QuietSeis™
An Ultra-low noise MEMS accelerometer for Seismology

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SERCEL

- French company founded in 1956, subsidiary of CGG
- More than 1500 employees in 8 countries and 14 sites
- Market leader in seismic instrumentation for O&G exploration in marine, land and transition zones
- Longstanding culture of technological innovation
Introduction

// Context

- Sensors for low frequency seismic applications (<2Hz):
  - Geophones (10Hz, ~5Hz)
  - Seismometers (1-2Hz)
  - Force Balance Accelerometers (FBA)

→ bulky, costly, power consuming, not deemed industrial..

→ phase rotation at low frequency, manufacturing tolerances, aging, environmental conditions: amplitude & phase distortions detrimental to the fidelity of the signal
Introduction

// Context

- MEMS accelerometers often perceived as too noisy at low frequency because of $1/f$ noise
  - True for most of the seismic MEMS on the market

- Latest generation of digital closed-loop MEMS accelerometer, initially designed for seismic imaging, exhibits very good noise performances at low frequency.
MEMS accelerometer

// Some benefits of MEMS accelerometer

- No sensor leveling required, can be used in any orientation
- Measures its own tilt (DC response)
- Compact and very low power
- Digital closed-loop architecture:
  - Frequency response flat and highly stable in amplitude and phase (down to DC):
    - Perfect time synchronization of events between sensors
  - Very low distortion
  - Very fast clip recovery time
MEMS Noise measurements

Noise floor for seismic imaging (Lainé, 2014)

- Noise measured above 1Hz in LSBB (France)
- <15ng/sqrt(Hz) above 10Hz
- 1/f noise at low frequency not characterized
MEMS Noise measurements

Low frequency noise measurement

- Basement of office building in peri-urban area
- Vibration isolation platform ($f_0 \sim 2.7$Hz)
- Soundproof acoustic chamber
- Data acquired at night over the course of several months
- Raw data processed using ANSS/USGS Matlab script: ANSS_noise_rms_rev4.m
MEMS Noise measurements

// Low frequency noise measurement

• 2 QS-DB boards: Vertical and horizontal
  – QuietSeis MEMS accelerometer
  – UART serial data transmission to external device

• 10 Hz and 5Hz geophone channels
  – low noise 24 bits / ADC
  – Velocity data converted in acceleration
MEMS Noise measurements

// Low frequency noise measurement

Noise limited by ambient vibrations above ~2Hz

MEMS 1/f noise lower than:
- 10Hz-geophone noise below ~2Hz
- 5Hz-geophone noise below ~0.1Hz
- NHNM down to ~0.1Hz
MEMS Noise measurements

// Low frequency Dynamic Range

Full scale @ +/-13m/s² pk:
- Vertical MEMS Dyn. Range ~131dB
- Dyn. Range 133dB (0.02-2Hz)
- Dyn. Range 126dB

Full scale +/- 5m/s² pk (3.5m/s² rms)

// Full scale @ +/-13m/s² pk:
- Vertical MEMS Dyn. Range ~131dB
Comparative testing vs. Trillium Compact broadband seismometer in a low noise test site is being scheduled with a French seismology institution.
Earthquake detection

// IRAN-IRAQ border M7.4 earthquake

- Nov 12th, 2017
- 18:18:19 (UTC)
Earthquake detection

Earthquake ground acceleration
(Clinton, 2002)

MEMS Noise floor (typ.)
Earthquake full scale 5m/s² pk
Vertical axis MEMS accelerometer
(MEMs Spectrum)
Natural frequency of isolation platform
Earthquake detection

- **t=180s → 18:25:09 in NANTES**
  - P-wave @ 18:25:06 in CLF

- **t=515s → 18:30:24 in NANTES**
  - S-wave @ 18:30:35 in CLF

Good correlation with CLF seismic station!
A new MEMS accelerometer with improved noise floor and reduced 1/f noise contribution has been evaluated for very weak signals and very low frequency measurements. A noise floor below NHNM down to 0.1 Hz has been demonstrated.

New possibilities for low frequency, weak signal applications:

- Ambient seismic noise imaging and monitoring
- Seismology
  - Replacement of Force Balance Accelerometer seismometers,…
- Structural Health Monitoring of large structures
  - Operational Modal Analysis using ambient vibrations
- Active stabilization platforms in low noise or low-g environments
References


