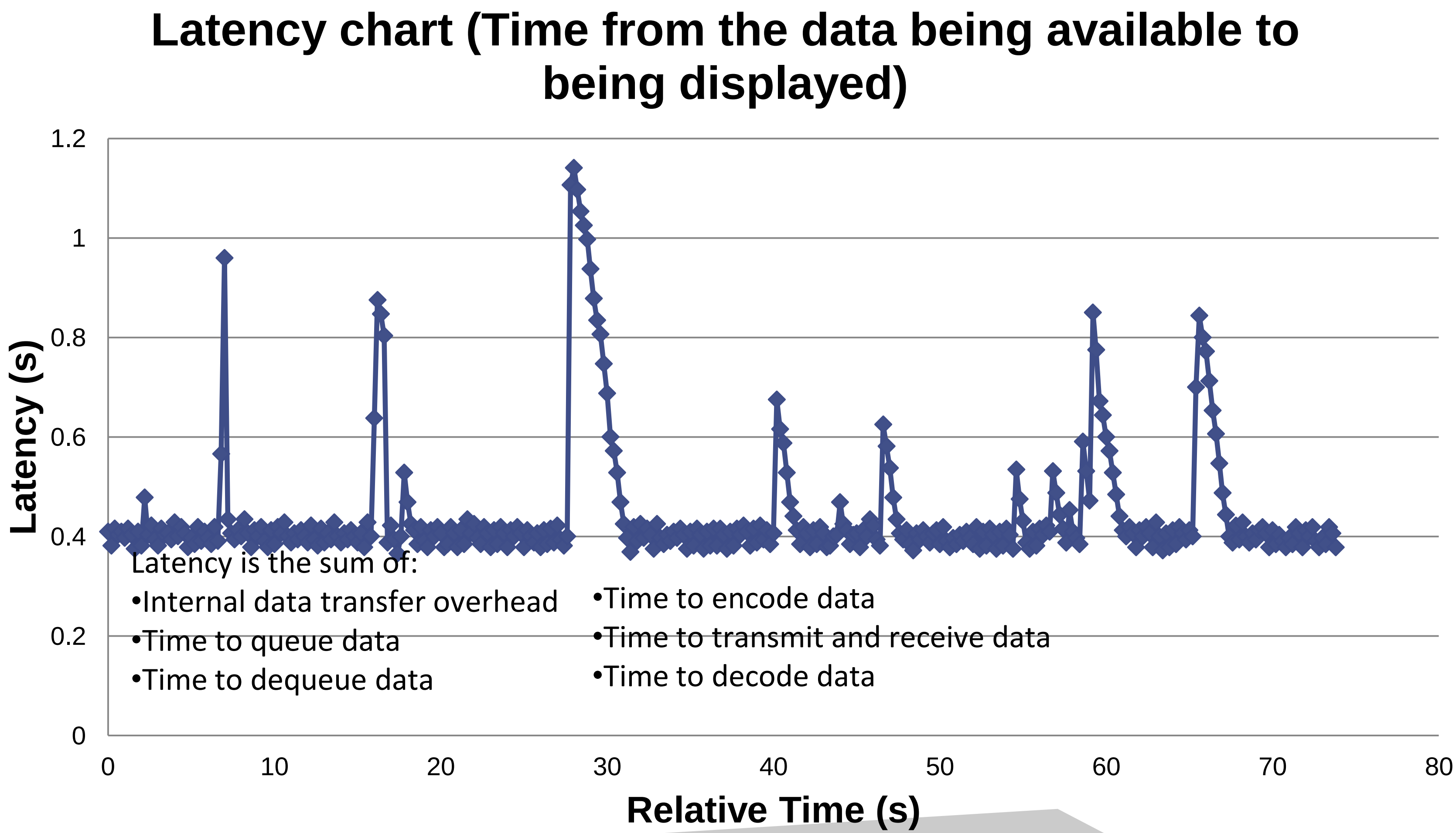


Latency Test – From System Power On

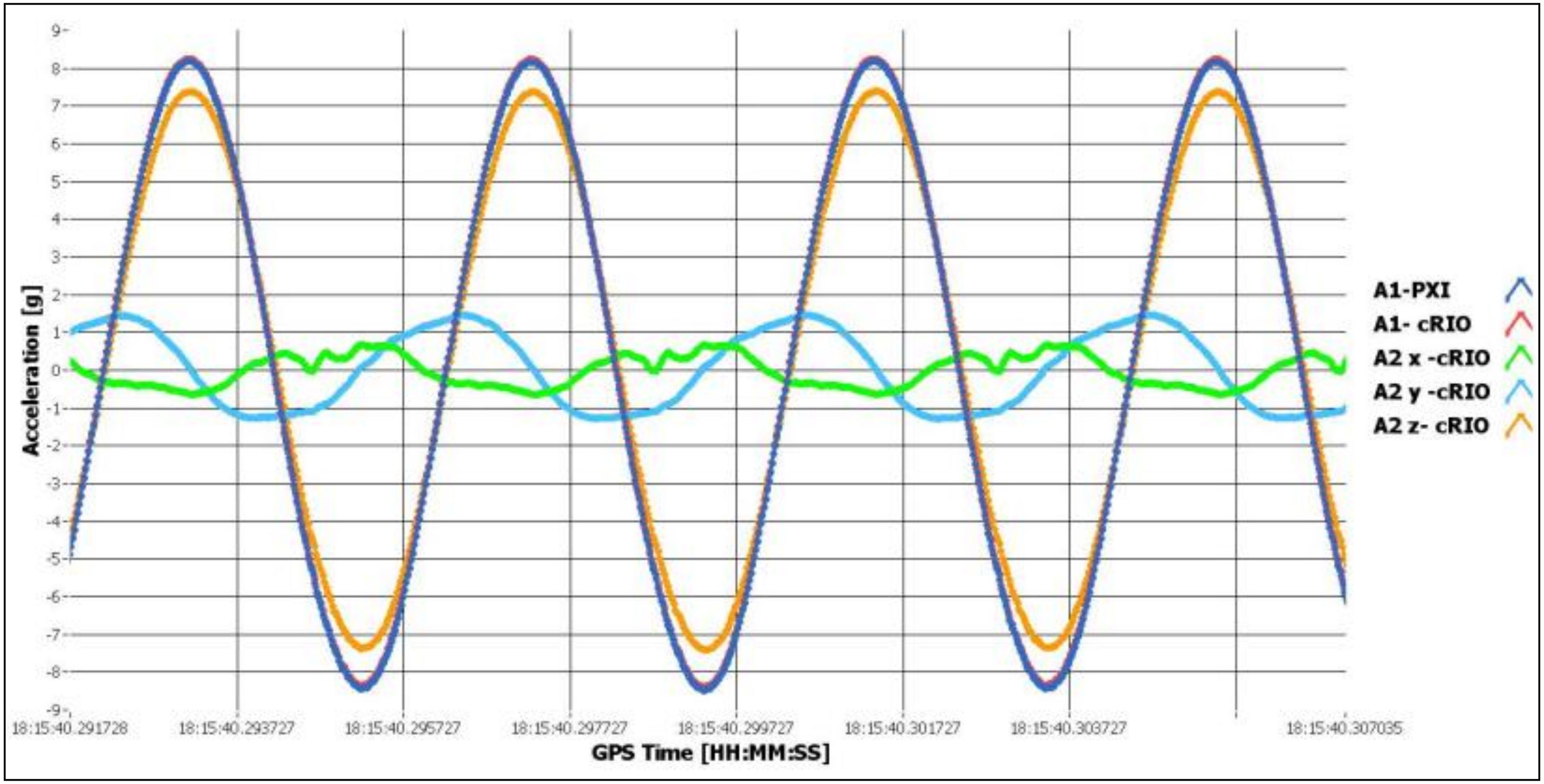
Latency chart from retrieval startup
(= time data buffer arrives – buffer timestamp)



Latency Test – Typical Time History

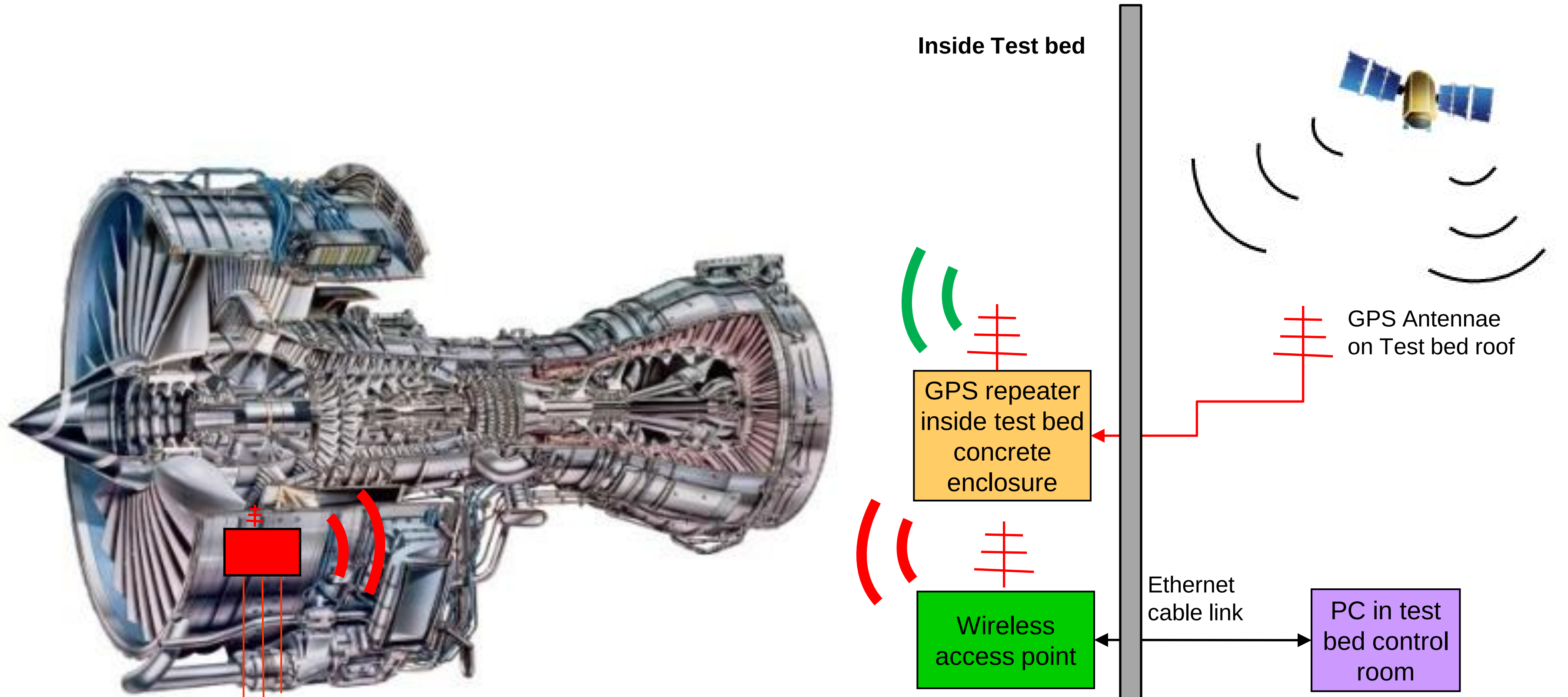


Synchronised Accelerometer Traces



- Time-stamps on data from PXI and cRio were synchronised.
- Amplitude difference is thought to be due to the sensitivity between the two types of accelerometers being different (5:1) and also having a 20% margin.

Proposed Test bed Layout



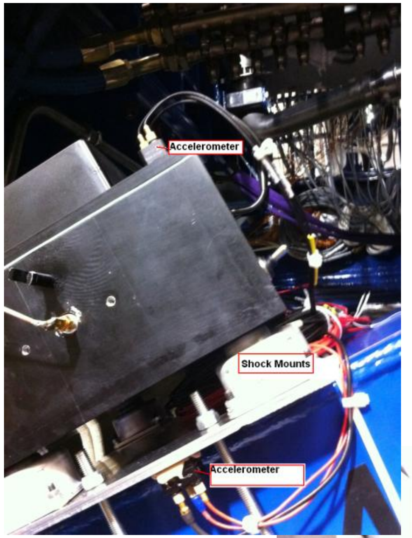
Wireless data concentrator

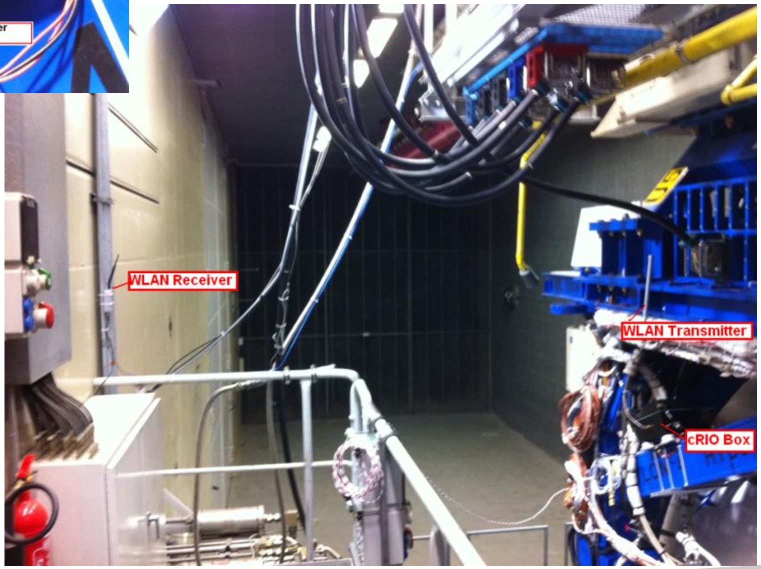
11 Accellerometers on engine

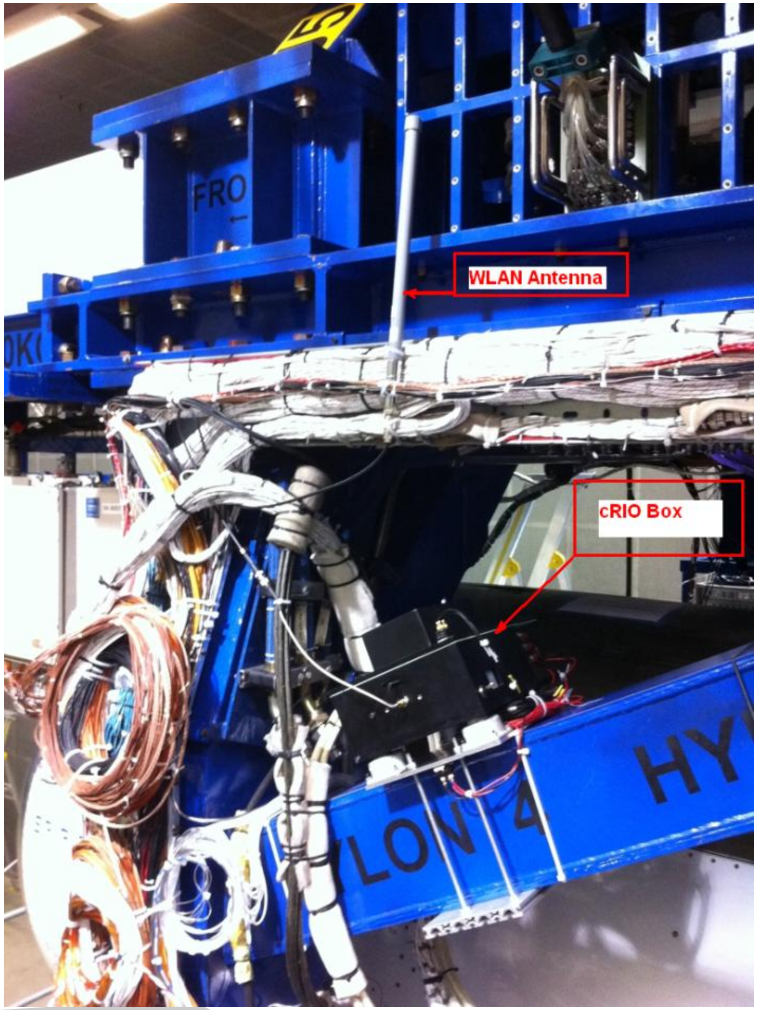
2 temperatures (battery and cRio)

1 Battery voltage

Engine test – Rolls-Royce BR725







Conclusions

- A battery powered wireless vibration sensor for GT engine testing has been developed using
  - 11 vibration channels, each capable to sample at 51.2 kSps
  - GPS link to achieve synchronisation
  - WiFi to stream data in real time
- Synchronisation of 3 µs has been achieved
- Latency has been optimised to 0.4 s. This is buffer size dependant.
- Due to non-existing gaps between buffers a signal can be recreated without data loss.
- The wireless sensor was successfully tested on a BR725 engine test
- Deployment is envisaged on a quick and ad-hoc basis without major disruption during GT test engine runs

Outlook

- Reduce system size and weight
  - ❑Can be achieved with existing COTS h/w
- System capability extension towards other parameters, such as T, p, e
- Understand limitations of using multiple systems in parallel
- Extension of environmental durability (T and g)

Acknowledgement

The wireless vibration sensor development was carried out under the WiTNESSS* project.

The WiTNESSS project, in which Rolls-Royce is a partner, is a collaborative Research and Technology programme supported by the Technology Strategy Board in the UK.

Rolls-Royce

* WIreless Technologies for Novel Enhancement of Systems and Structures Serviceability

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Greetings from Derby

Any Questions ?

RIQC UKAS

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