

# Developing a Synchronised Distributed Data Acquisition System

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London, UK

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Vibration Engineering Section

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## Vibration Engineering Section

### Introduction to the Vibration Engineering Section

The Vibration Engineering Section (VES) is led by Professors Aleksandar Pavic, James Brownjohn and Paul Reynolds, with exceptional post-doctoral and post-graduate researchers with an international reputation in vibration serviceability, structural health monitoring and active vibration control and their application to real world problems. We have opportunities for you to study as an under-graduate or post-graduate or undertake research.

#### + About VES

Read about VES

#### + Research

Read about our research

#### + Join us on twitter

VibrationUoE 08 Jul  
@VibrationUoE  
Check out the reconfigured platform in our #structures #lab  
<https://t.co/Ec3SUaMeff>

#### + MSc Structural Engineering

##### MSc Structural Engineering

#### + Research news

EPSRC to fund project on uncertainty quantification for ambient vibration testing

Modal testing and analysis of reconfigurable test-bed structure in the Structures Lab

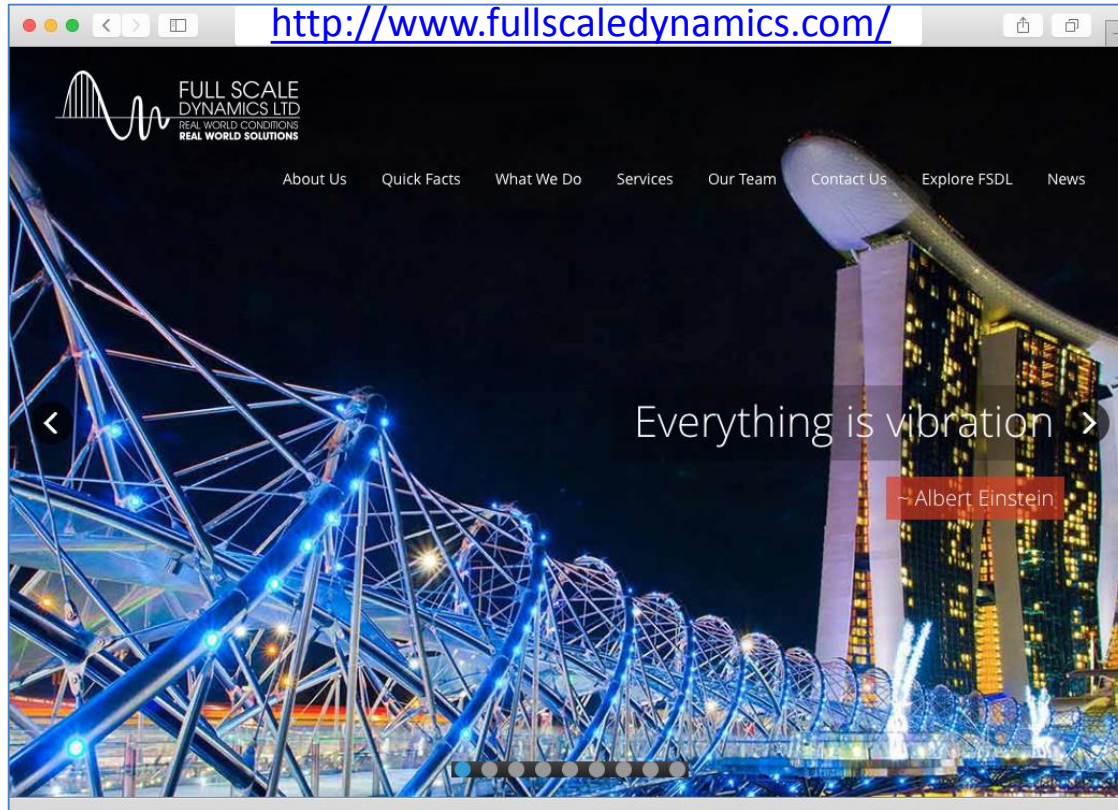
Detecting dynamic displacement of Tamar Bridge using remote sensors

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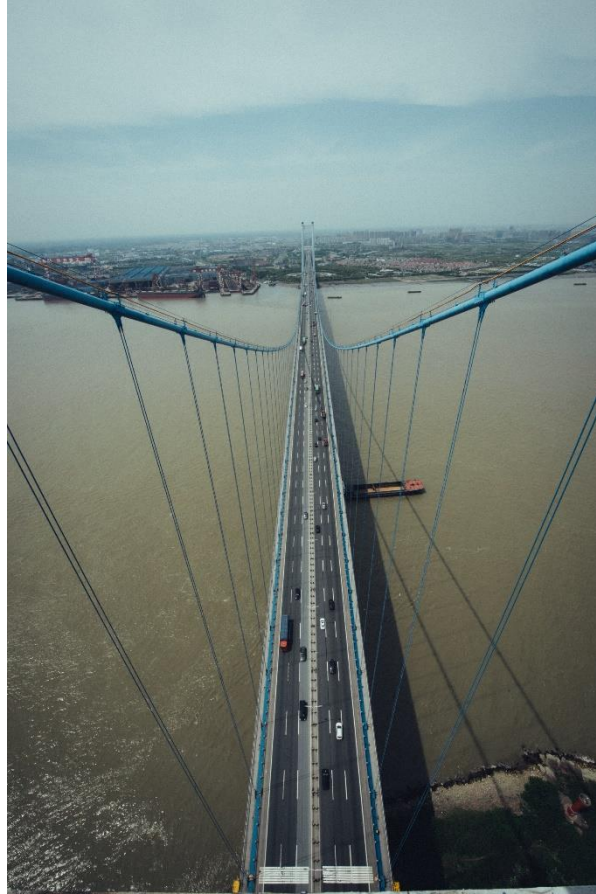
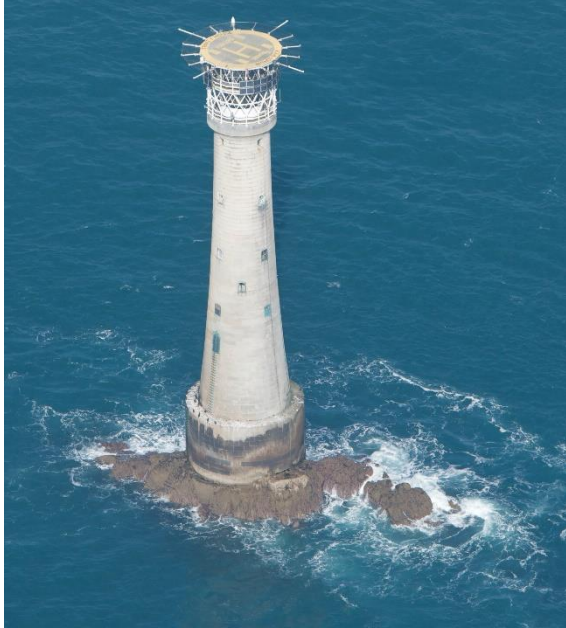


# Full Scale Dynamics Limited



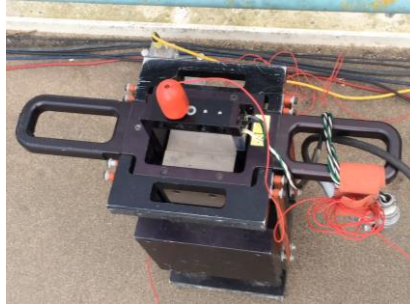








Free vibration test  
(zero input)



Forced vibration test  
(Known input)



**Ambient vibration test**  
**(Unknown input)**

- Testing under **ambient condition** (no input info) is the future for extreme long/tall structures but results have significant uncertainty
- Uncertainties are critical in ambient tests!
- BAYOMALAW project aims to understand how best to manage these uncertainties

# Data Acquisition System Requirements

- Distributed sensors separated over long distances
  - NO CABLES!
- All sensors synchronised to a common clock
- Long duration data acquisition with no drift in clock
- Able to work inside / with no reliable GPS signal
- Option to add additional units at a later stage

## Design

- CompactRIO platform
- Oven Controlled Crystal Oscillator (OCXO) @ 10MHz





# **SYSTEM DESIGN**

# General Design

Task 1 – Data acquisition triggered from a local clock (FPGA)

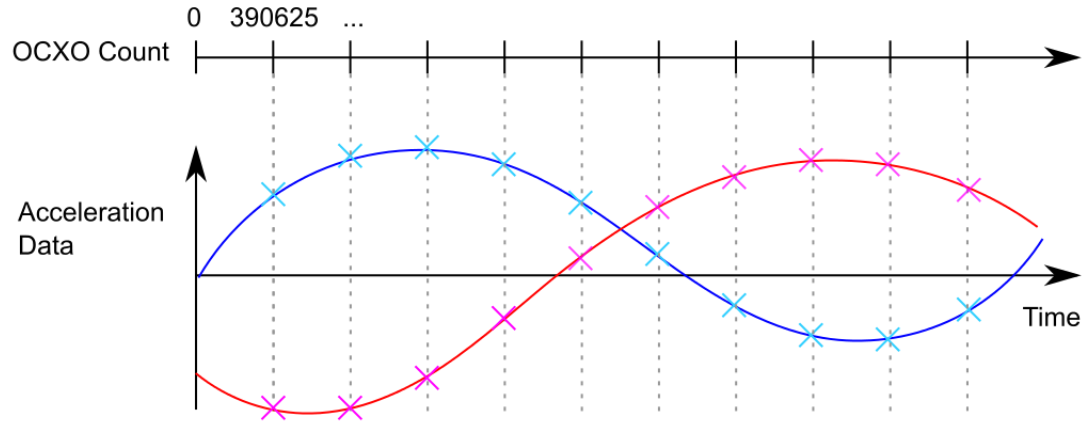
Task 2 – Update the slave clocks based on a ‘master’ clock (FPGA)

Task 3 – Log the synchronised samples to file (Real Time)

## Task 1 – Data acquisition based on local clock

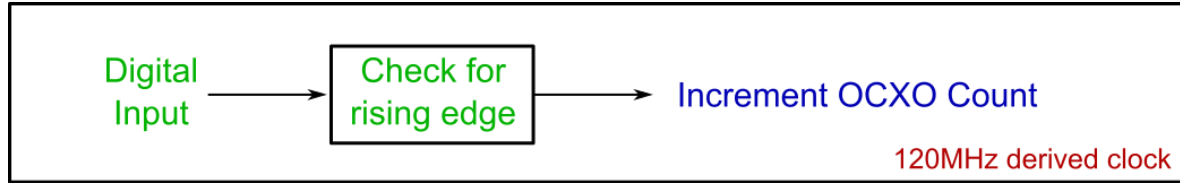
- Connect OCXO to Digital Input
- Increment OCXO Count on rising edge
- Trigger to take a sample after 'n' counts
  - E.g. OCXO frequency = 10MHz
  - Sampling frequency = 25.6Hz
  - $n = 390,625$
- Filter to reduce aliasing issues!



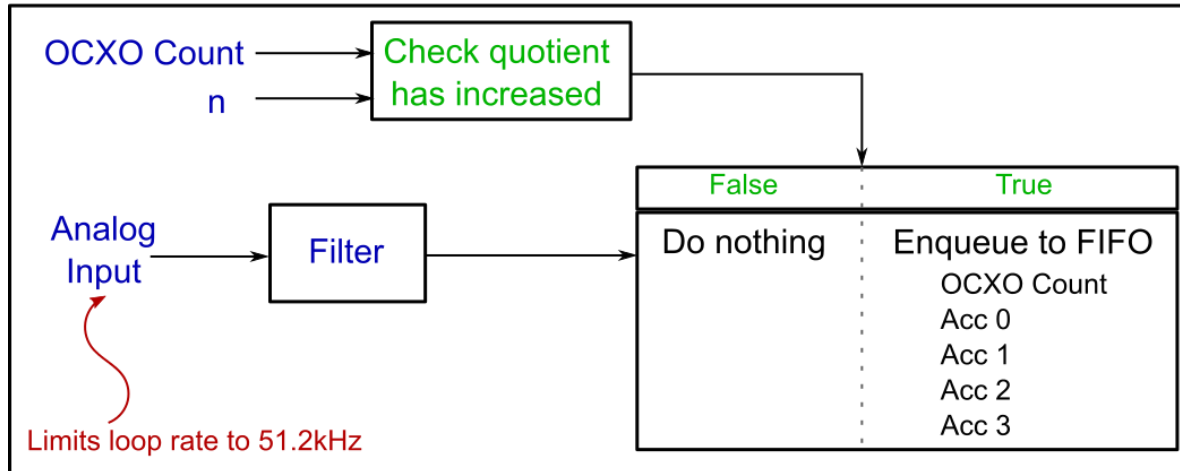


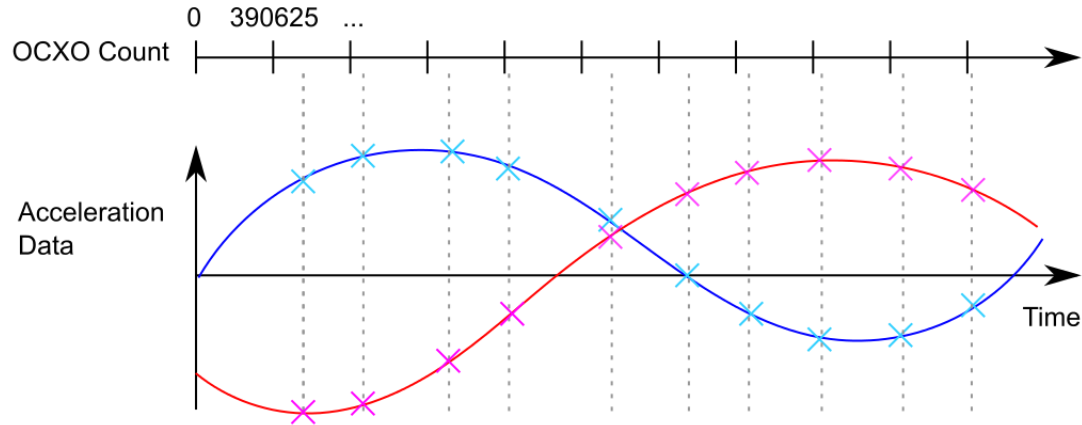
# FPGA Design

Loop 1



Loop 2

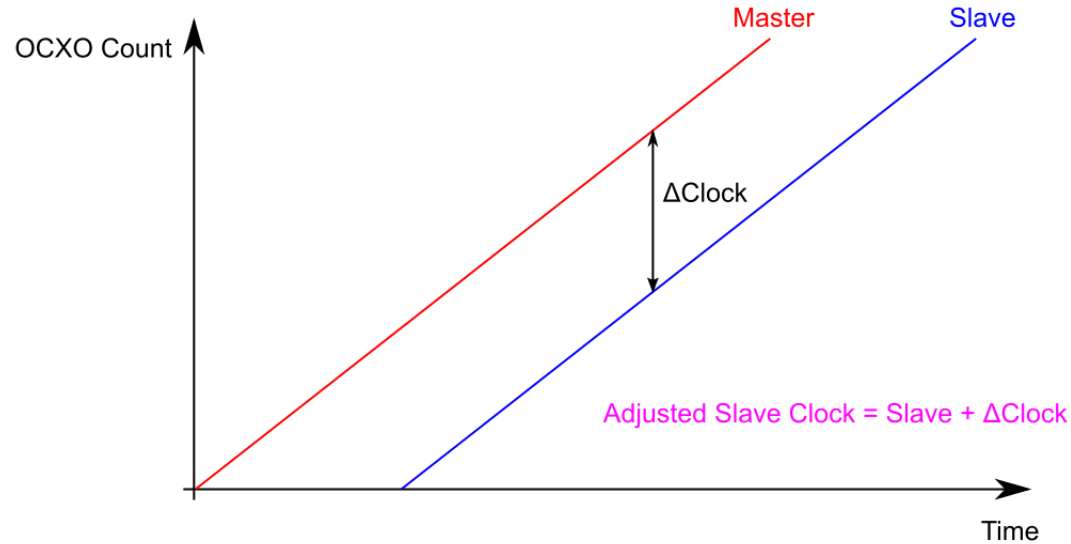




Could interpolate if REALLY wanted to

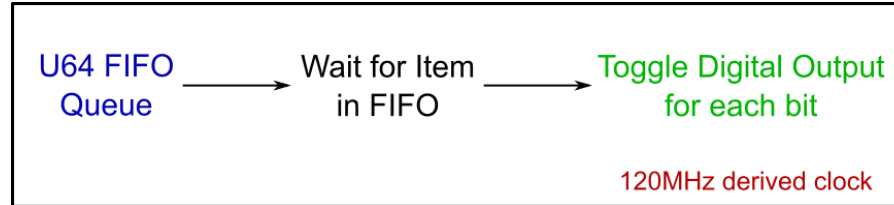


## Task 2 – Update the slave clocks based on a ‘master’ clock

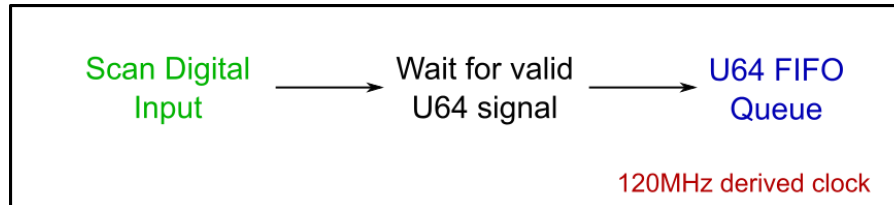


- Send OCXO Clock from ‘Master’ unit to ‘Slave’ units
- Use Digital I/O line – synchronise using a BNC cable
- “FPGA Send Data.vi” and “FPGA Receive Data.vi”
  - Nick Williamson @ National Instruments
  - “Passing fast data between compact RIO targets using single DIO”

Loop 3 (Master)



Loop 3 (Slave)



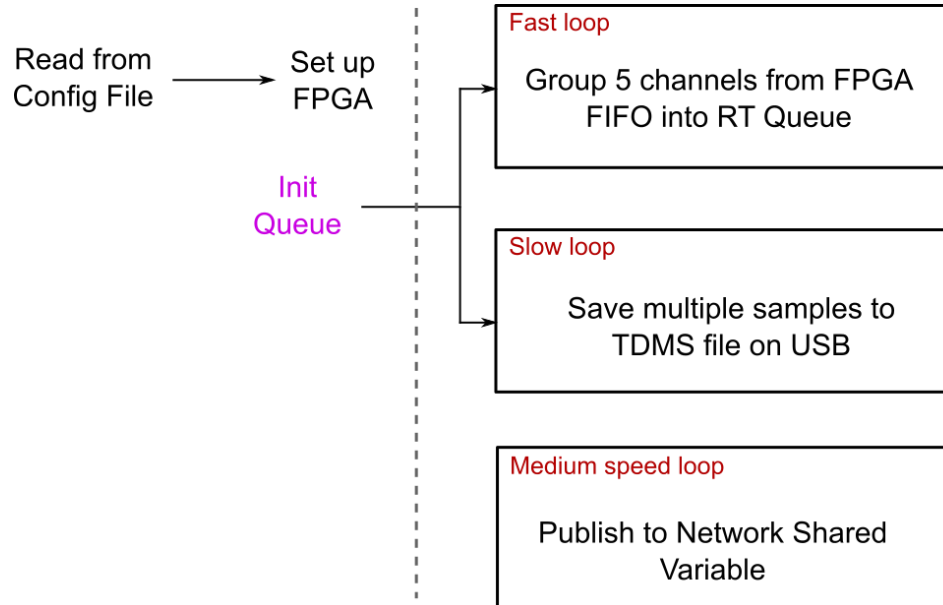
## **Final FPGA code has four loops:**

1. Increment OCXO count
2. Acquire + filter data, then put in FIFO
3. Send OR receive 'master' clock
  - Update  $\Delta\text{clock}$
4. Flash LED code
  - Device is Master
  - Device is Slave and IS NOT synchronised
  - Device is Slave and IS synchronised



# RT Design

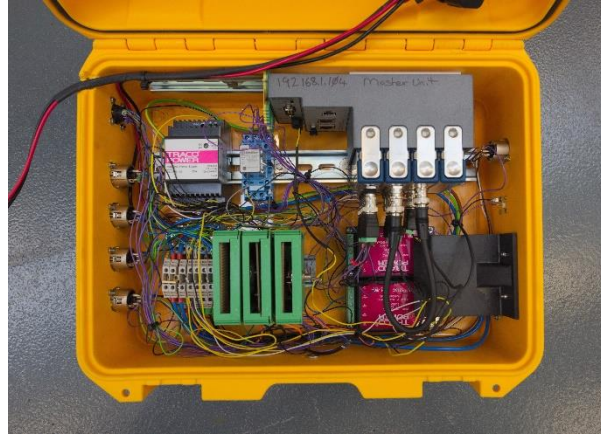
## Task 3 – Log the synchronised samples to file



**HARDWARE**

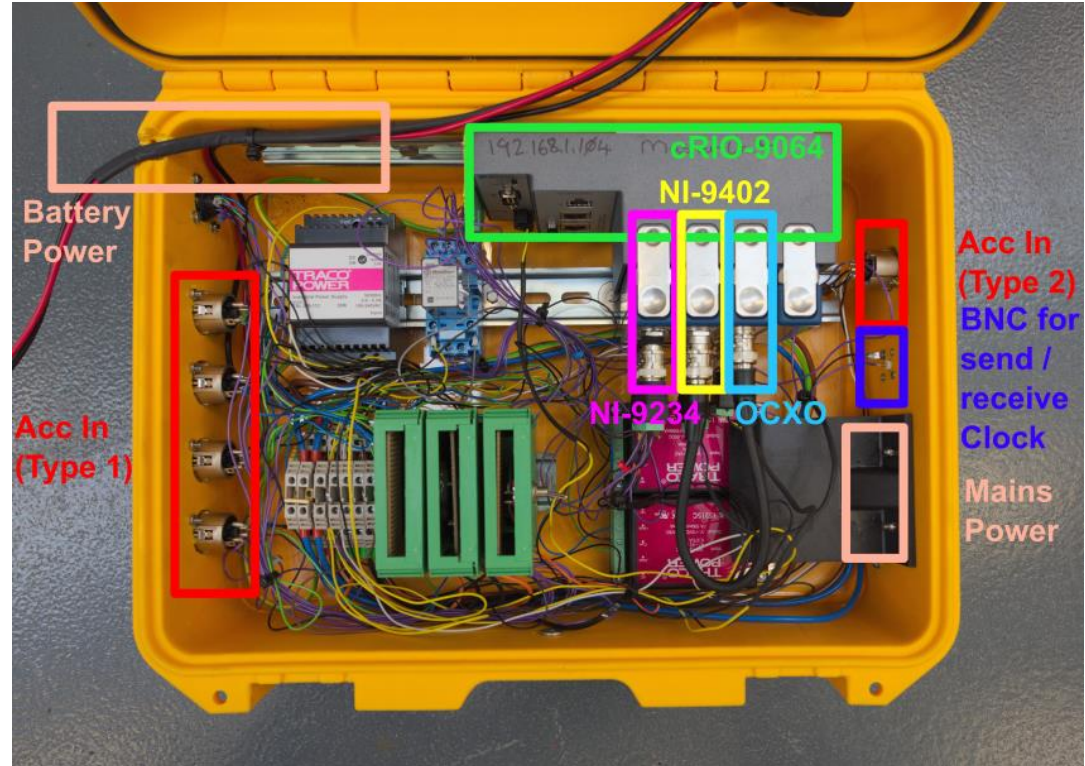
A light blue line graph is plotted on a white background. The graph features a thick blue curve. On the left side, the curve is composed of several vertical lines of varying heights, creating a stepped appearance. This transitions into a smooth curve that dips below the horizontal axis, then rises to form a series of oscillations, resembling a sine wave, before tapering off towards the right edge of the frame.

# Hardware



# Hardware

- NI cRIO-9064
- NI-9234 (4 Channel Analog In)
- NI-9402 (4 Channel Digital IO)
- OCXO
- Connect one of two accelerometer types
- Power through mains or battery
- DIN rail mounted

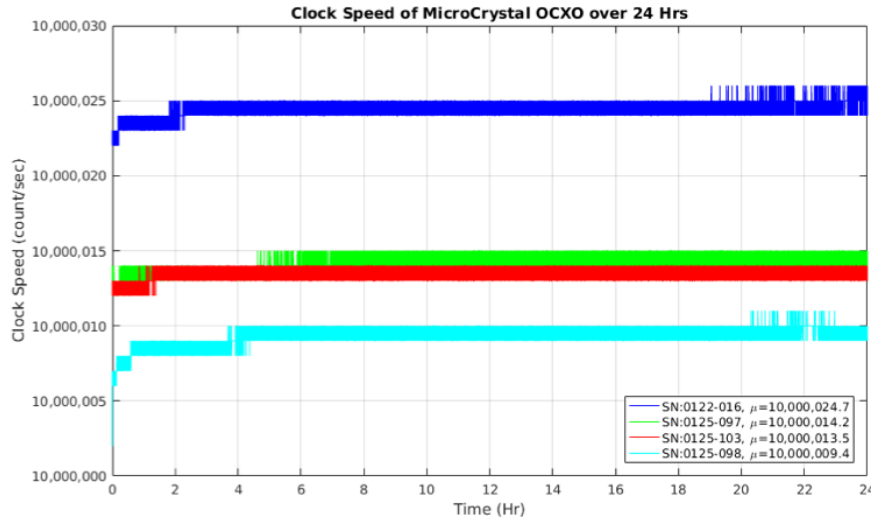


# Testing in Exeter

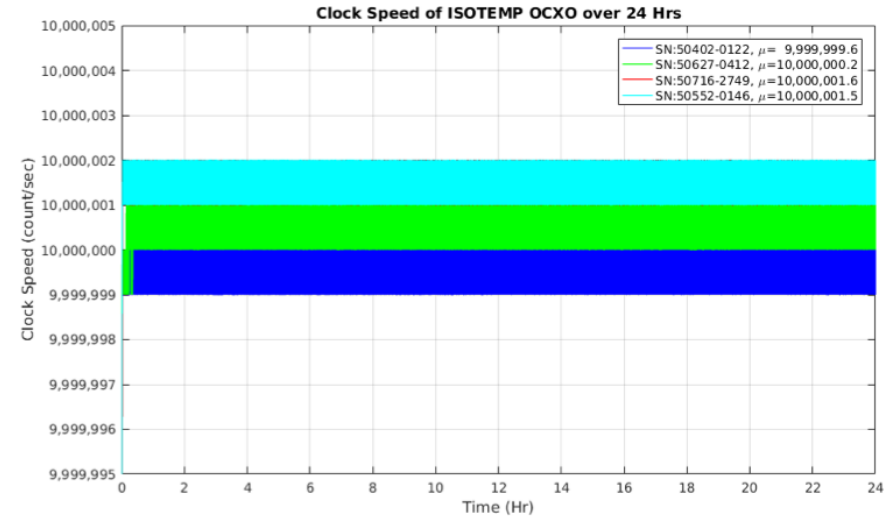




# Test OCXO against GPS



OCXO type 1: **2ppm** difference  
 → 20° phase at 1Hz after 8 hours



OCXO type 2: **0.2ppm** difference  
 → 2° phase at 1Hz after 8 hours

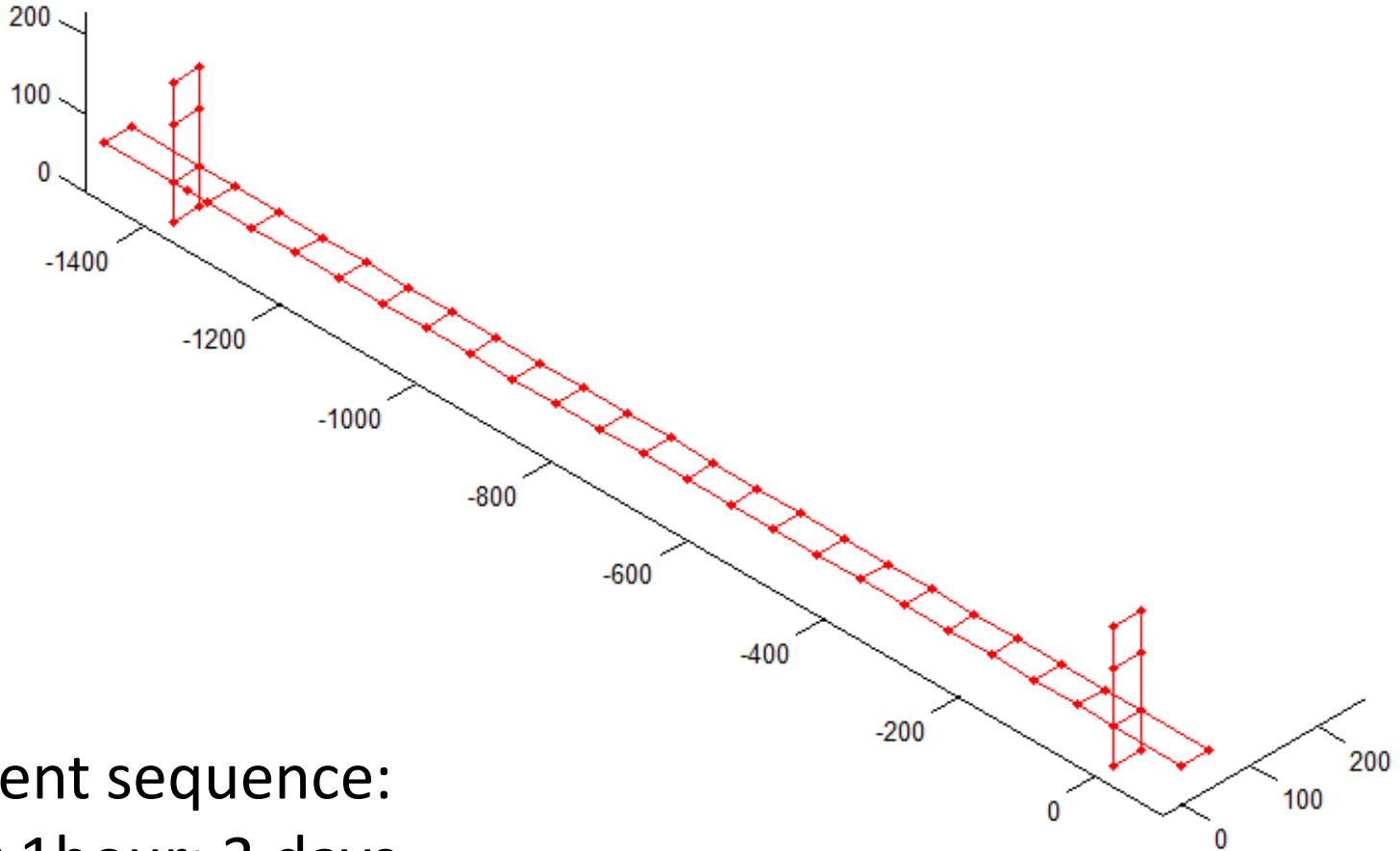


**FIELD TESTING**

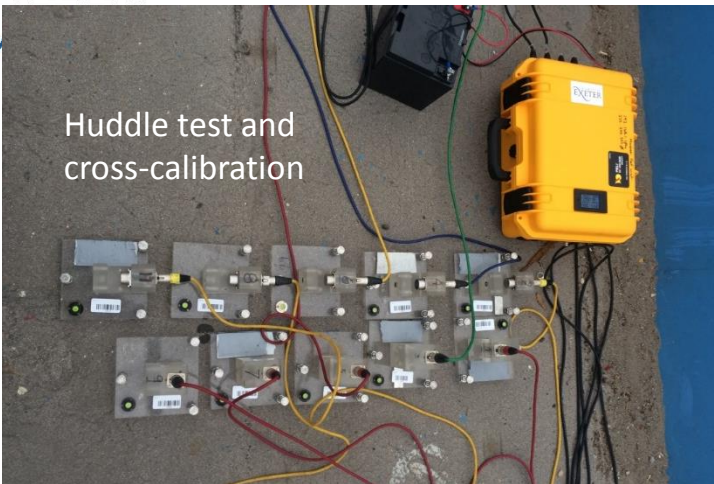


# Jiangyin Bridge (April 2017)





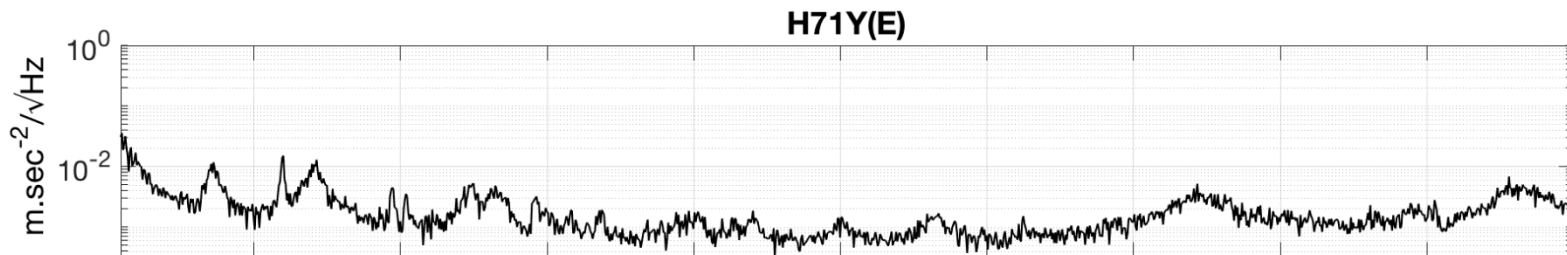
Measurement sequence:  
13 setups x 1hour; 3 days



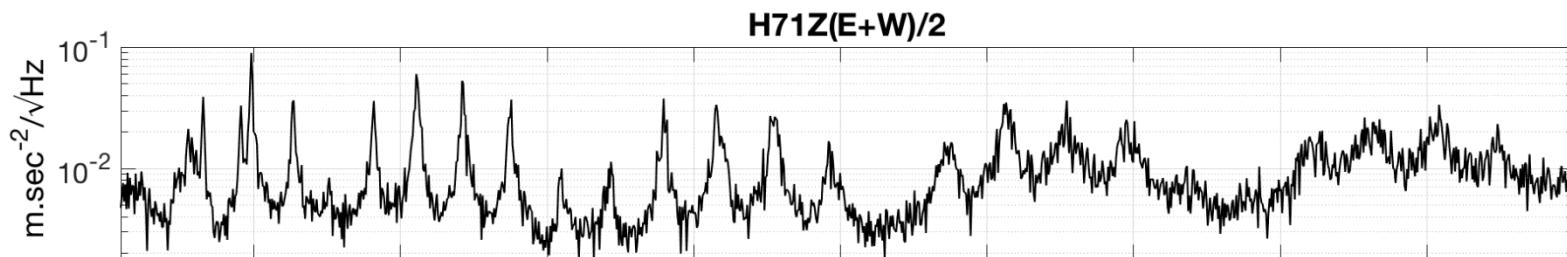


# Modal (log) acceleration PSD

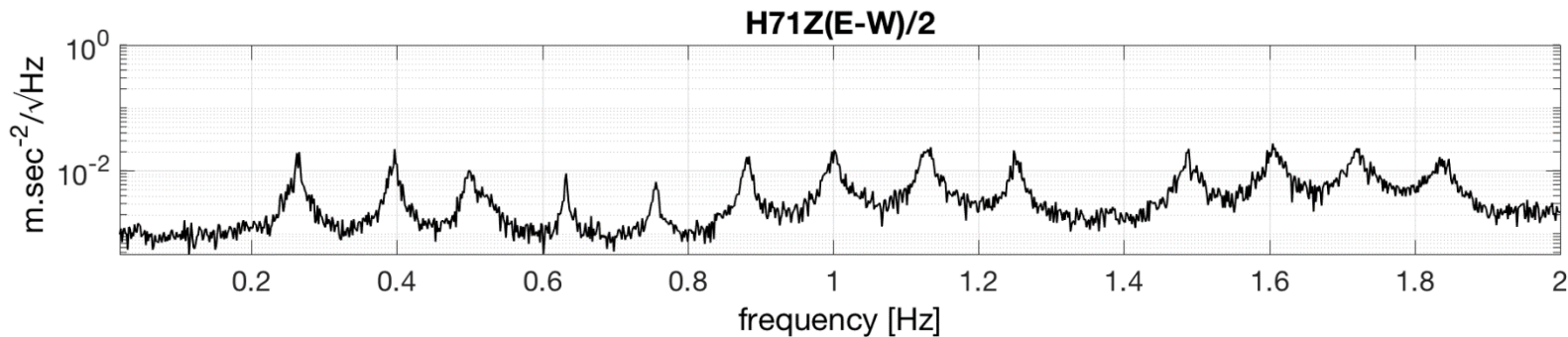
Lateral



Vertical

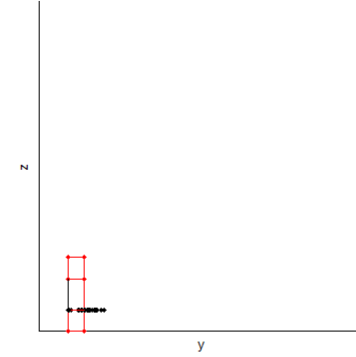
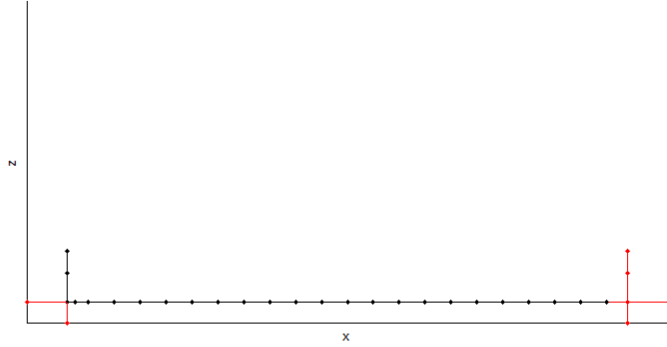


Torsional

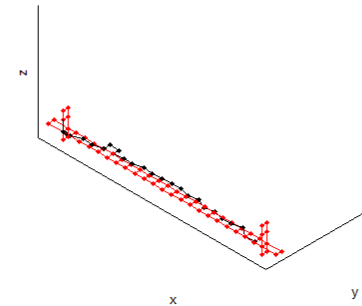
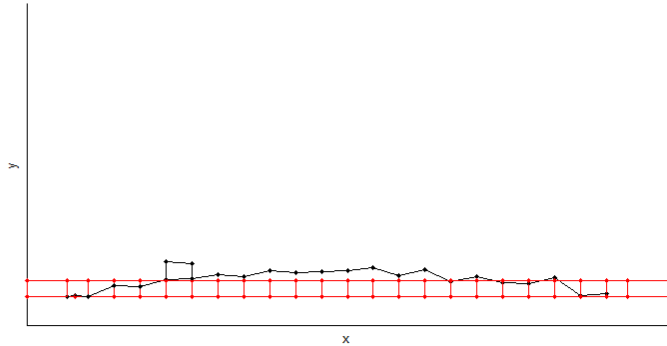


# Modes: Lateral 1

$f=0.0536 \text{ Hz } (\pm 3.6\%) \quad \zeta = 4.4\% (\pm 88\%)$



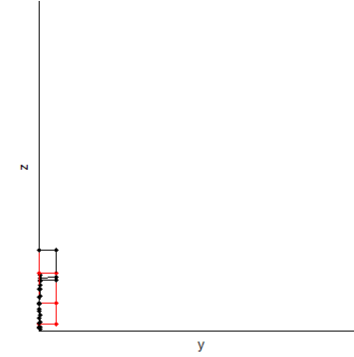
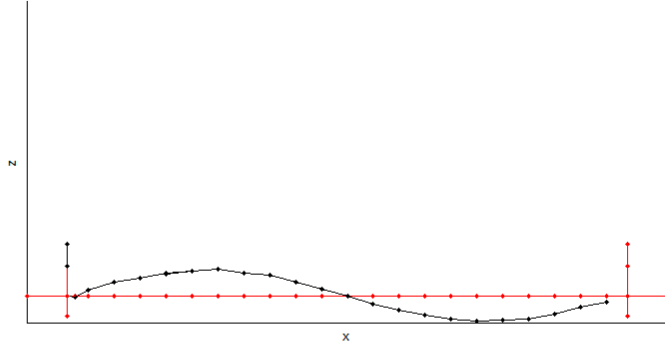
0.0536Hz (3.6%)  
4.3% (88%)



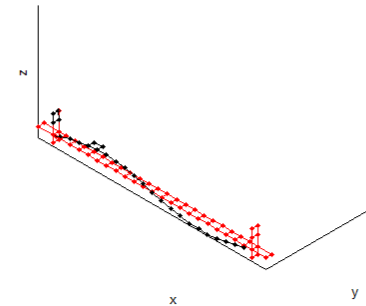
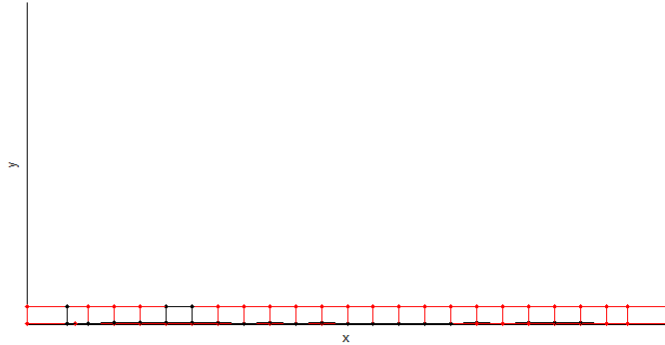


# Modes: Vertical 1

$f=0.110$  Hz ( $\pm 1.2\%$ )  $\zeta = 4.9\%$  ( $\pm 41\%$ )

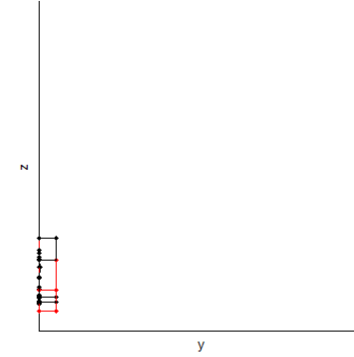
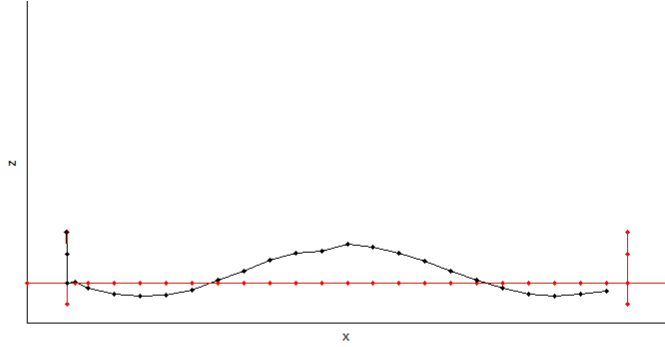


0.11Hz (1.2%)  
4.9% (41%)

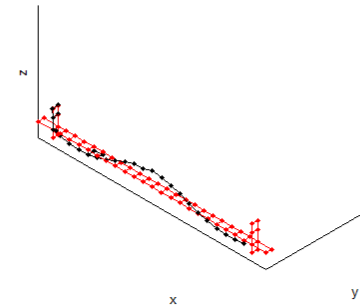
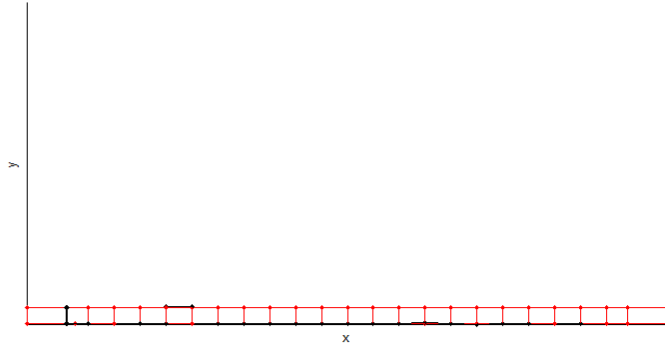


# Modes: Vertical 2

$f=0.130 \text{ Hz } (\pm 0.54\%) \quad \zeta = 1.4\% (\pm 54\%)$



0.13Hz (0.54%)  
1.4% (54%)



# Queensferry Crossing



Comprehensive SHM system requires identification of:

- global dynamic properties
- multimode damping and frequency for all 288 stay cables

# Test plan (October 2017)

- Minimum 58 TPs for measuring accelerations
- Will use ten recorder boxes with 3 or 4 accelerometer signals per box: uni-axial and tri-axial.
- One set of accelerometers will be maintained at the same location close to tower in one of the main spans.
- First mode 0.15 Hz - 0.20 Hz with damping  $\sim 2\%$ 
  - 1 hour duration is suggested



# **CONCLUDING REMARKS**

# Concluding Remarks

- Developed a novel distributed data acquisition system
- Highly synchronised
  - Minimal phase difference over long duration measurements
- Highly distributed
  - Suitable for long span bridges, tall buildings, inside / outside
- Highly modular
  - Expanding capabilities to test even larger structures



# Acknowledgements

- UK Engineering and Physical Sciences Research Council (EPSRC)
  - BAYOMALAW project (EN/N017897/1)
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- **Professor Ivan Auas** (University of Liverpool)
- **Yichen Zhu** (University of Liverpool)
- **Zhen Yu** (Jiangsu Transportation Institute)

# Thanks for listening!

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- Any questions?

Extra slides ...

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