Thermal Testing & Correlation in the Frequency Domain

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accelerating innovation

ACKNOWLEDGMENTS

This work has been mainly performed by

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- Joris Feijen (ATG Engineering)

With the guidance and senior contribution from

- Arturo González-Llana (ATG Engineering)

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- TU Delft for providing a masters student and TVAC facilities
- DHV Technology for sending us an in-house built MLI for the tests

Question: Is frequency domain thermal testing a feasible method to perform or complement *some* thermal tests?

OUTLINE

- Introduction, typical test objectives, why frequency domain?

- Proof of concept - Testing and practical application on a basic thermal strap
- Application on a more complex model – virtual testing
- Ongoing activities – unlocking the real benefits, integration in real test setups

- Conclusions

TESTING

TVAC remains a key milestone in TCS verification of space systems

Three main objectives

- Verification
- Qualification
- **Correlation**

TVAC OBJECTIVES

Verification

- Vacuum is a key feature of the orbital environment
- No options to reduce time

Qualification

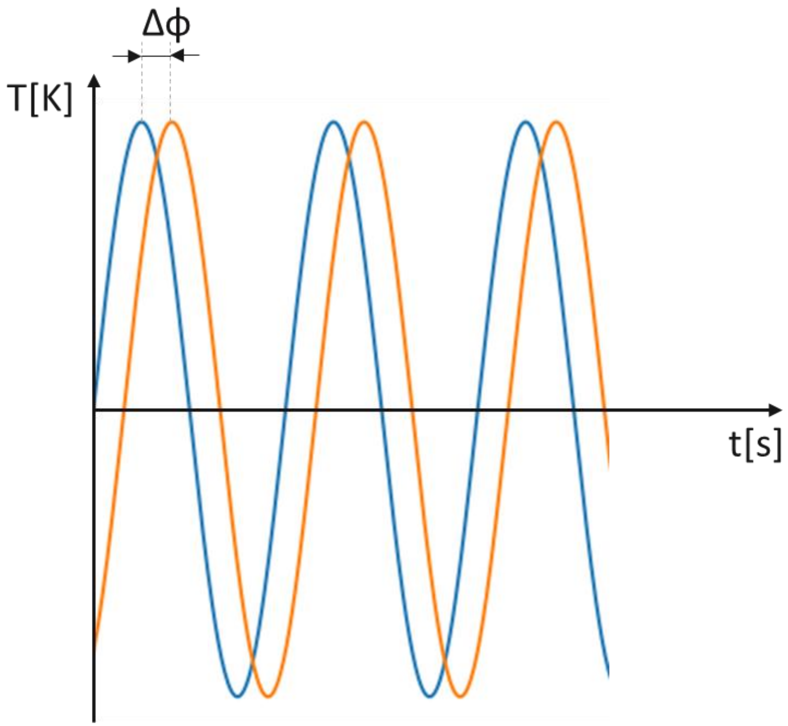
- Loads defined by thermal predictions
- Vacuum environment needed for system safety

Correlation

- Quasi-equilibrium required, balance phases long and limited configurations
- Risk of damaging the system when applying artificially temperature gradients for local correlation

FREQUENCY DOMAIN THERMAL CORRELATION

Phase-shift Δϕ based correlation

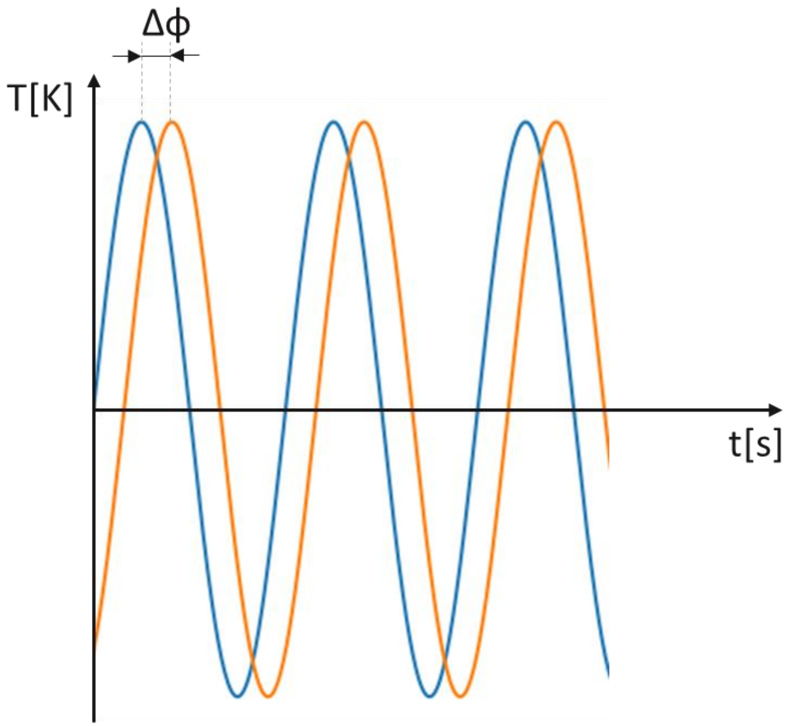


FREQUENCY DOMAIN THERMAL CORRELATION

Phase-shift Δϕ based correlation

Advantages:

- Absolute temperature measurement accuracy is not important
  - →No need for quasi-equilibrium
  - →Small thermal loads suffice for correlation
  - →**Mostly unsensitive to heat leaks**
  - →Impact of local design/model features remains local
  - →Potential to correlate in ambient!



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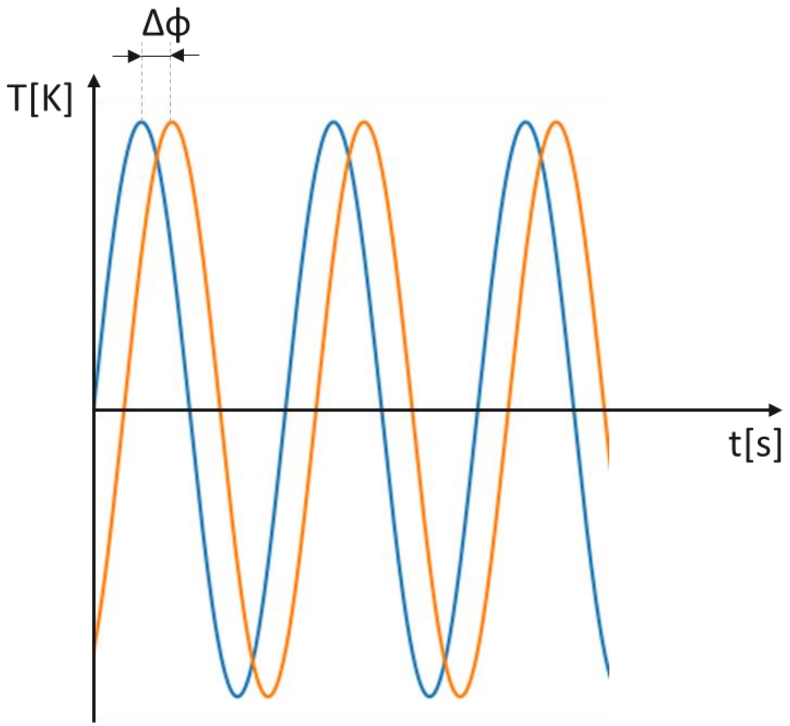
Phase-shift Δϕ based correlation



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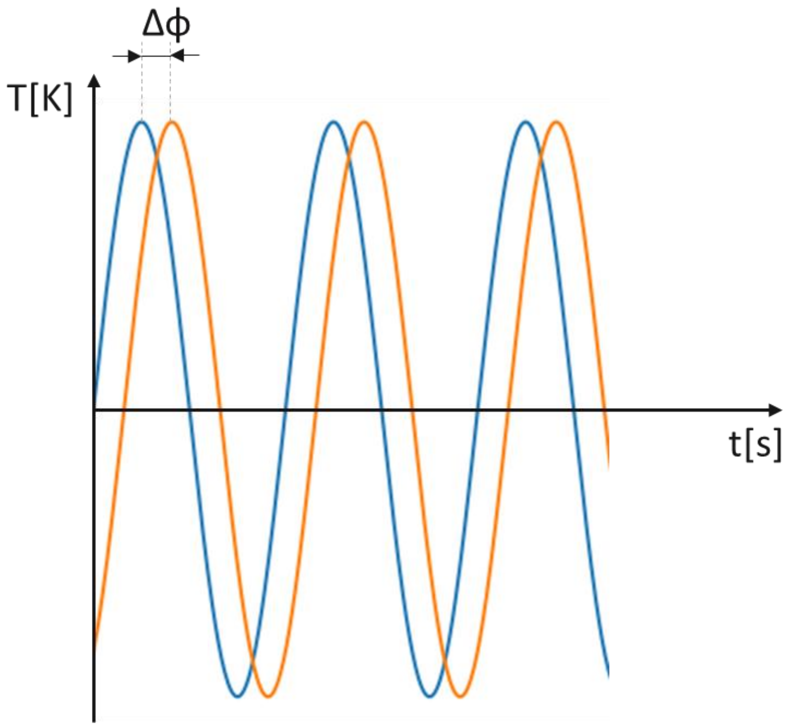
- Absolute temperature measurement accuracy is not important
  - → No need for quasi-equilibrium
  - → Small thermal loads suffice for correlation
  - → **Mostly unsensitive to heat leaks**
  - → Impact of local design/model features remains local
  - → Potential to correlate in ambient!
- Ability to open to use the toolbox of “frequency analysis tools”
  - → Frequency decomposition: performing multiple tests at the same time

FREQUENCY DOMAIN THERMAL CORRELATION

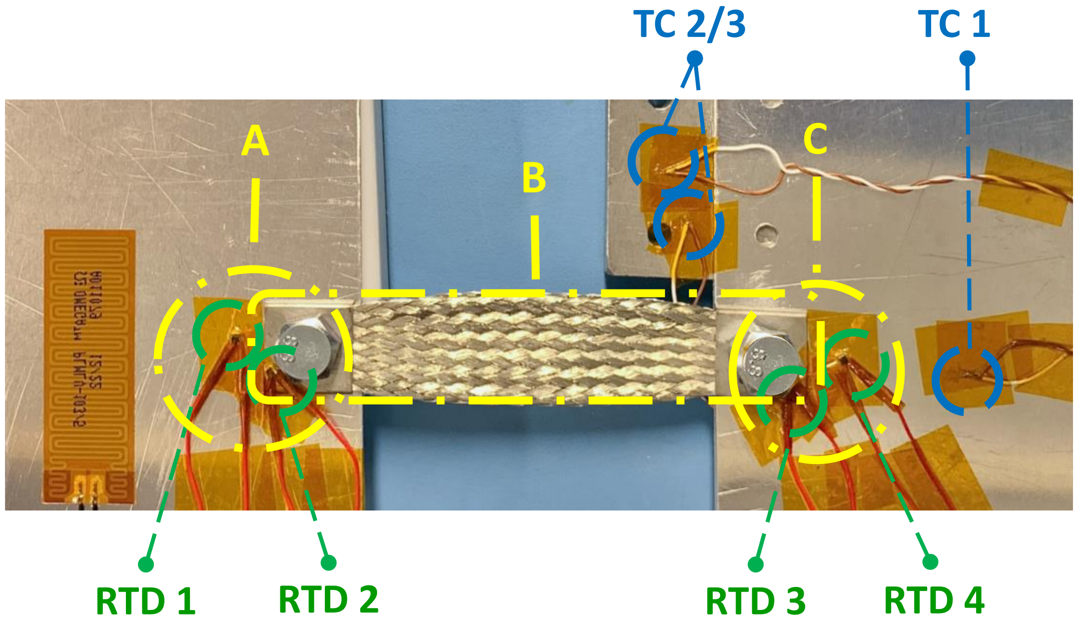
Phase-shift Δϕ based correlation



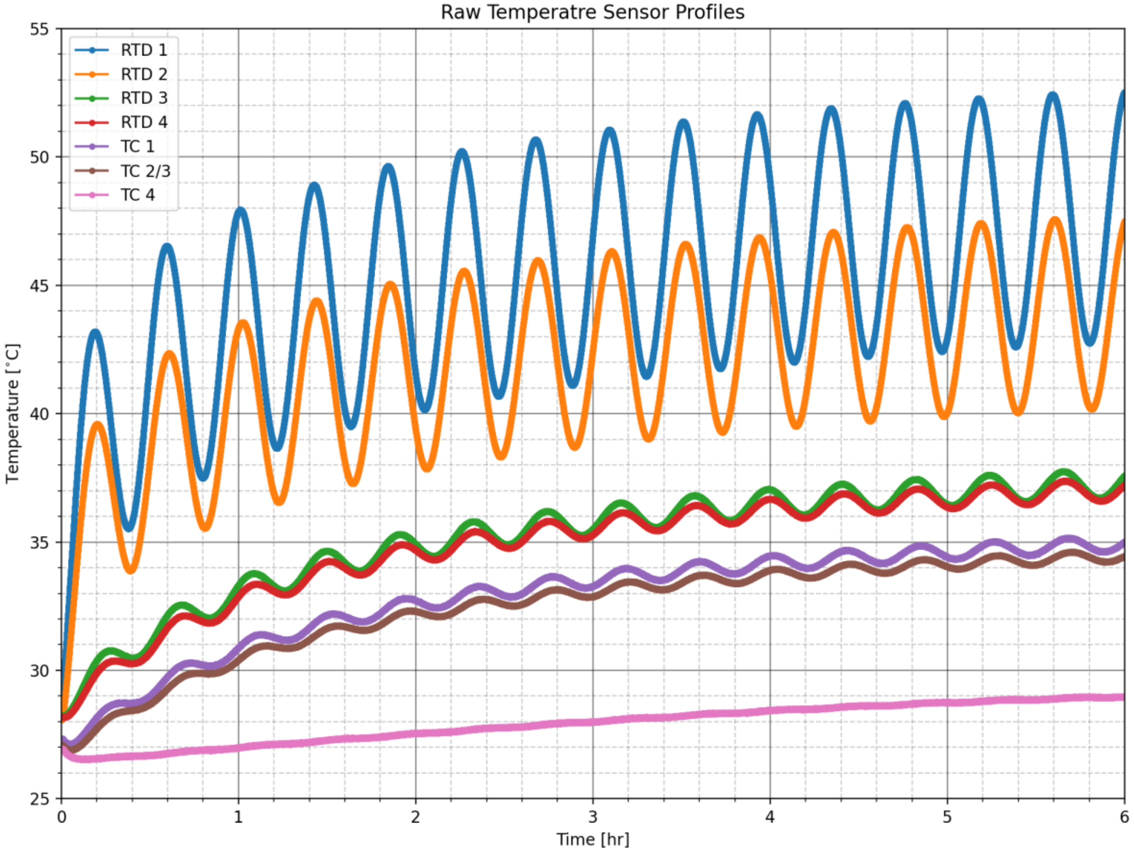
Disadvantages:

- Limited applicability
- Absolute temperature measurement accuracy is not needed
  → **Potentially unsensitive to heat leaks**
- Environment may no longer be representative
- Accurate knowledge of thermal mass required
- May still require long test periods…

SAMPLE TVAC OSCILLATORY LOAD TEST



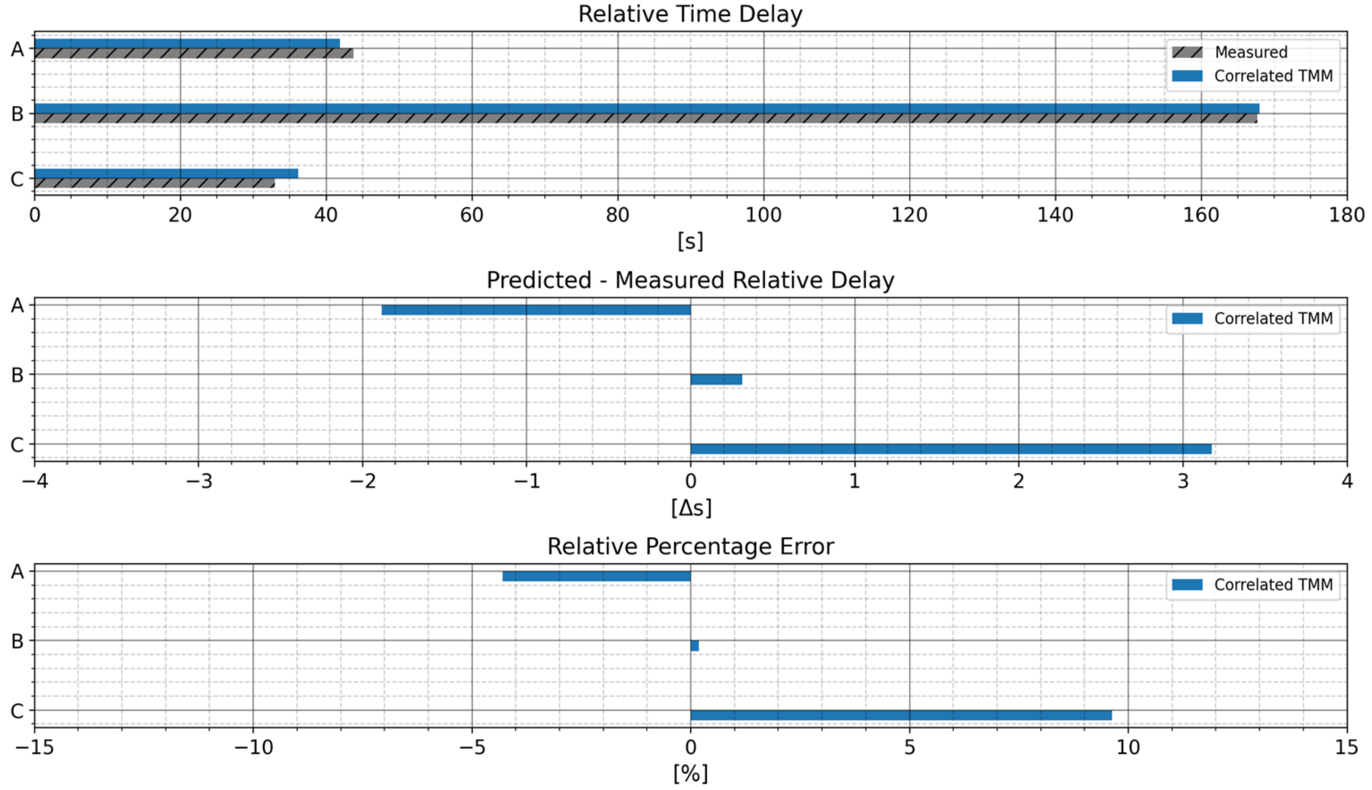
Test Parameters	
Oscillation Period	1500 s
Power Amplitude	3 W
Chamber Pressure	$8.6\text{x}10^{-3}$ mbar
Initial Chamber Temperature	27.7 ℃



SAMPLE TVAC OSCILLATORY LOAD CORRELATION

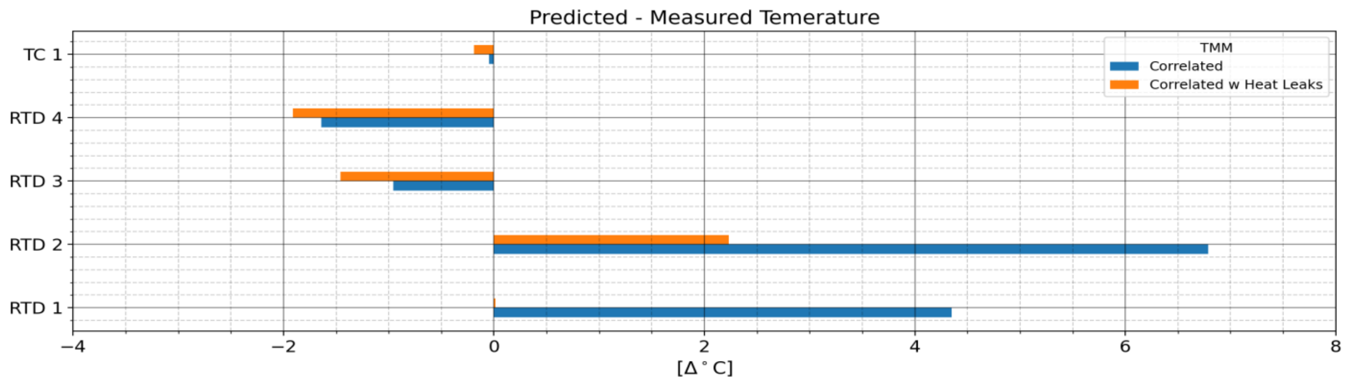
Phase-shift base correlation

Correlated Model Parameters	
Thermal Contact Conductance [W/m²K]	
Feature A	1656
Feature C	2080
Heat Sink	800
Strap Conductance Factor	
Feature B	0.475



TVAC OSCILLATORY LOAD VS BALANCE CORRELATION

Initial Model Parameters	
Thermal Contact Conductance [W/m^{2}K]	
Feature A	1656
Feature C	2080
Heat Sink	800
Strap Conductance Factor	
Feature B	0.475
Heat Leaks [W/K]	
Heater plate to TVAC	0.037



→ Frequency domain thermal correlations remain valid after adding heat leakages in the steady state correlation

TVAC OSCILLATORY LOAD VS BALANCE CORRELATION

- Method works (as expected)

- Similar results between:
  Ambient (outisde TVAC) <-> Ambient (inside TVAC) <-> TVAC

- **Useful correlation data can be extracted from very low amplitude signals**

CORRELATION OF REAL OPTICAL PAYLOAD MODEL

Computational test → Oscillatory load at $10^{-4} Hz$

- Data generated with model with unknown key features:
  -Random adjustments to typical uncertainty parameters
  -Artificial heat leakages added

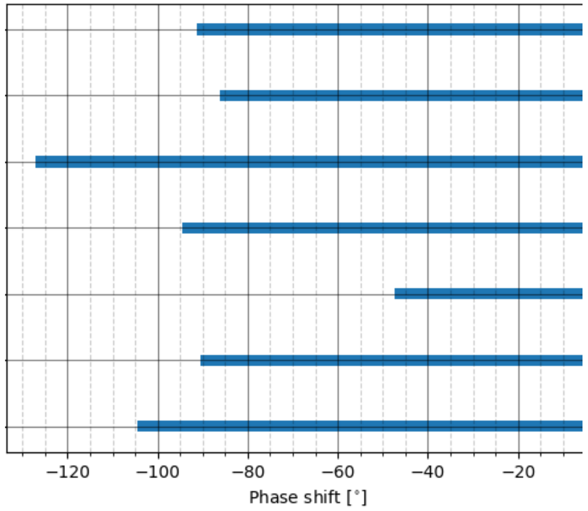
- Correlation based on a different configuration of the same model
  →Only limited set of adjusted parameters considered

- Analysis in both time domain and using ESATAN's frequency domain solver

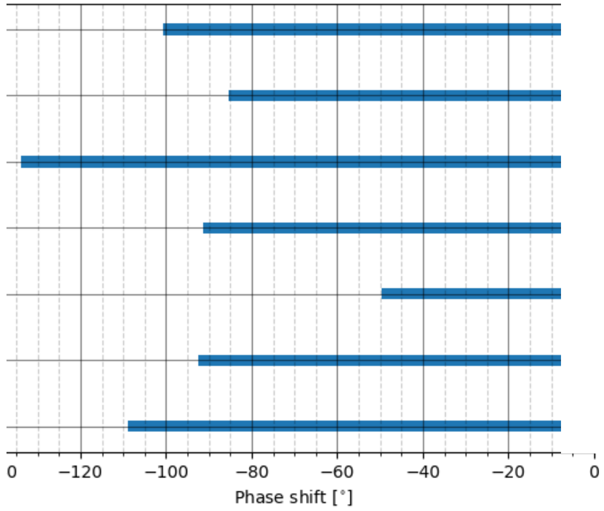
CORRELATION OF REAL OPTICAL PAYLOAD MODEL

Sensor pairs

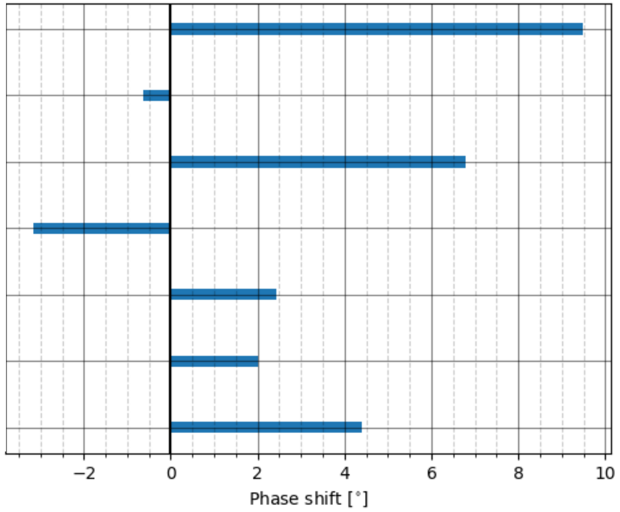
Uncorrelated model



Reference model
(random variations added)



Difference in phase shifts



CORRELATION OF REAL OPTICAL PAYLOAD MODEL

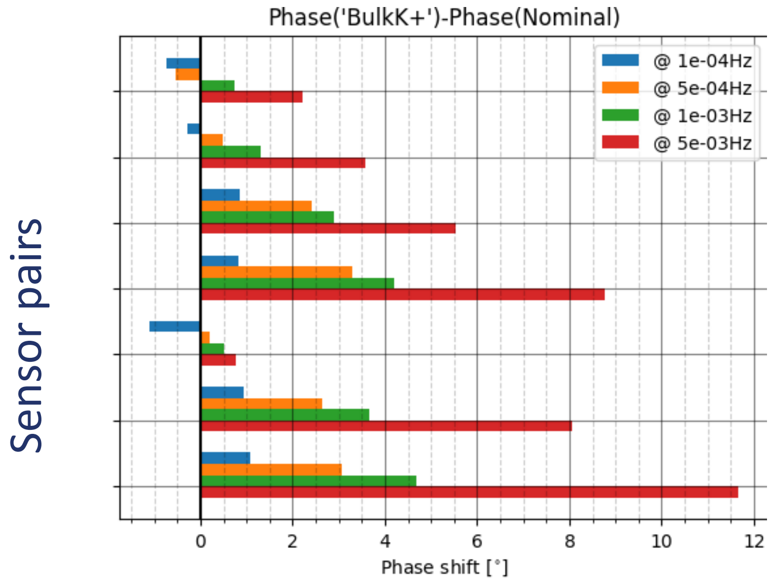
Lower input frequency:

- Higher gain → Better measurability of output signal
  -Measurability can also be improved with increased heater amplitude
- Small phase shift in the frequency domain
- Larger phase shifts in time domain → Better measurability of phase shift

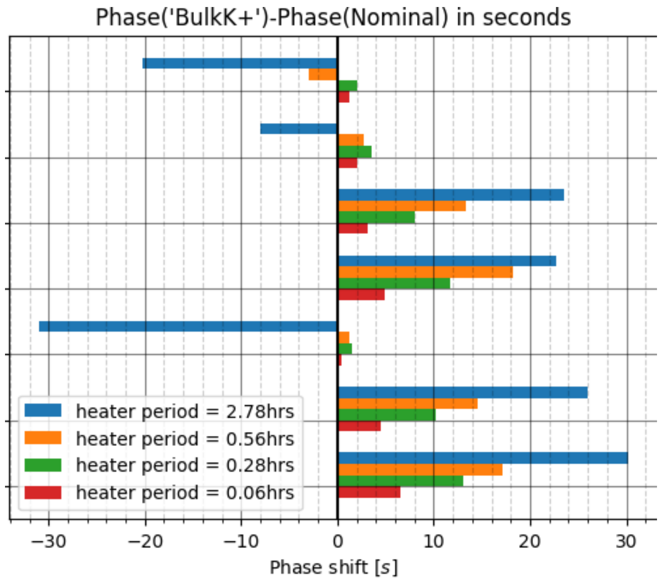
Higher input frequency:

- Faster oscillations → shorter test duration

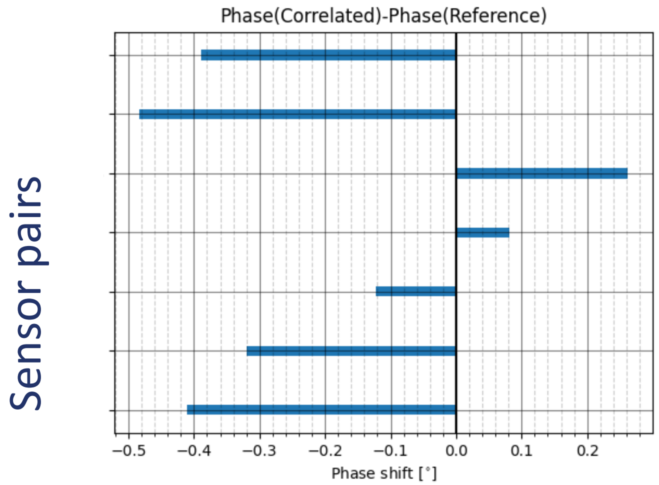
Units: degrees



Units: seconds



CORRELATION OF REAL OPTICAL PAYLOAD MODEL



In this model, this reached a correlation in thermal balance of 1°C or below

- Differences in phase shift between data and predictions below 0.5°C

Component	Reference [°C]	Correlated [°C]	Difference [°C]
Sensor pair 1	-53.3	-52.8	-0.5
…	-63.0	-62.5	-0.5
…	-72.5	-70.8	-1.7
…	-58.1	-57.7	-0.4
…	-52.9	-52.3	-0.6
…	-51.8	-51.2	-0.6
Sensor pair 7	-57.9	-57.4	-0.7

CORRELATION OF REAL OPTICAL PAYLOAD MODEL

- A “traditional” correlation process can also be applied
- Oscillation periods and amplitudes remain in a realistic range
- Insensitivity to heat leakages still applies

ONGOING ACTIVITIES

- Data filtering and processing – noise reduction and frequency decomposition
- Integration methodology into “standard” tests
- Testing at multiple frequencies at the same time

CONCLUSIONS

Thermal test correlation achieved based on frequency domain responses

- Without considering heat leaks
- Without the thermal balance data

This methodology seems to work, potential to gain capacity with minimum cost

- Works for both simple and complex models

Next steps:

- Feasibility of integrating methods in real tests
- Performing tests for multiple frequencies at the same time
- Apply on a real project

Questions?

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