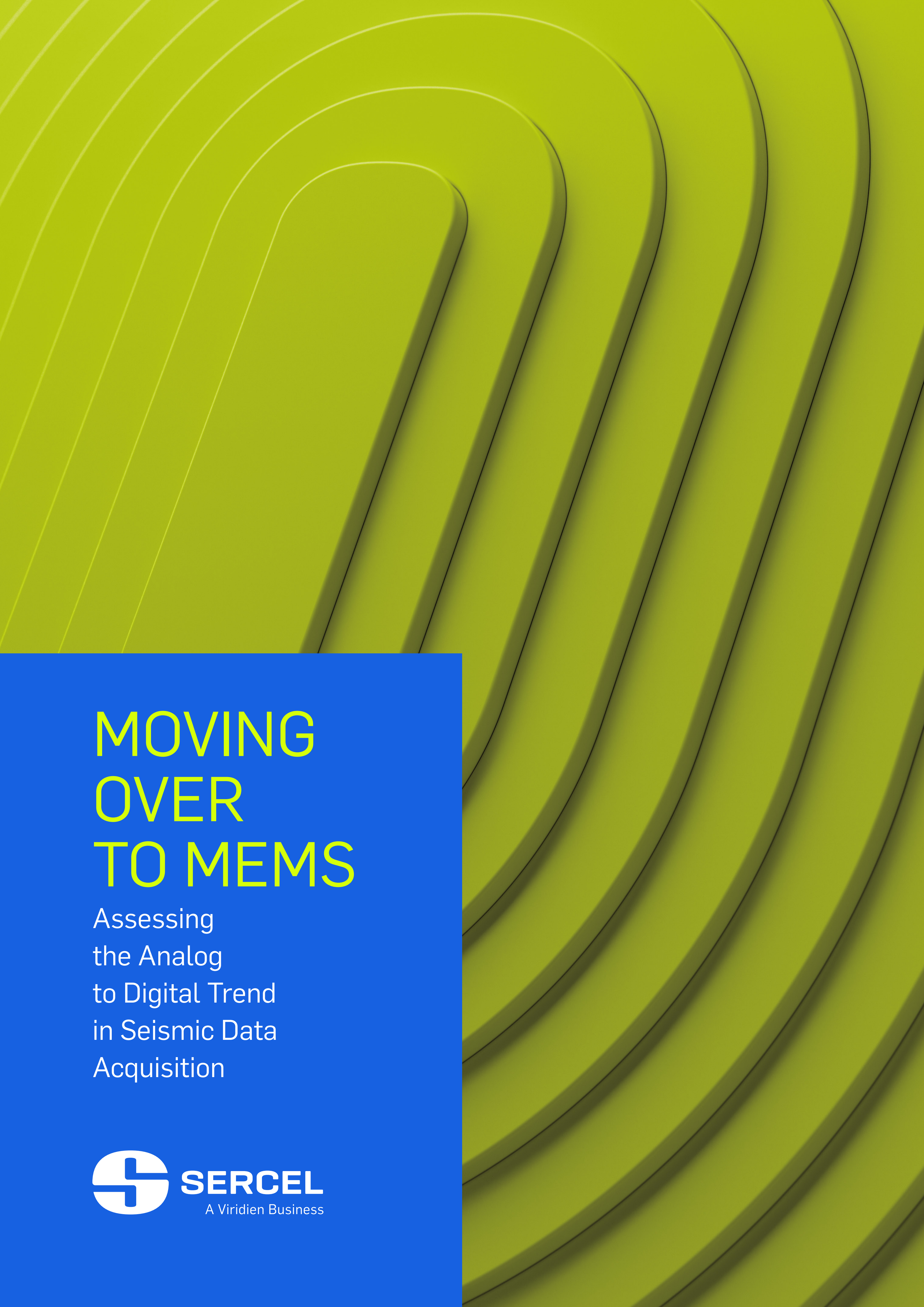


MOVING OVER TO MEMS

Assessing the Analog to Digital Trend in Seismic Data Acquisition

SERCEL
A Viridien Business

The transition from analog to digital technology for use in seismic data acquisition has taken longer than might have been expected.

But the low-noise performance of microelectromechanical systems-based (MEMS) sensors and the accuracy of their recordings, in combination with their reduced power consumption and lower price, means that industry is increasingly looking to take advantage of new performance capabilities.

1

SETTING THE SCENE, **THE EARLY STAGES OF DIGITAL TECHNOLOGY**

THE MOVE FROM ANALOG TO DIGITAL TECHNOLOGY HAS BEEN AN EVOLUTION RATHER THAN A REVOLUTION IN THE SEISMIC INDUSTRY, STARTING AS LONG AGO AS THE 1970S WITH THE LAUNCH OF THE FIRST DIGITAL RECORDERS AND OTHER TELEMETRY SYSTEMS.

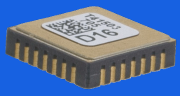
Throughout this gradual transition, there have been some notable milestone moments, particularly with the introduction in the early 2000s of the first digital seismic sensors based on microelectromechanical systems (MEMS) accelerometers. These small and highly-accurate devices promised significant performance benefits over traditional analog geophones, prompting an expectation in the seismic sector that MEMS would quickly become the technology of choice.

However, while there is no doubt that MEMS-based digital sensors have established a foothold, analog geophones still account for the vast majority of market share. The historical reliance on geophones for data acquisition means that many operators have been reluctant to move away from a technology that they know and understand. But despite this slower-than-expected uptake, MEMS-based digital sensors manufacturers have continued to invest in research and development, and the latest MEMS devices offer performance levels that could not have been conceived even ten years ago. For instance, there has been considerable progress made in the area of ultra-quiet performance, with the latest MEMS devices capable of operating at lower than 15ng/√Hz, resulting in a dynamic range of 128dB. This low noise level compares to 40-45ng/√Hz for previous generations of MEMS and is equivalent to the quietest ambient noise detectable anywhere on Earth.

In addition to improved noise performance, there has been technical progress in other areas. For example, power consumption on the latest single-sensor devices has been reduced to 85mW, meaning that seismic operators can benefit from optimum deployment and cost benefits for crews conducting high-resolution, high-density surveys.

This whitepaper therefore attempts to give an assessment of existing digital sensor capability, before expanding on how the latest generation of devices can deliver real value for land-based seismic data acquisition.

SG-10
Geophone



QuietSeis®
MEMS

2

REVIEW OF **GEOPHONE** AND **MEMS** TECHNOLOGIES

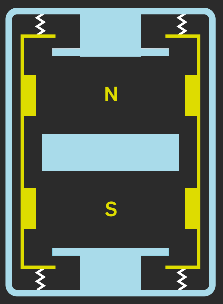
Traditional coil-based geophones have been around for almost a century, and they represent a reliable solution for land seismic acquisition, being passive devices requiring no power supply, and having proved to be rugged and cheap. But that doesn't make them the perfect solution for all applications.

Over time, there has been a growing requirement for lighter, broader-band and better-calibrated sensors for seismic surveys. Traditionally, land crews with high channel counts and large arrays have had difficulty setting up and handling substantial quantities of geophone strings. Also, the renewed interest for multi-component recording has called for new types of 3C receivers with tighter integration between field electronics and sensors. Each of these trends has underscored the development of new digital sensors based on microelectromechanical-based technology for land seismic data acquisition.

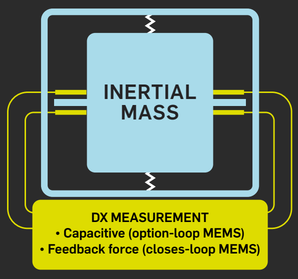
In terms of general principles, a MEMS accelerometer is based on the same principle as a coil geophone; it is a mass-spring system. For geophones, the resonant frequency is low: the spring stiffness is weak in relation to the dense mass of the coil driven by the spring. As a result, for any signal above the resonant frequency, the coil acts as the reference point. When the ground is subject to movement, the coil stays still, but the geophone casing and the magnet moves in relation to the coil.

The electromagnetic nature of the geophone device means the output voltage signal produced by the coil is proportional to the relative displacement rate of the magnet attached to the casing. As such, geophones act as velocimeters above their resonant frequency, and the result is that they create an analog voltage proportional to ground velocity. Around their natural frequency, geophones act as accelerometers, measuring the derivative of an acceleration force below. This is important for the current trend towards low-frequency operation.

For MEMS accelerometers, the resonant frequency is high because the spring stiffness is substantial when compared with the associated 'light' mass. This resonant frequency is higher than the frequency bandwidth of interest for the purpose of seismic imaging. This means that when subjected to a seismic wave, the proof mass shifts in phase with the casing. As a result, when the velocity is constant, there is no relative force applied to the mass. When the sensor casing encounters a variation in speed, then a force is applied to the mass that moves from its stationary position by a particular value. Digital sensors, therefore, act as accelerometers below their resonant frequency (around 1 kHz) and deliver measurements proportionally to ground acceleration.



Geophone



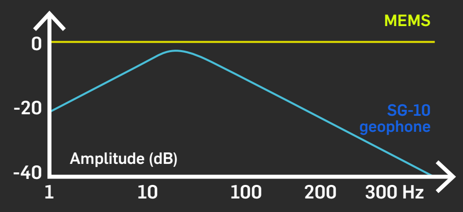
MEMS Technology

3

MEMS BENEFITS

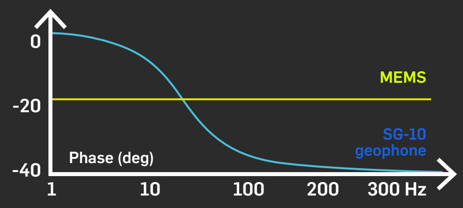
DIGITAL RECORDING DELIVERS DIGITAL FIDELITY

These fundamental technical differences translate into very different levels of operational performance.



Thick fog was observed
during the major part
of the survey period

Amplitude response



Thick fog was observed
during the major part
of the survey period

Phase response

For example, unlike geophones whose response is damped below their natural frequency and distorted above their spurious frequency, MEMS sensors offer linear and flat amplitude and phase responses from DC to 800 Hz in the acceleration domain. Their specifications are not affected by temperature, ageing or manufacturing tolerances, making the signal recorded accurate in both phase and amplitude on the entire seismic bandwidth of interest.

The preservation of amplitudes has been recognized for amplitude versus offset (AVO) applications. The coil-free design makes the sensor insensitive to electromagnetic noise, and the sensor distortion (-90 dB) is much lower than that of geophones (-62 dB). Since their introduction in the early 2000s, MEMS sensors have proved beneficial for a range of applications, e.g., thin gas reservoir identification, detection of tight oil (for the phase consistency), or high-resolution shallow surveys (for the streamlined deployment and preservation of high-frequency signal). By extending the fidelity of digital to the entire acquisition chain, MEMS sensors have emerged as good candidates to address the industry concern for high trace density, single receiver surveys.

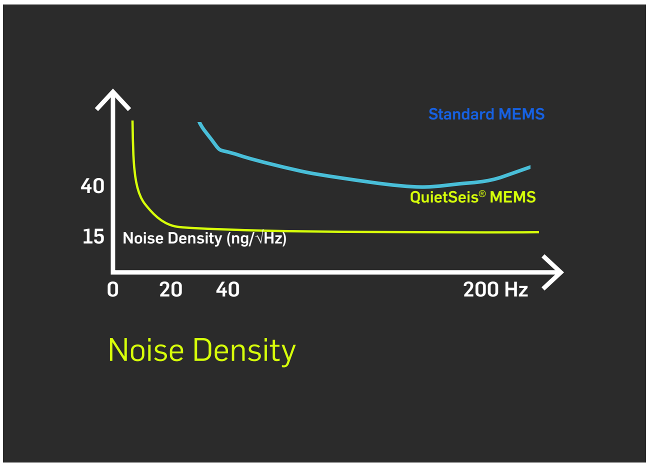
4

MEMS BENEFITS

NOISE FLOOR AND LOW-FREQUENCY CAPABILITY

In recent years, much progress has been made in lowering the noise floor of MEMS sensors, improving the detection of low frequencies and weak signals such as those that come from faraway targets or from micro-seismic events.

In simple terms, the noise floor is described as the output of the sensor in the absence of any external perturbations. This output relates to the noise created by the sensor itself, which is produced primarily as a result of the impact of gas molecules contained within the sensor's encapsulation. This noise, known as Brownian noise, is lessened by a high vacuum maintained by a device that attracts any remaining particles. The noise created by electronic components when operating has numerous different sources, the primary one being the excitation of the charge carriers in electrical conductors, also commonly referred to as thermal noise.

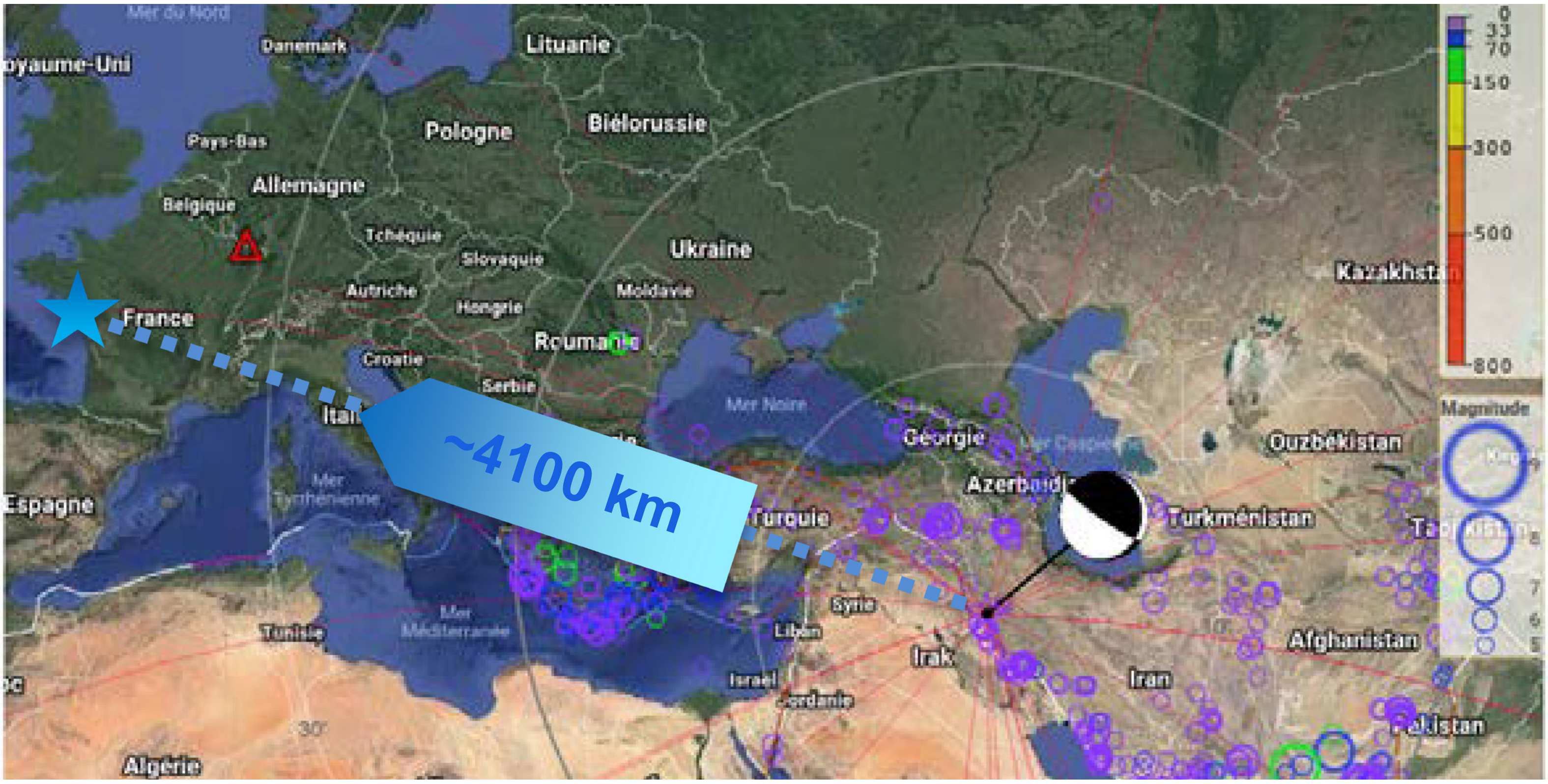


In the mid-2010s, MEMS devices could commonly achieve a noise floor (40 ng/√Hz from 10 to 200 Hz), a performance that is lower than the ambient noise in most of the surveyed areas. However, this noise increased toward low frequencies, particularly below 5 Hz, where it could exceed ambient noise. Below 55 Hz, it was still higher than that of a single geophone connected to a digitizer. Even if processing data recorded from closely spaced MEMS accelerometers could mitigate this gap, it became essential to have the MEMS noise floor at a level similar to that of a geophone, particularly for low frequencies and weak-reflection recording. For that, it was felt that significant changes in the MEMS and associated ASIC design were required.

To reach the target specification of 15ng/√Hz for a new generation of MEMS devices, there was a need to mitigate all internal electronic and mechanical noise sources without any increase in power consumption. This was achieved in several ways. For electronics, the physical layout of the sensor was improved, while the noise of the reference voltages it used was lowered. The other main electronic noise level that needed attention was the force actuator that closed the loop. As feedback force is defined by the amplitude of the signal sent on moving electrodes, and by the duration of its application, these two parameters were redesigned to remove as much amplitude and phase noise as possible in the control signals applied to the MEMS electrodes.

On the mechanical side, meanwhile, the MEMS vacuum was increased further to lower the Brownian noise. Moreover, a detailed analysis of all spurious high-frequency modes was performed. Mechanical design was modified to mitigate all aspects that could impact system noise performances.

These advances produced the desired effect, creating a leap in performance capability. Indeed, by around 2014, the latest ranges of MEMS sensors, called QuietSeis®, had progressed to show a significantly lower noise floor than previously available designs, achieving -10dB and thus a higher dynamic range in the region of +10 dB. As MEMS sensor response is linear in the acceleration domain down to DC, research showed they exhibited no attenuation and sufficient signal-to-noise ratio toward the lower end of the spectrum. These proved to be the ideal conditions to record low frequencies down to 1Hz, which provided a breakthrough for oil and gas use and enables MEMS-based monitoring of weak micro-seismic events such as those generated by hydraulic fracturing.



Iran-Iraq border M7.4 earthquake - Nov 12th, 2017 - 18:18:19 (UTC)

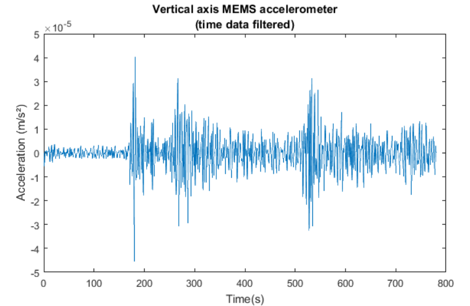
5

MEMS BENEFITS

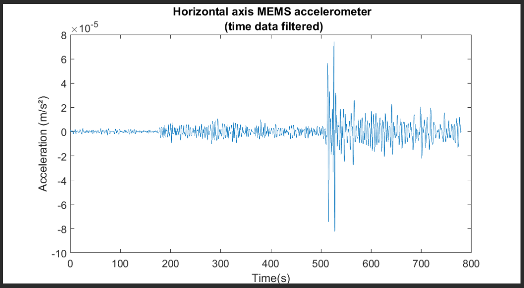
RECORDING DOWN TO 0.001 HZ

But the technological progression of MEMS sensors didn't stop there. While research and development activities had ensured that the noise floor of the latest accelerometers had fallen considerably, seismologists studying areas such as plate tectonics and teleseisms were still challenging device manufacturers to develop affordable sensors capable of operating at even lower frequencies below 1Hz.

To measure the MEMS performance at very low frequencies, a refined sensor design was developed, with recent tests carried out in a noise-isolated acoustic chamber, located in the basement of an office building in Nantes.



Vertical Axis MEMS Accelerometer



Horizontal Axis MEMS Accelerometer

During tests which took place towards the end of 2017, an Earthquake took place beneath the Iran-Iraq border, some 4,100km away from the testbed, producing a teleseism of magnitude 7.4. Both horizontal and vertical accelerations were recorded. These two observations proved the capability of the sensing devices to record weak, very low-frequency signals arising from distant seismic events.

Specifically, the results showed that it is possible to develop MEMS accelerometers with a noise floor below New High Noise Model (NHNM) down to 0.1Hz and showing only a slight increase down to 0.001 Hz, opening up new possibilities for below hertz signal recording for both academic and oil and gas applications.

6

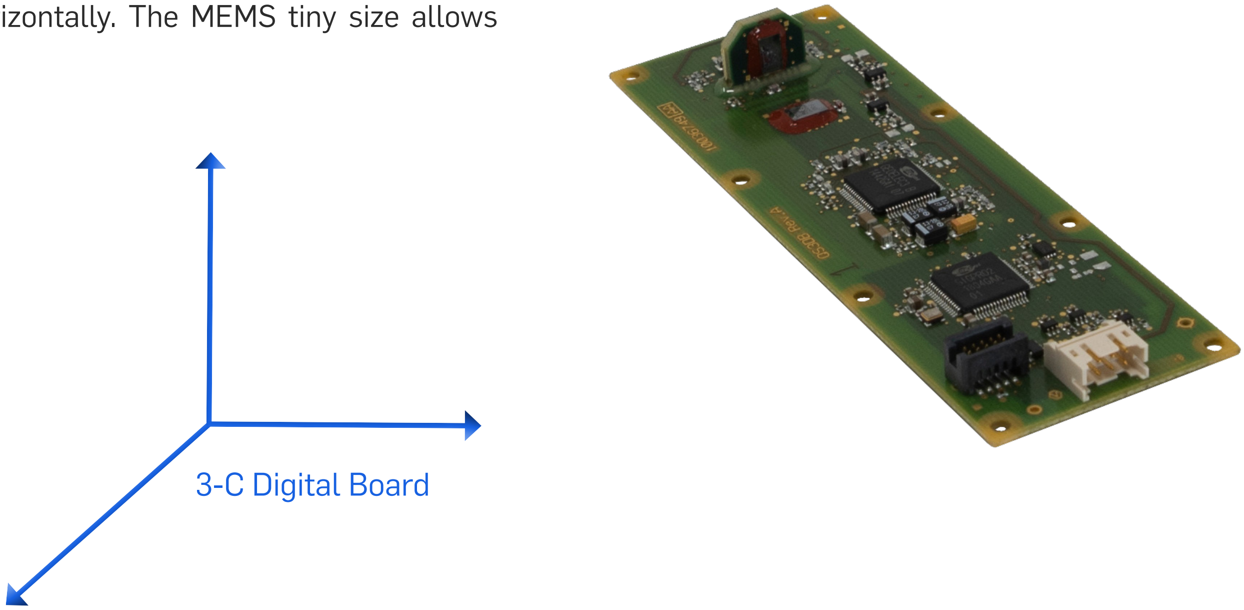
MEMS BENEFITS

3C RECORDING AND VECTOR FIDELITY

3C acquisition has a proven track record of success in complex geologies: fracture and anisotropy analysis can be improved, lithology better identified, P-wavefield accurately reconstructed, imaging performed through gas chimneys, and additional seismic attributes collected. For these types of surveys, MEMS have emerged as the receiver of choice over analog tri-phones.

From an operational perspective, the 3C MEMS channel is omni-tilt and compact, and removes potential errors when connecting geophones to three digitizers. The same sensor can be used for the three components, while geophones must be compensated for gravity when operated horizontally. The MEMS tiny size allows for a correspondingly small housing form-factor, thus enabling an efficient rejection of parasitic signals, such as ground-roll induced rotations. The compactness of the 3C sensor also favours optimal coupling to the ground – a paramount factor for the proper recording of horizontal components.

Another significant benefit of 3C MEMS lies in the excellent vector fidelity it provides to seismic measurements. Indeed, good MEMS accelerometers are fitted with a feedback loop that enables the measurement of static signals (DC/0 Hz), such as the Earth gravity. Thanks to this feature and contrary to the case with 3C geophones, 3C MEMS sensors can be easily factory-calibrated by using a very accurate gravitational acceleration reference, and consequently, the manufacturing orthogonality tolerances of the three axes can be compensated for. Similarly, the planting tilt can be measured and compensated for in the field. As a result, 3C MEMS sensors with DC capability exhibit much better accuracy in terms of vector fidelity: the ground acceleration is measured with a very accurate separation of horizontal and vertical components, and with true amplitudes and timings. The high-fidelity data recorded in this way thus enables rigorous analysis of anisotropy.



3-C Digital Board

7

MARKET ACCEPTANCE OF MEMS TECHNOLOGIES

It's clear, then, that much progress has been made with MEMS-based digital seismic sensors. And yet, after almost 15 years on the market, MEMS still accounts for a relatively small amount of the market compared to geophones.

There are several reasons for the slower-than-expected market acceptance. Looking back, the release of MEMS in the early 2000s may have been ahead of time, with sensor specifications poorly understood. The price of a dense digital sensor spread could not be justified compared to the sparser conventional geophone arrangement. But now, more than a decade later, the economics look very different. A digital channel is now competitive with a single geophone/digitizer combination. The same tendency can be observed for power consumption, which in fact is now lower for digital spreads. Full digital recording offers valuable high-fidelity seismic signal, especially as blended and single source / single receiver data gets noisier than ever, and provides an attractive platform for the industry transition towards higher trace densities and point receiver acquisitions.

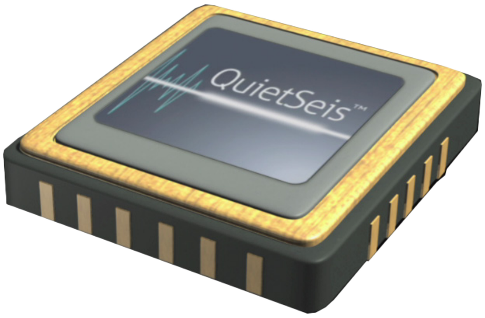
Also, operational expenditure needs to be considered. Geophone strings take up more time and resources when it comes to transport, deployment, retrieval and maintenance, adding significantly to logistics and labour costs out in the field. The use of MEMS-based digital sensor units, on the other hand, provides savings in each of these areas.

Meanwhile, the steady growth in popularity of MEMS devices has also delivered manufacturing economies of scale, which drove prices down. Also, a single sensor's power consumption has been reduced to 85mW, which provides logistical benefits for large-scale, high-density deployments.

IN CONCLUSION

ANALOG TO DIGITAL TREND IS GATHERING PACE

So, then, after almost 15 years on the market, it is fair to say that digital sensors have proven their technical and geophysical effectiveness for seismic applications. This development has led to the introduction of recorders that have been fully optimized for seismic land operations.



For example, a new digital sensor featuring a second-generation QuietSeis MEMS accelerometer – providing a noise level of 15ng/√Hz, some three times lower than previous systems – has been integrated into the DSU1-508, making it the best recorder that Sercel has ever made. This unit is capable of high-density, high-resolution acquisition, and comes with a totally scalable nodal architecture called X-Tech, making it the first system capable of acquiring 1 million channels, with full immunity to statics.

This kind of performance means MEMS-based sensors now exhibit many desirable characteristics that make them the technology of choice across numerous seismic applications. While there's no doubt that, historically, the shift from analog to digital technology has been slow to take place, it is increasingly clear that the momentum behind MEMS deployment is now rapidly gathering pace.

Want to know more?

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