

HP MEMS Seismic Sensor for Oil and Gas Exploration

Introduction

The oil and gas industry uses seismic imaging to provide 3-dimensional images showing the locations of oil and natural gas deposits. Imaging accuracy is critical to determining the optimum location for drilling to increase extraction efficiency. Two critical needs for improving image resolution and fidelity above today's results are increasing the spatial density of sensors deployed in the field and generating ultra low noise measurements in a wider frequency band.

HP and Shell have recently announced a collaboration to develop a next generation wireless seismic sensor network for oil and gas exploration. HP's inertial sensing technology is deployed to provide very low noise at frequencies below the bandwidth of traditional geophones and existing MEMS devices. The small size and lower power consumption of the sensor nodes will significantly reduce the cost of large scale deployments, enabling data from more channels to be collected, thus increasing the channel density in any given survey.

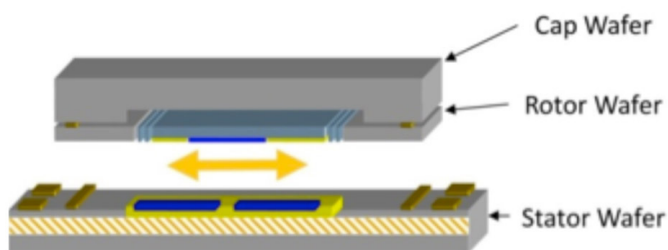


Figure 1. Three wafer MEMS Technology

HP MEMS Sensor Optimized for Seismic Imaging Applications

The HP surface electrode inertial sensing technology enables a new class of low noise, low-power MEMS accelerometers [1]. The MEMS sensor is fabricated from 3 separate single crystal silicon wafers bonded together and singulated into a small vacuum encapsulated die [2]. The proofmass is suspended by Si flexures etched through the center wafer. Electrodes are arrayed on one surface of the proofmass and on the stationary wafer opposite the proofmass. A small gap is maintained between the two wafers. Schematic diagrams of the device are shown in Figures 1 & 2. The large electrode area and small electrode gap provides very high sensitivity with high dynamic range in an open-loop configuration. The large mass obtained with the thickness and area of the proofmass results in a low Brownian noise for the sensor. A Scanning Electron Microscope (SEM) picture of the silicon proofmass is shown in Figure 3.

The HP inertial sensing technology has been optimized for seismic imaging applications. The sensor is a single axis accelerometer that can achieve full dynamic range with the sense axis in any orientation by using three-phase capacitive sensing [3]. The MEMS sensor is shown in figure 4. Custom electronics have been designed to extract optimum performance from the sensor. The sensor circuits were first developed using discrete electronics. The electronics are now being implemented into a custom ASIC to achieve the high performance with low power, small size and in high volumes.

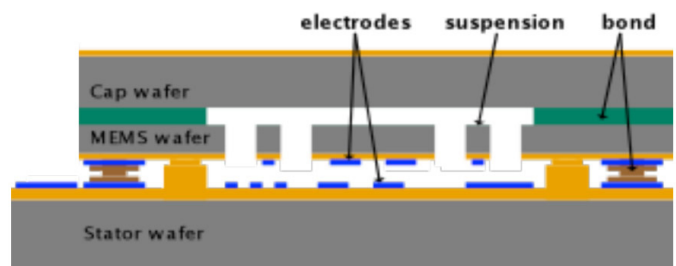


Figure 2. Schematic cross-section of MEMS accelerometer

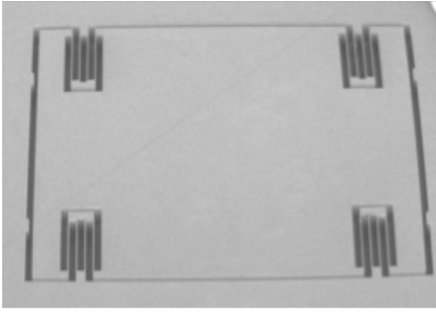


Figure 3. SEM of Silicon Proofmass

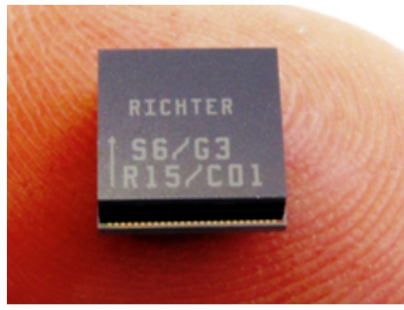
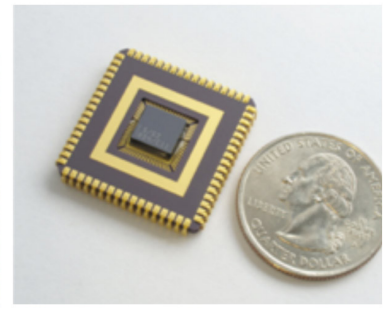


Figure 4. HP MEMS Seismic Sensor



HP Sensor Demonstrates Flat Frequency Response with Linear Output

One of the advantages that MEMS accelerometers have over geophones is the flat frequency response at low frequencies. Unlike geophones which are velocity sensors and operate above their resonance frequencies, accelerometers operate below their resonance frequencies. The frequency response of the HP MEMS sensor is shown in figure 5. It can be seen that while geophones roll-off below their resonance frequencies, the gain and phase of the HP MEMS sensor is flat at frequencies from 200 Hz down to DC. Figure 6 shows the voltage output of the HP sensor vs. acceleration. The sensor has a linear output with no hysteresis

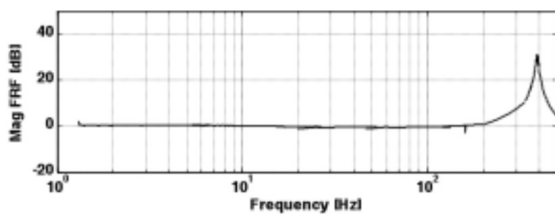


Figure 5. Frequency response of HP MEMS Sensor

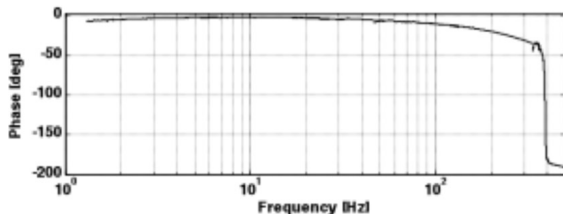


Figure 6. Linear Output of HP MEMS Seismic Sensor

Test Results Demonstrates Sensor Noise Floor of 10 ng/rtHz

The HP MEMS seismic sensor was tested at the U.S. Geological Survey's Albuquerque Seismological Laboratory (ASL). The primary goal of the testing was to measure the self noise of the sensor. The testing was done in a vault used for testing seismometers because of the extremely low ambient noise. The USGS provided a high resolution seismometer (GS-13) to be used as a reference during the testing.

To determine the noise floor, the HP MEMS sensor was placed next to the GS-13 in the vault on a block of granite. The experimental setup can be seen in Figure 7. Figure 8 shows the noise PSD from 1 mHz to 100 Hz. The sensor demonstrated a dynamic range of 120 dB and a noise power spectral density (PSD) of less than



Figure 7. Experimental Setup for USGS noise testing

10 nG/rHz. This noise level is equivalent to the peak of the Peterson Low Noise Model [4]. This peak results from the noise of ocean waves hitting the earth's shorelines, detected at the most remote locations on earth.

The noise corner frequency is determined to be at 1 Hz, where the noise was 16 nG/rHz. Below this frequency the inherent 1/f noise in the discrete sensor electronics increases inversely with frequency. When combined with the custom ASIC however, the noise density performance expected from the sensor is < 10 ng/rHz at frequencies from 1 to 200 Hz.

Comparison of Earthquake Signal

During the testing at the USGS Lab, data from the GS-13 and the HP MEMS sensor was also logged during an earthquake in the Gulf of California (Figure 9). The specific earthquake data is shown in Table 1.

Fig 10 shows the time series of the vertical waveforms from the two sensors during the earthquake. A portion of this data was taken to do an analysis of the HP MEMS sensor. Figure 11 shows the noise density of the two sensors during the earthquake. These waveforms show excellent agreement down to frequencies of 25 mHz, indicating a flat frequency response for the HP MEMS sensor.

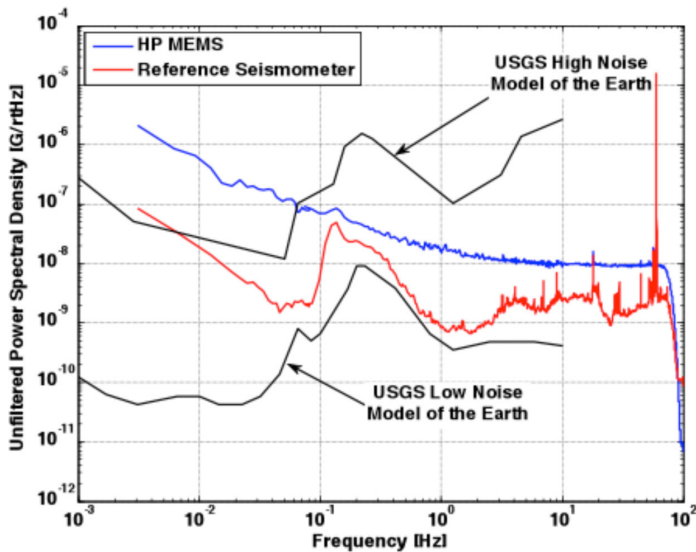


Figure 8. Noise PSD spectrum of HP MEMS sensor and GS-13 reference sensor from USGS noise test

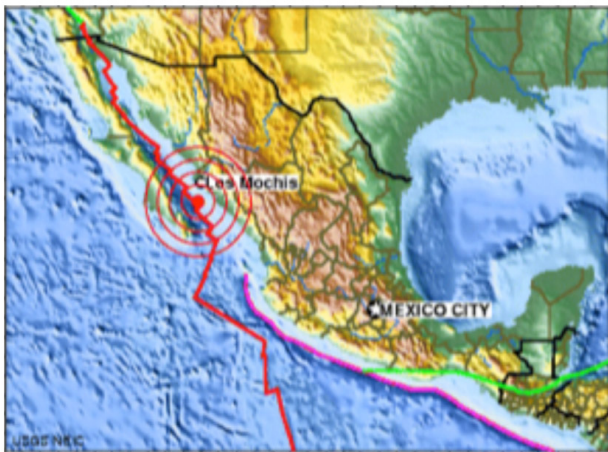


Figure 9. Location of earthquake recorded during USGS testing (<http://earthquake.usgs.gov/>)

Magnitude	6.7
UTC Date and time	2010/10/21 17:53:14
Latitude (Deg)	24.84
Longitude (Deg)	-109.17
Depth	10 km
Region	Gulf of California

Table 1. Earthquake recorded during testing.

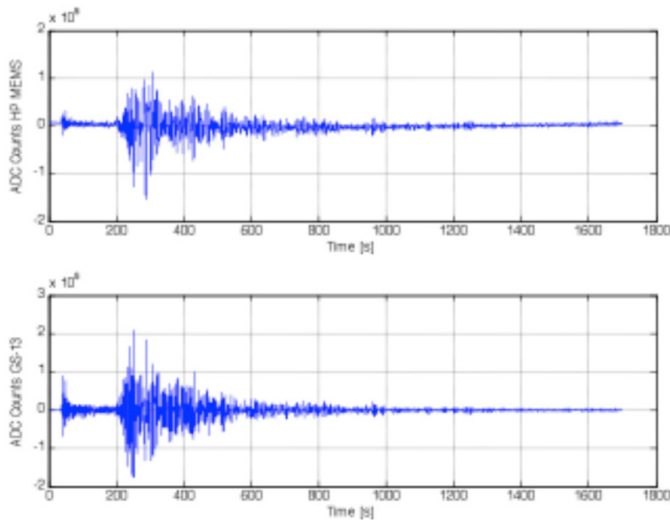


Figure 10. Time series of earthquake from HP sensor (top) and GS-13 reference sensor (bottom)

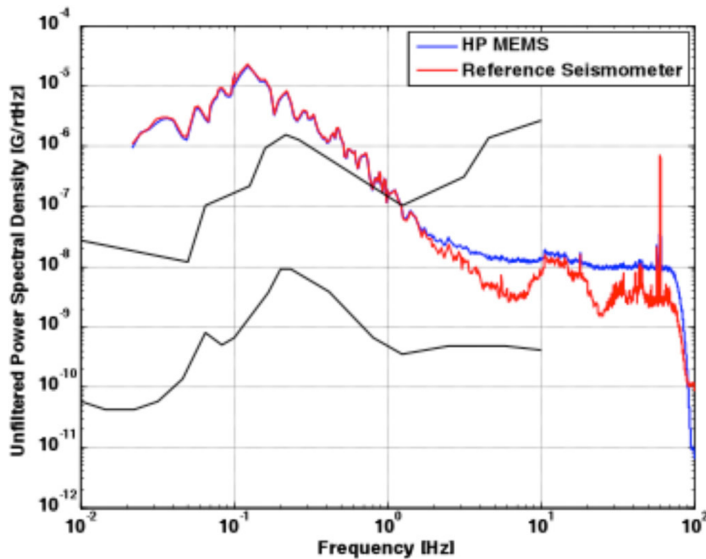


Figure 11. Noise density spectrum of the HP MEMS sensor and the GS-13 reference sensor recorded during earthquake

Summary

HP has developed a MEMS accelerometer for use in a wireless seismic sensor system, utilizing HP's inertial sensing technology. Unlike conventional geophones used for seismic imaging, the MEMS sensor has a flat frequency response at low frequencies. Comparison to a USGS reference sensor during an earthquake confirms frequency response down to 25 mHz.

The sensor is optimized to provide very low noise at low frequency. Testing has confirmed a noise floor of < 10 ng/rHz. A custom mixed signal ASIC is under development that will enable low power, small form factor sensors for use in remote wireless sensor arrays. When combined with the custom ASIC the sensor is expected to have noise < 10 ng/rHz down to 1 Hz.

References

- [1] R. Walmsley, L. Kiyama, D. Milligan, R. Alley, D. Erickson and P. Hartwell, "Micro-G silicon accelerometer using surface electrodes", IEEE Sensors, 2009.
- [2] B. Homeijer, D. Lazaroff, D. Milligan, R. Alley, J. Wu, M. Szepesi, B. Bicknell, Z. Zhang, R. Walmsley and P. Hartwell, "Hewlett Packard's Seismic Grade MEMS Accelerometer", IEEE MEMS, 2011.
- [3] R. Walmsley, M. Hopcroft, P. Hartwell, G. Corrigan, D. Milligan, "Three-Phase Capacitive Position Sensing", IEEE Sensors, 2010.
- [4] Peterson, J., "Observations and Modeling of Seismic Background Noise", USGS Open-File Report 93-322, 1993 (available at <http://earthquake.usgs.gov/regional/asl/pubs/files/ofr93-322.pdf>).