Extending Low-Frequencies with a new seismic air source design

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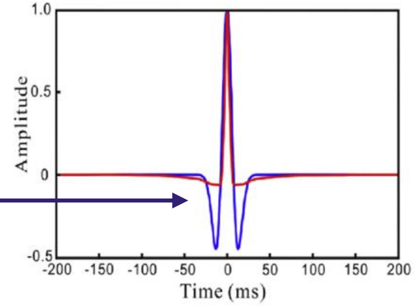
Drivers for Low Frequencies – Extending Broadband

LOW FREQUENCIES:

Broader amplitude spectrum

- More octaves the better
- Lows reduce the side-lobes of the wavelet
- Smaller side-lobes improve the resolution



Seismic Inversion

- Inversion requires a flat spectrum from 0Hz
- Better lows improve the reliability of the inversion, less reliance on low-frequency models

Full-waveform Inversion

- Starting frequency can have a significant effect on the final result

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Basic source design

- Amplitude is linearly proportional to the number of guns
- Amplitude is linearly proportional to the firing pressure
- Amplitude is proportional to the cube root of the volume
- Frequency output of an airgun is proportional to its volume

- More guns are better than big guns
- Big guns have better low frequency output
  - If two guns are near enough to each other, their bubbles coalesce
    - Output frequency is the same as if it was a single gun of the combined volume
    - Power output is up ~60% over a single gun

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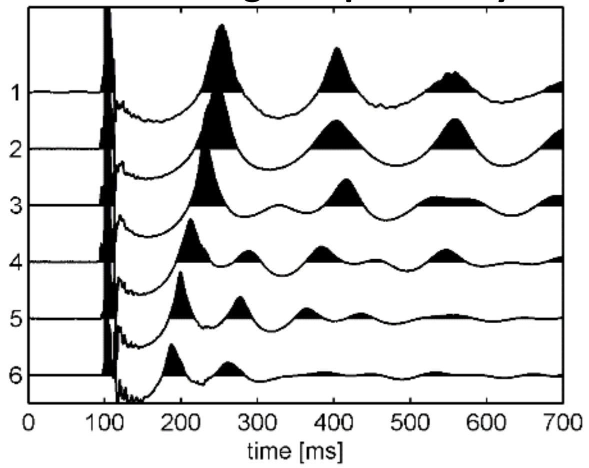
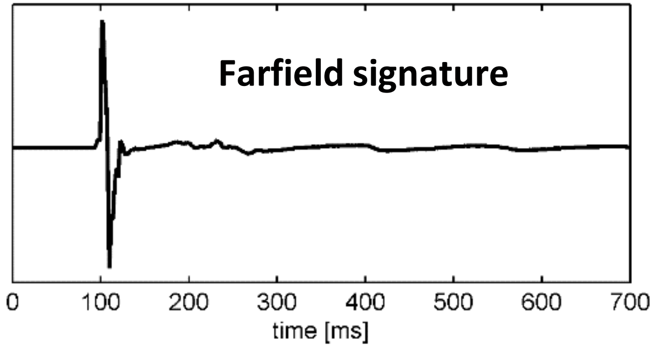
Classical airgun arrays

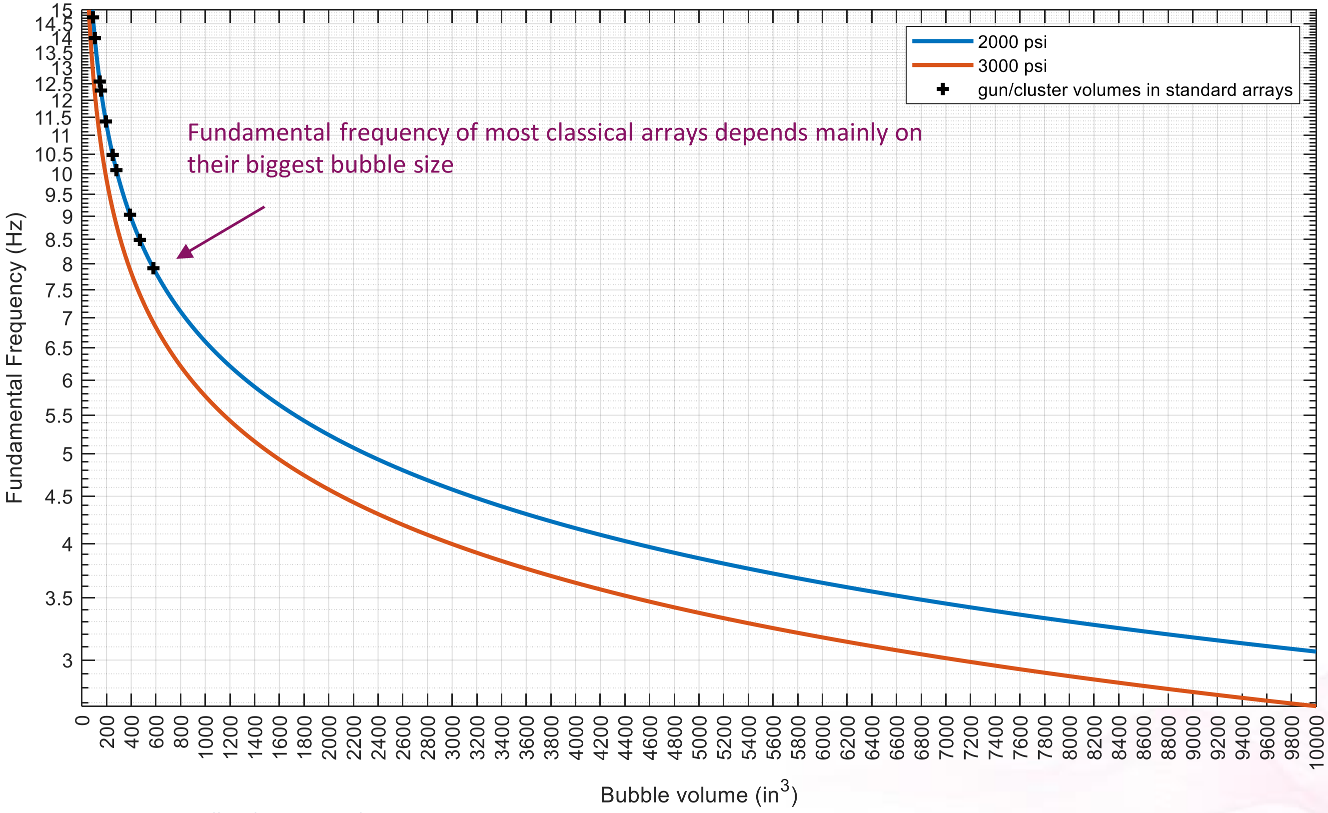
- We want to tune out the bubble effect –sharp spike
  - Bubbles oscillate with different frequency.
  - Bubble frequencies chosen for maximum destructive interference.
  - Gun distances chosen to ensure that the bubbles oscillate independently.

Oscillating independently





Fundamental frequency vs. Gun/Bubble volume



Rayleigh-Willis formula

$$f_0 = k\frac{\left(1 + {}^{d}\!/_{10}\right)^{5/6}}{(P \cdot V)^{1/3}}$$

P = airgun firing pressure
V = airgun fire chamber volume
d = airgun depth
k = empirical factor depending on gun type and volume

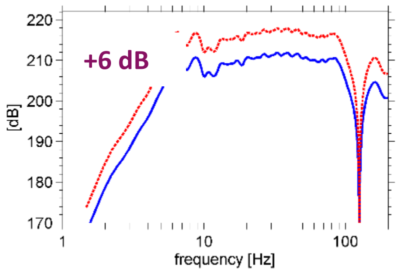
Ways to **change** the low frequency output

Increase Total Volume

More of the same

Limited by compressor capacity

Lifts entire spectrum



Depth Changes

- Bubble frequency varies as cube-root of effective volume

–tow deep and the hydrostatic pressure increases=small bubble=less lows

..but better zero notch

-tow shallow, bigger bubble

…but operational constraints

Increase Bubble Size

Bubble frequency varies as cube-root of effective volume.

Larger guns – reliability trade off

Clustering – limited # of guns in a cluster

Frequency locking [1]

[1] Laws, Hatton and Haartsen, 1990

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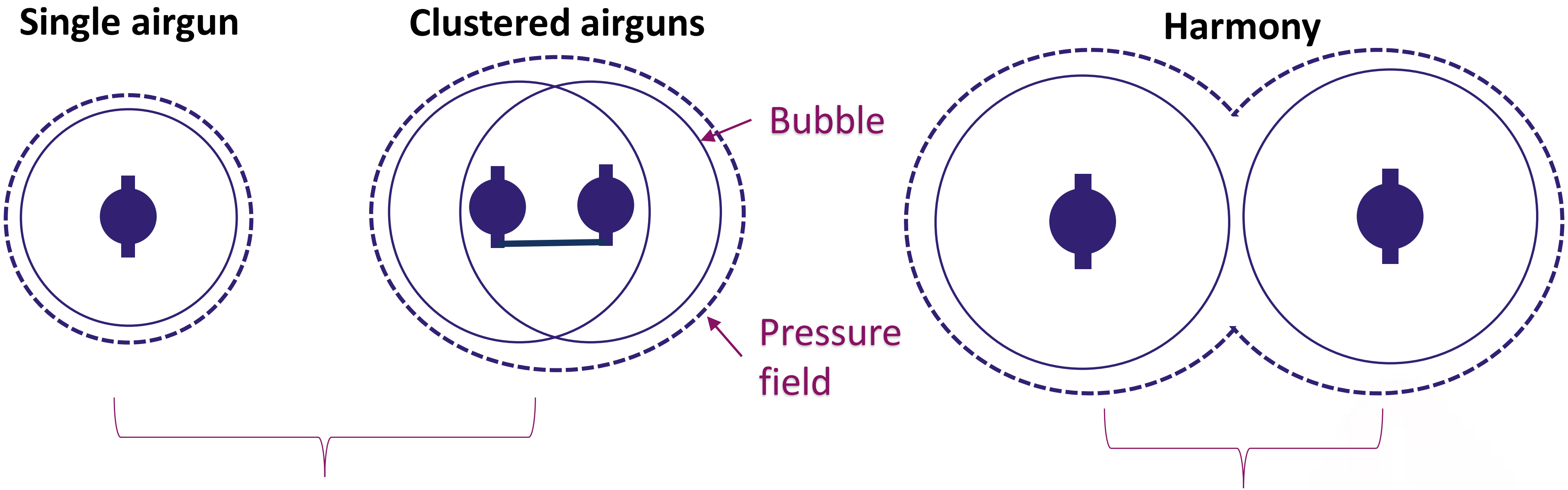
Bubble Interaction Changes the Oscillation Frequency



Standard source
Single elements/clusters do not interact through pressure field

Frequency Locking
No bubble interaction
Pressure fields interact and “lock”[1]

[1] Laws, Hatton and Haartsen, 1990

Atlantic Deep Water Test

- Endurance testing
- Full source deployment

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Test objectives

Reliability testing

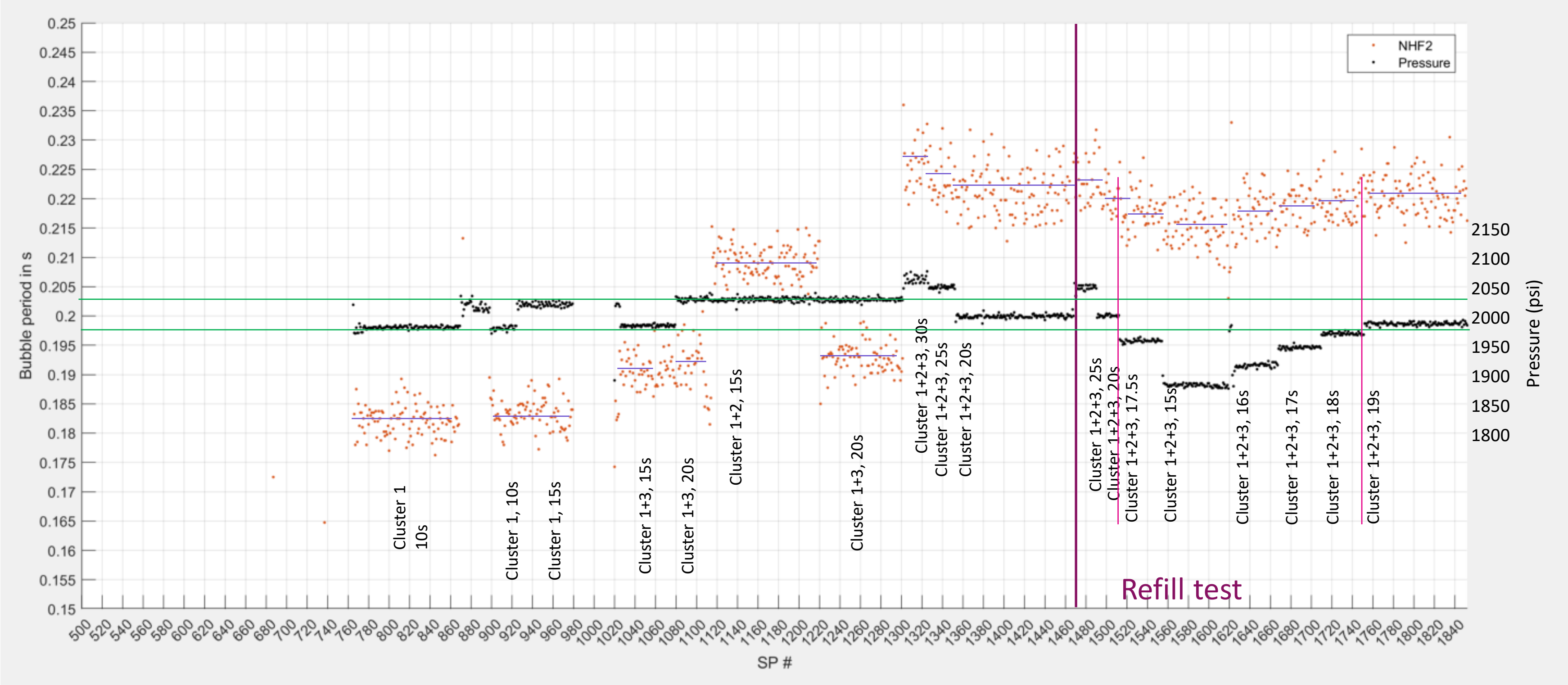
Refill times

Different cluster configurations

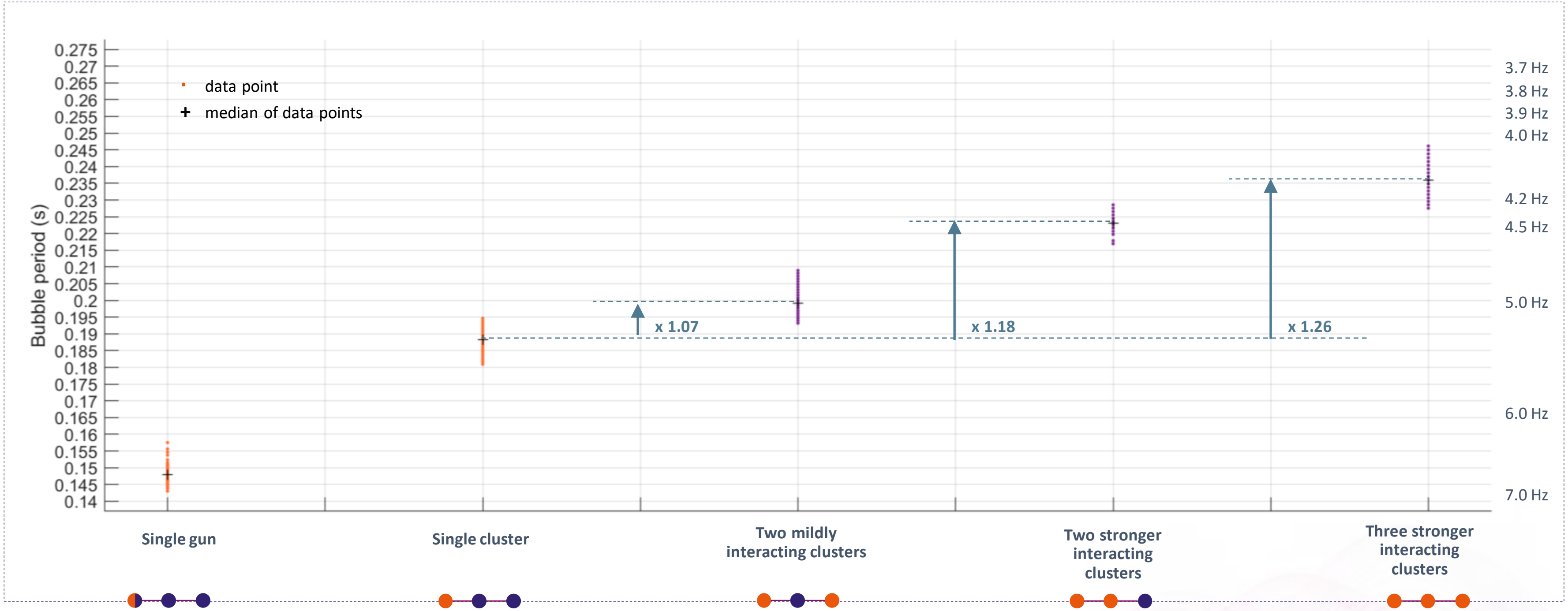
Normal source QC over time

Test for frequency locking

Bubble Period estimates NFH2 only (peak to peak pick) 06/07/2021



Partial Frequency Locking Increments on Raw NFH Bubble Period



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Johan Sverdrop Test

- Endurance testing
- Full source deployment

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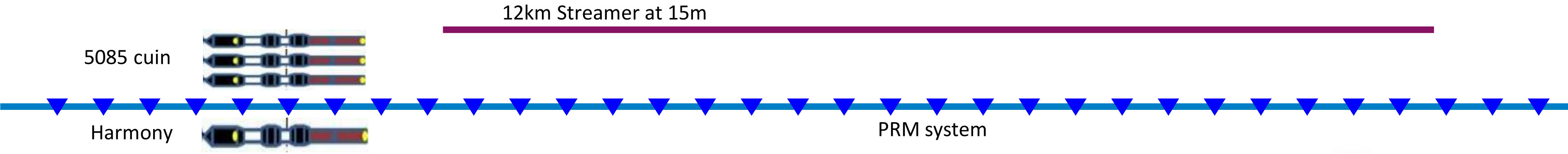
Johan Sverdrop Test configuration



Both sources at 8m depth
CoS seperation 16m

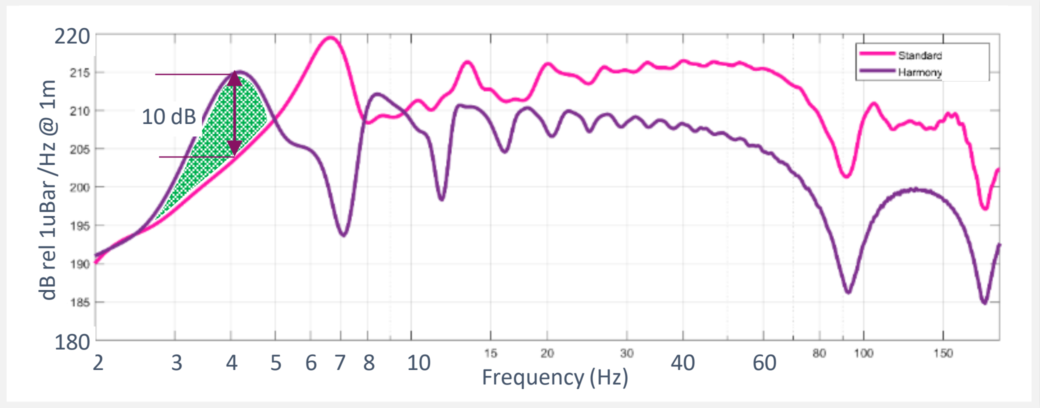
Co-located sources, 25m flip-flip acquisition

Harmony Spectra

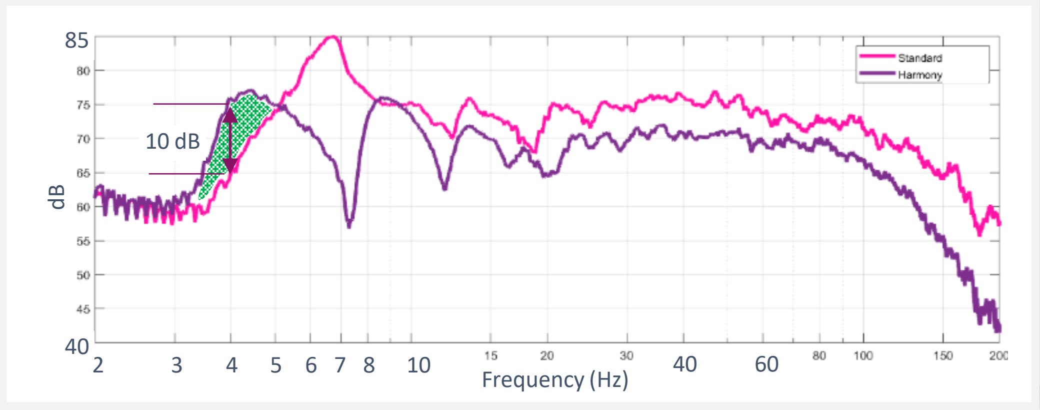
Data courtesy Equinor

- Farfield signatures computed from nearfield hydrophones

  ~uplift approx. 10dB @4Hz



- Spectra from common shots, permanent reservoir monitoring nodes



Reference high-output source
5085cuin, 3 sub-arrays, 24 elements

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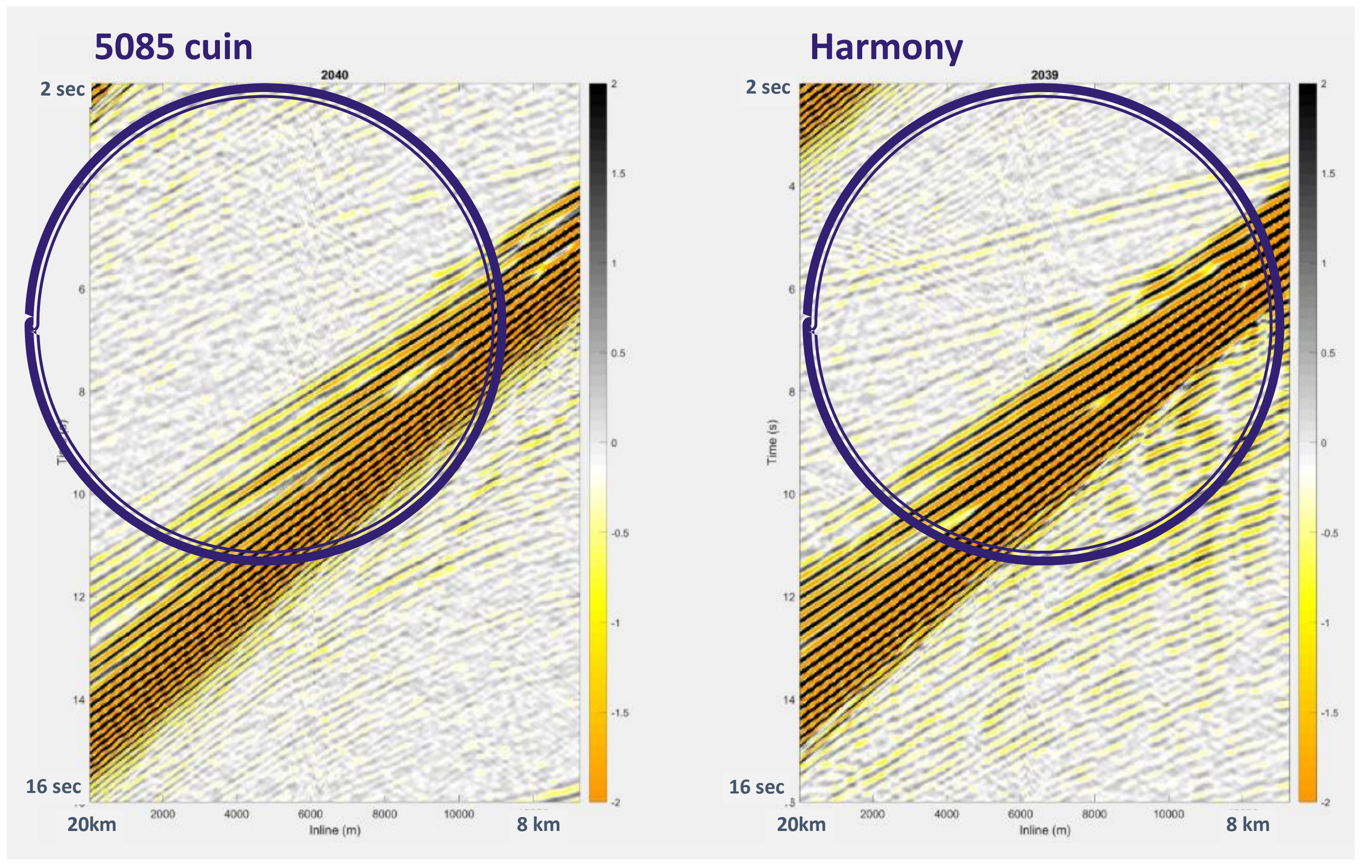
Data courtesy Equinor

Shot gathers

Full Bandwidth

PRM system

Max offset ~20km



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Harmony Flexible by Design

- **Design**
  - Uses equipment suitable for fleet-wide deployment
  - Harmony occupies a single sub-array position (+hot spare if required)
  - Field tested for endurance and reliability

- **Standalone broadband source**

OR

- **Incorporate with standard sources**

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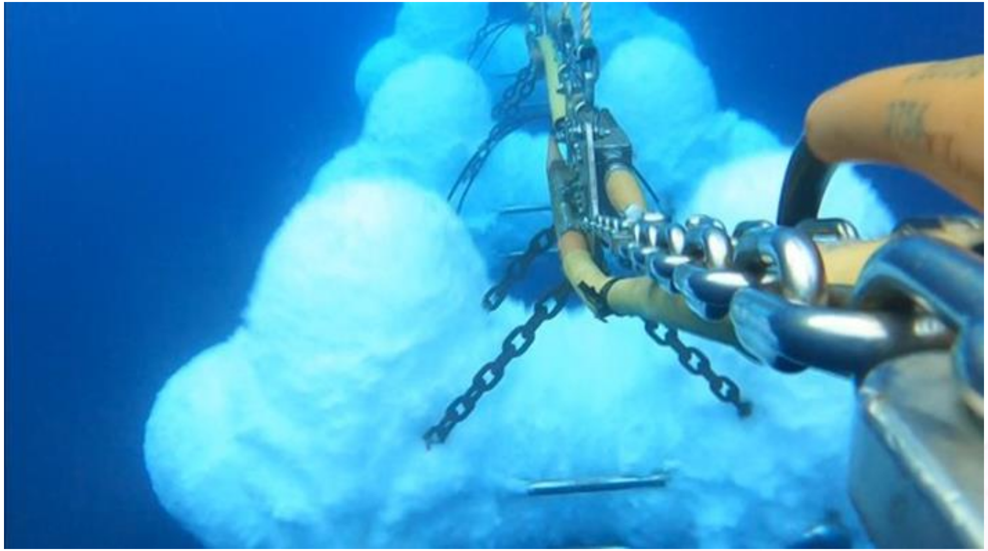
Summary

- Low-frequency rich source
- Enabled by frequency locking
- One sub-array design –flexible options



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