Seismic Monitoring With Next Generation Smart Meters™

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Background

- Over the last 30 years PG&E spent approximately $3B on seismic upgrades
- Updated seismic ground motion models and a non-ergodic seismic hazard framework will significantly improve prioritization of resources and budgeting for seismic upgrades and improved system resiliency
- Dense ground shaking information within hours after an earthquake will help inform post-earthquake response decisions

Technical Need for More Empirical Data

- To have enough data from moderate and large magnitude earthquakes at short distances to build empirical models, we combine data from around the world
- The global variability observed in ground motion is assumed to represent the variability that would be observed in ground motion at a single location if given time to sample enough earthquakes.
- We now have enough data from regions such as Taiwan, Japan, and parts of southern California to show how bad this assumption is

The Advantage of Instrumenting Smart Meters

- Creation of a dense seismic network throughout the PG&E System using accelerometers in electric Smart Meters is an efficient approach to help address current data limitations
- A denser network will provide valuable data to develop the correlated coefficients necessary for implementing the new non-ergodic GMPEs/hazard

(N)ext (G)eneration (M)eter Accelerometer

NGM prototype & Accelerometer

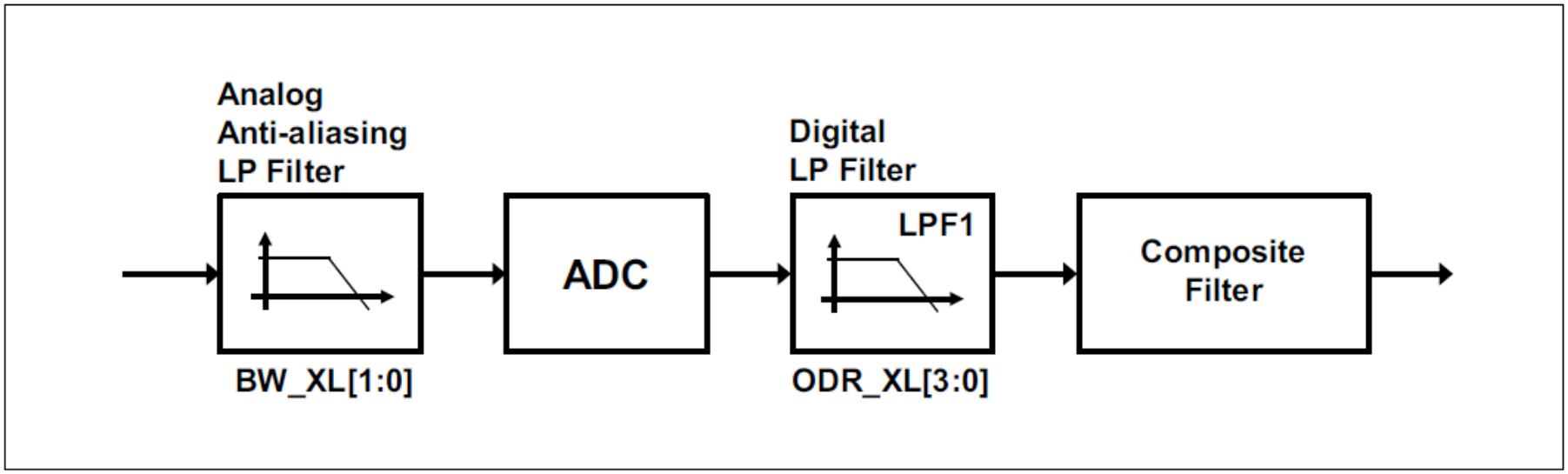
- Uses Existing NGM Arcitecture for Power and Communications
- Accelerometer is added to the motherboard
- The seismic data recording and cloud communications are built into the firmware
- Low Per-Unit Incremental cost (<$3/unit)

NGM Accelerometer Prototype Design

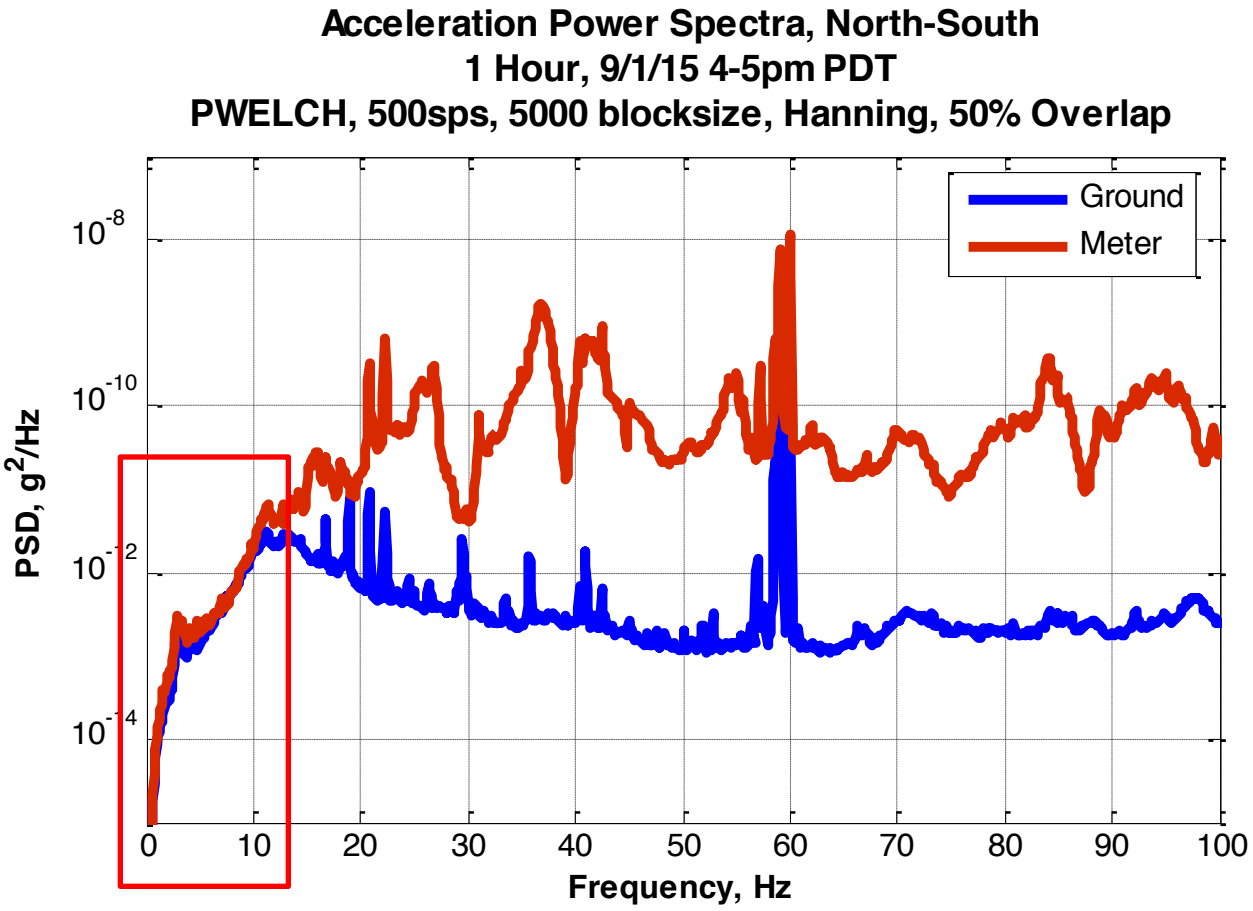
- 3 channels of acceleration sampled at 208 sps per channel
- Digital resolution is approximately 14 bits over a +/-2g range
- Anti-alias lowpass filter at 50 Hz and a digital lowpass filter at 208/9 = 23 Hz
- Sensing is direct digital, using an ST Micro LSM6DS3 inertial module with 3D accelerometer and 3D gyro
- Continuous data flow into a ring buffer. A processor trigger algorithm decides when to record an earthquake packet (90 seconds fixed length). Trigger on simple threshold on one or more channels.
- Horizontal orientation is uncertain and possibly not critical as long as the Z-axis is vertical

NGM Accelerometer Prototype Design

Figure 5. Accelerometer chain

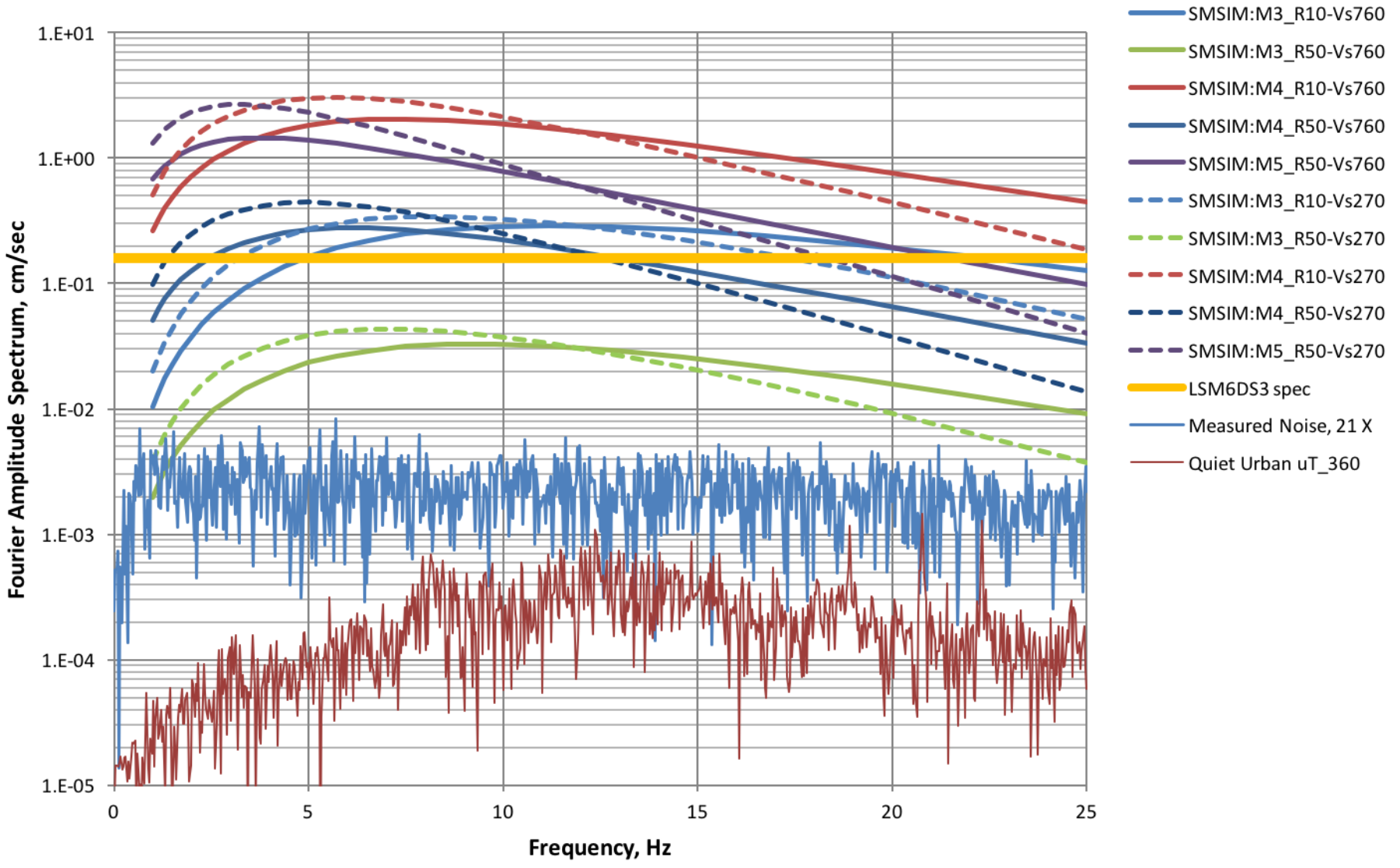


Initial experiment, still monitoring in 2018


Acceleration Power Spectra, North-South
1 Hour, 9/1/15 4-5pm PDT
PWELCH, 500sps, 5000 blocksize, Hanning, 50% Overlap
Ground
Meter
PSD, g2/Hz
10-8
10-10
10-12
10-14
0
10
20
30
40
50
60
70
80
90
100
Frequency, Hz

Fourier Amplitude Spectra

SMSIM, Prototype NGM Noise, and Quiet Urban Microtremor



NGM Data Flow

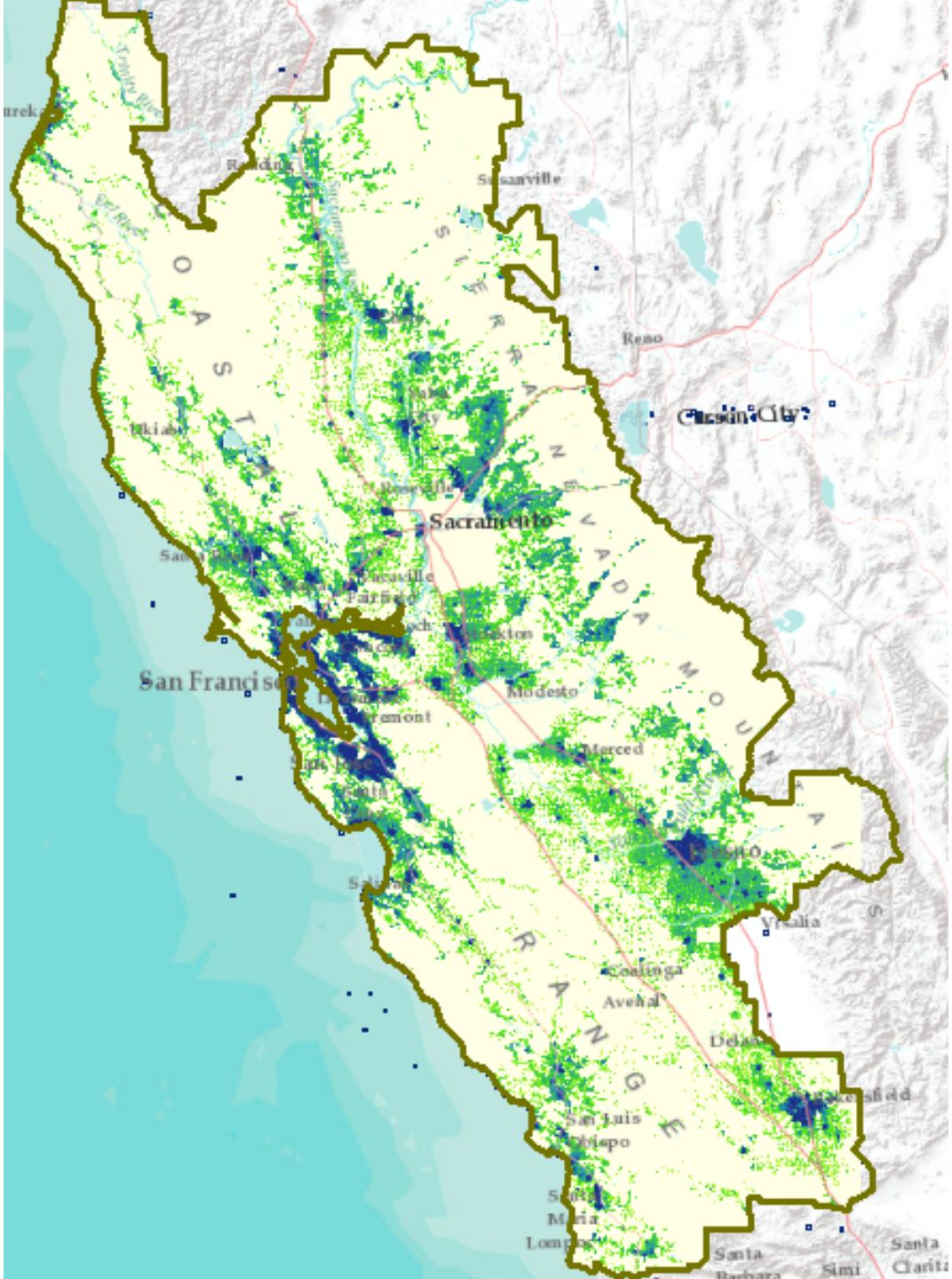
PG&E
Geosciences
Updated Models
Fragility
Risk Evaluation

Amazon Cloud

Publicly Available
Aggregated Data

Seismic Processing
and Aggregation

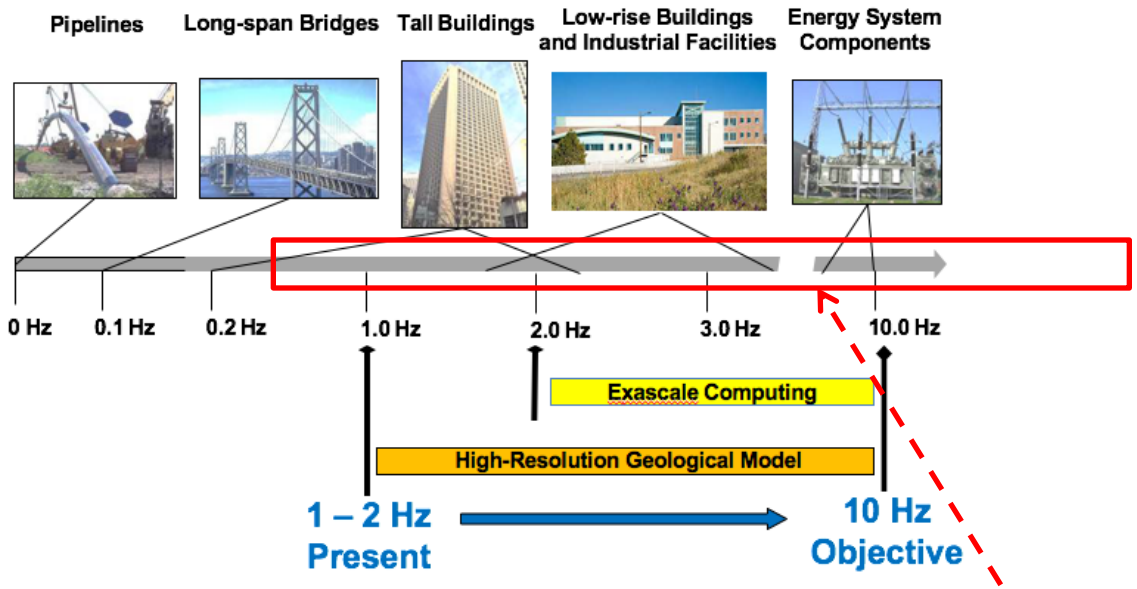
Smart Meter Density: Electric Meters



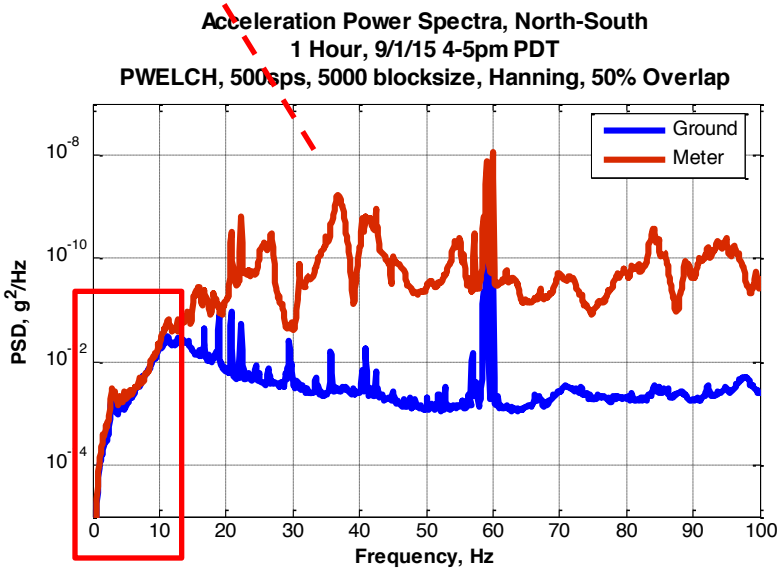
Number of meters per sq km

- 0 - 1
- 1.000000001 - 2
- 2.000000001 - 4
- 4.000000001 - 8
- 8.000000001 - 10
- 10.00000001 - 20
- 20.00000001 - 50
- 50.00000001 - 100
- 100.0000001 - 250
- 250.0000001 - 500
- 500.0000001 - 10,000
- 10,000.00001 - 15,257

M4-5: 800,000
M5-6: 500,000



NGM recordings fall within useful range to evaluate PG&E infrastructure



Questions & Answers

Sensor: ST LSM6DS3

3D accelerometer and gyroscope in small package with enhanced embedded features

The new LSM6DS3 iNEMO module offers best-in-class accuracy and efficiency as well as always-on low-power features for an optimal motion experience.
The combination of a high-resolution 3D accelerometer and 3D gyroscope in a single package significantly reduces the risk of drift over-time and temperature, while reducing footprint on the final PCB.

*Best in MEMS & Sensors Innovation Awards -MEMsies- MEMS Industry Group

KEY FEATURES

- Acceleration range: ±2/±4/±8/±16 g
- Angular rate range: ±125/±245/±500/±1000/±2000 dps
- Smart FIFO up to 8 kbyte
- Noise density (Axl): 90 µg/√Hz
- Rate noise (Gyro): 7 mdps/√Hz
- 16-bit output resolution
- Current consumption (gyro & axl):
  - Normal mode 0.9 mA @ ODR = 208 Hz
  - Low-power mode 0.42 mA @ ODR = 13 Hz
- Supply voltage range: 1.71 to 3.6 V
- Temperature range: -40 to +85 °C
- Embedded sensor hub: up to 4 external sensors data collection
- I²C/SPI digital interfaces
- 14-pin plastic land grid array (LGA) package (2.5 mm x 3 mm x 0.83 mm)

KEY APPLICATIONS

- Full gesture recognition and movement detection
- Activity monitoring
- Gaming applications
- Wearable devices
- Mobile phone and portable devices
- Headsets and virtual reality
- Remote control
- IMU for helicopters, drones and robots
- Dead reckoning
- Electronic Image Stabilization (EIS)

PG&E NGM/SMA Progress 1/25/17 RN

Application: Local Ground-Motion Model Development Collaboration

- 3-D simulations of site and path effects for the local model
- Lawrence Berkeley National Lab (LBNL)
- U.S. Geological Survey (USGS)
- Empirical evaluation of smart meter data to test the simulations
- Pacific Earthquake Engineering Center (PEER)

Initial Region for Local Model

LBNL PEER

Current Limitations of Ground Motion Models

- Use of globally-averaged models limits our ability to accurately estimate the seismic hazard and risk
- Limits our ability to distinguish between the seismic risk at different facilities
- May not have optimized prioritization for seismic retrofits or new projects
- Current seismic stations are not dense enough to constrain the site and path effects required for development of local ground-motion models
- Creation of a dense seismic network throughout the PG&E System using accelerometers in electric Smartmeters is an efficient approach to help address these issues