

# How technology drives high-productivity vibroseis: a historical perspective

Denis Mougnot\* and Daniel Boucard

Sercel, B.P. 30439, 44474 Carquefou Cedex, France

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## ABSTRACT

The development of high-productivity seismic recording using the vibroseis method over the last 30 years is treated from a Sercel perspective. The simultaneous use of vibrators has been highly dependent on real-time field computing capabilities such as those delivered by the correlator-stackers in the early 1980s. A second step forward in the mid 1980s–early 1990s was related to digital vibrator electronics, which provides efficient management and quality control of fleets of vibrators. However, it was only in the late 1990s with the advent of real-time satellite positioning (GPS) of these fleets that alternate or simultaneous sweeping was commonly used in production. During the last ten years, thanks to GPS timing, continuous data recording and innovative simultaneous sourcing methodologies, vibroseis has been able to reach unexpected levels of productivity. As a result, the cost per seismic trace has dropped, enabling denser spatial sampling and associated seismic imaging improvement.

**Key words:** Correlator-stacker, Vibroseis.

## INTRODUCTION

Compared to marine seismic acquisition, land vibroseis is particularly suitable for simultaneous sourcing because of the relatively low cost of adding vibrators. The emitted signal, easily parametrized to design multiple sweeps as well as a variable start times ( $T_0$ ), makes it possible to extract the contribution from each of the sources. Although the theoretical capabilities of vibroseis are obvious, their operational implementation lagged until advances in electronics, computer power, wireless transmissions and the Global Positioning System (GPS) made it possible to manage multiple fleets of vibrators in real-time over large distances. The result has been a tremendous increase in land seismic crew productivity by multiple orders of magnitude (from several hundred Vibration Points (VP's) per day to more than 10 000 VP's/day), at least in open terrain. Below is a description, essentially based on Sercel acquisition systems, of the developments from the early 1980s until the

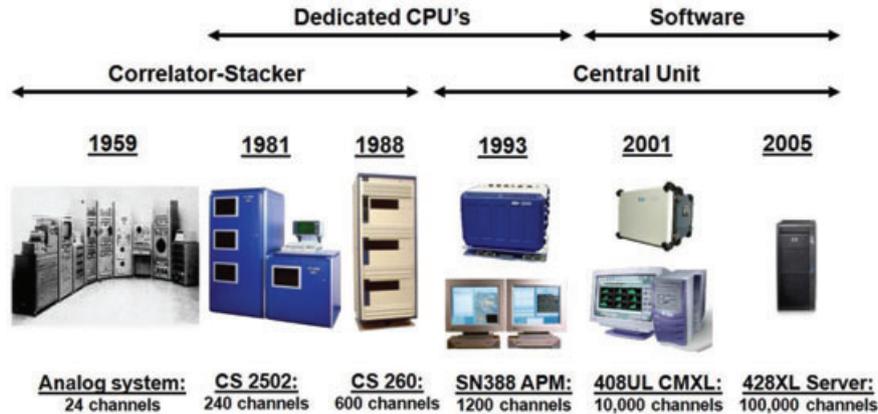
last decade that were successfully applied for acquisition in the Middle East and North Africa.

## THE EARLY 1980s

### Field correlator-stacker and the first simultaneous vibrators

Simultaneous vibroseis recording started in the early 1980s when electronic memories and processors became compact and affordable enough to be gathered in racks that could be put into a recorder to perform real-time correlation and stacking of the vibration points. In 1981, a field correlator-stacker such as the Sercel CS 2502 required the assembly of 300 Central Processing Units (CPUs) into a large card, each one able to process two channels at a 2 ms sampling rate. Correlation was performed in the time-domain and multiple sweep stacking offered the possibility to attenuate ambient as well as impulse noise. The maximum capability was only 240 channels (Fig. 1) but the benefits were many: data volume reduction by summing and correlating to an amount that could be written to tape and real-time display of the VP's for Quality Controls

\*E-mail: denis.mougnot@sercel.com



**Figure 1** Chronology of the correlator-stackers with examples based on Sercel acquisition systems. Channel capability is real-time at a 2 ms sampling rate. CS: Correlator-Stacker; SN: Système Numérique; APM: Acquisition and Processing Module; CMXL: Control Module of eXtra Large capacity; UL: Ultra Link; XL: eXtra Large.

(QC's). Hence, significant time was saved during data processing. By interfacing two CS 2502s, the correlator-stacker capability was extended to two simultaneous fleets of vibrators using two different sweeps. Thanks to encoding (plus-minus, phase rotation and/or up-down sweeps), correlation and sweep stacking enabled the cancellation of the contribution from the other source to a certain extent ( $-25$  dB to  $-35$  dB practically).

Simultaneous vibrators were tested as early as 1982 in France (Garotta 1983, 1987) to speed up 3D acquisition by shooting on each side of a receiver spread. The same approach was also implemented in various domains including: the mix of a low-frequency sweep array with a single-point high-frequency sweep (Garotta and Pennacchioni 1985); the recording of deep refraction data at the same time as a normal survey (Garotta 1986); the simultaneous VSP acquisition from different offsets or azimuths (Naville 1984); the combined use of P and S vibrators in different frequency ranges.

At that time, pilot generation and sweep control inside the vibrator were still analogue (e.g., the GeoSource 310C or the Pelton Advance 1). No real-time sweep QC's were available in the recorder, except the print-out of the correlated VP's.

## THE MID 1980s–EARLY 1990s

### Digital vibrator electronics offers new capabilities

By the mid 1980s, the conventional analogue phase-lock systems were replaced by the first vibrator electronics capable of phase and force control (e.g., the Pelton Advance II and the Texas Instrument VCS V; Glenn, Alvi and Shoffner 1984). At the end of the 1980s, the first 3D acquisitions using the

phase-encoded high-production vibroseis mode were completed. Among the largest were the surveys in Prudhoe Bay (480 live channels, two vibrator groups) and over the Dol-larhide field TX (384 live channels; two vibrator groups), the latter with a 35% productivity increase (Reblin *et al.* 1990, 1991).

In 1988, the first digital servo-controlled vibrator electronics based on a numerical model of the vibrator and of the ground below the baseplate was introduced by Sercel (VE416; Garotta 1990; Boucard and Ollivrin 2010; Fig. 2). Like the other controllers, VE416 was split into two components communicating by radio (VHF). The Digital Pilot Generator (DPG) in the recorder was able to generate a large choice of digital pilots, including random sweeps (Burger and Baliguet 1992). The Digital Servo Drive (DSD) was placed in each vibrator to perform an auto-adaptive control of the emitted groundforce. At the beginning, the sweeps started at regular intervals selected to be longer than the move-up time. Soon, the observer became able to manually trigger the sweep after a 'ready tone' was sent by the drivers. After the sweep some QC's were transmitted from which the observer was able to evaluate on prints the discrepancy between the pilot signal and the emitted groundforce (peak force, phase and distortion). Up to four simultaneous fleets of vibrators were managed from a single radio frequency but this capability did not have a significant impact on operations due to the limited efficiency of the source separation at that time. In practice, too many sweeps were required to separate the cross-correlation of the harmonics with the fundamental of the other sweeps. Therefore, it was not a significant time-saver (Lansley, written communication). Alternate sweeps (flip-flop) started to be

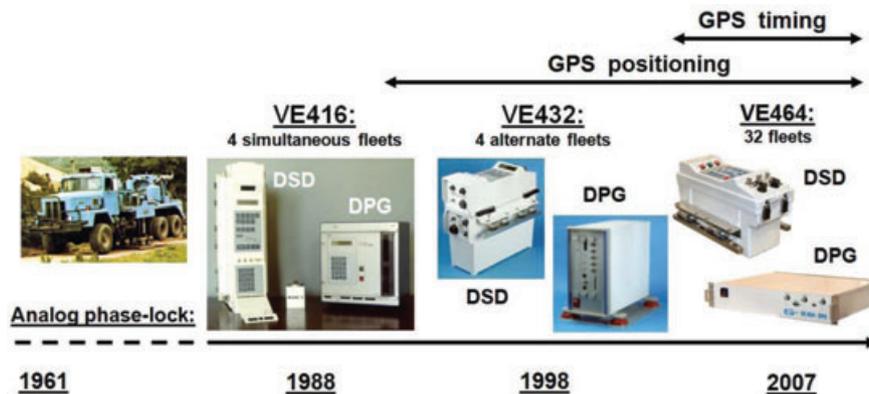


Figure 2 Chronology of the vibrator electronics with examples based on Sercel acquisition systems. VE: Vibrator Electronics; GPS: Global Positioning System; DPG: Digital Pilot Generator; DSD: Digital Servo Drive.

implemented in Oman in 1991 (Onderwaater, Wams and Poters 1996; Wams and Rozemond 1998) but with only two fleets each vibrating along a zig-zag pattern.

At the same time, the capabilities of the field correlator-stacker improved thanks to the ability of processors to correlate in the frequency domain (e.g., the Sercel CS 260 in 1988, Fig. 1). This evolution was mandatory to handle the increasing number of channels made available (e.g., 1200 channels real-time at 2 ms with the Sercel SN388).

## THE LATE 1990s

### GPS positioning and the start of high-productivity vibroseis

Significant progress to improve efficiency with vibrator recording occurred in the late 1990s thanks to a new generation of vibrator electronics (e.g., the Pelton Vib Pro and the Sercel VE432; Fig. 2), which were inter-compatible with the main recording systems. GPS positioning was integrated not only for QC purposes but also to be able to manage different fleets of vibrators in alternate (flip-flop and slip-sweep) or simultaneous (HFVS; Allen, Johnson and May 1998; Wilkinson *et al.* 1998) modes. Thanks to real-time differential satellite positioning (DGPS), vibrator fleets could transmit in the digital 'ready tone' the position of the Centre of Gravity (CoG) of their baseplates. Then, the recorder uses this position to find the corresponding pre-planned VP and starts the acquisition accordingly (i.e., with the correct associated spread). This 'navigation' mode requires the capability to network all the vibrators of the same fleet by WiFi via an Ethernet bridge to define their CoG. Then, the central unit forms the spread corresponding to this CoG and checks the status of the other sources before triggering the corresponding VP. This of course requires reliable radio communications that could start the

vibrator at a long distance and return vibrator QC data to the observer for their examination on the recorder screen.

Flip-flop became common in terrain where short move-up time was possible and with three fleets saw a doubling of production (up to 180 VP's/hour) with respect to a single fleet. Close collaboration between Petroleum Development Oman and Sercel led to the first slip-sweep tests being performed (1995–1998) (Rozemond 1996; Burger, Duijndam and Wasmuth 1999). The methodology was soon implemented in production in Oman (Fig. 3; Mahrooqi *et al.* 2008) and in North Africa (Thacker *et al.* 2000). However, its acceptance was limited outside Oman due to equipment constraints (one specific vibrator electronics (DPG) and one radio frequency required per fleet of vibrators) and to the clients reluctance to adopt new methodologies.

At the same time, the correlator-stacker became even more compact and an integrated part of the central unit (e.g., the APM of the Sercel SN388 recording system; Fig. 1).

## FIRST DECADE OF THE 21<sup>ST</sup> CENTURY

### The boom of vibroseis productivity

The last ten years have seen an increase in vibroseis productivity to unprecedented levels (Fig. 4) as the result of the introduction of new technologies, which have enabled the development of innovative methodologies (Bagaini 2010). Examples of these new field acquisition techniques are: aggressive slip-sweep with short slip-time as used in CGGVeritas V1 methodology; simultaneous sweeping as implemented in BP's Distance Separated Simultaneous Sweeping (DSSS) and Independent Simultaneous Sweeping (ISS<sup>1</sup>). The first major

<sup>1</sup> ISS is a trademark of BP.

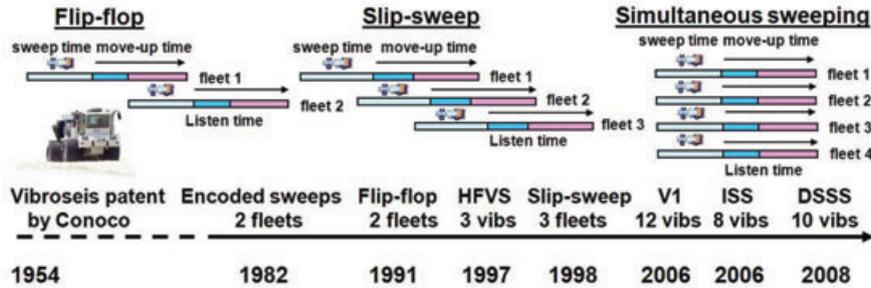


Figure 3 Chronology of simultaneous vibroseis sourcing. HFVS: High-Fidelity Vibroseis Seismic; ISS: Independent Simultaneous Sweeping; DSSS: Distance Separated Simultaneous Sweeping.

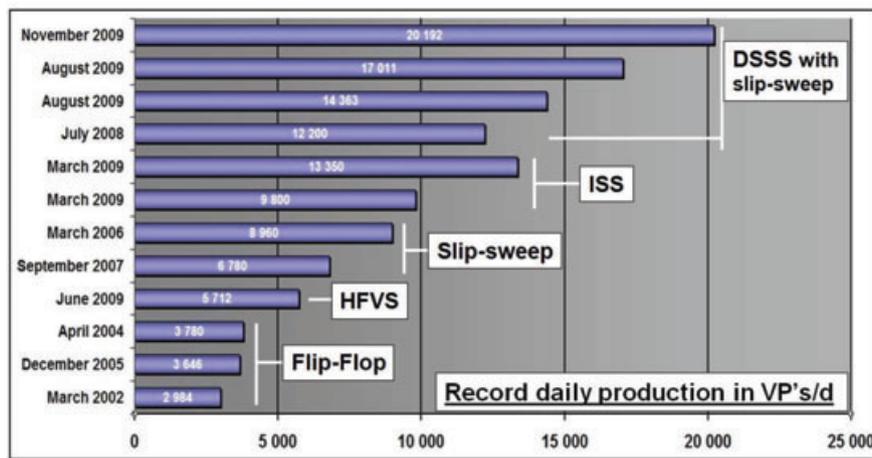


Figure 4 High-productivity vibroseis records from different methodologies during the last ten years as obtained by a combination of 428XL and VE464 in operations.

improvement came with the recording systems (e.g., the Sercel 408UL and 428XL) providing lighter equipment whose quick deployment and activation in the field complemented higher source productivity. They also contributed to an increase in channel count over the past decade from 10 000 to over 100 000 currently recorded (in real-time at 2 ms). Sufficient computer power and memory were made available to process simultaneous sources. The major step involved removing the dedicated correlator-stacker hardware and implementing these operations in software. Recently (since 2005; Fig. 2) this number-crunching no longer involved a specific memory card as it was able to directly benefit from the several tens of gigabytes available in the central unit server's memory.

The second major evolution has been the synchronization of the recorder and the vibrators by GPS timing. With the latest generation of vibrator electronics (e.g., the Sercel VE464 in 2007) radio transmission is digital, multiplexed and synchronized by GPS (Time Division Multiple Access or TDMA). This not only increases the capabilities on offer (up to 32 vibrator

fleets managed by a single radio frequency) but also the transmission range and the flexibility (recording time-zero (T0) becomes the GPS time at which we would like the vibrator to sweep). TDMA transmission has become a standard. It is used by other vibrator electronics such as the Pelton Vib Pro and the Seismic Source Co. Force III when they are complemented by a TDMA communication module. Within each vibrator new capabilities are made available such as the guidance for stakeless acquisition and an improved recording of the groundforce (formatted as a SegD file by VE464) and related control attributes (one phase, peak force and distortion value every 0.5 s instead of the average value during the sweep length).

With these improvements, slip-sweep has been freed from previous constraints (memory, radio frequency availability and range). In North Africa, surveys with 12 fleets of single vibrators using long sweeps (e.g., 40 s) but a short slip-time (e.g., 5 s) were performed with production above 700 VP's/hour providing much denser spatial sampling on the

source side (Meunier, Bianchi and Ragab 2007; Meunier *et al.* 2008). Capitalizing on the very long spreads laid out in desert areas (more than 20 km-long receiver lines), BP prompted the simultaneous use of widely separated flip-flop or slip-sweep fleets with their DSSS methodology, which depending on the number of vibrator groups theoretically doubles or triples productivity (Bouska 2008, 2009, 2010). Using this combination of DSSS with slip-sweep average daily productivity above 5500 VP's/day was maintained for months by super-crews in Oman (Matheny 2009). Pushing the limits further still, BP freed vibrators and the recorder from the requirement of interactive radio communication using their ISS approach, which is adaptable to hilly terrain that can cause radio shadows (Howe *et al.* 2008). Thanks to GPS timing, the recorder is put in continuous recording mode and each vibrator sweeps as soon as it is ready in the area of the spread that has been allocated to it. With such a methodology, productivity of over 1000 VP's/hour was achieved with the drawback of a high level of interference between VP's (blended acquisition). If communications are not possible between the recorder and vibrators, QC's are not available in real-time, except warning inside the vibrators when some QC thresholds are reached (VE464 DSD). Using ISS with 18 fleets of single vibrators shooting simultaneously over a fixed spread of about 10 000 channels, Argas was able in 2010 during a test for Saudi Aramco to achieve a productivity of 45 000 VP's/day (Pecholcs *et al.* 2010; Huo *et al.* 2011). This is where we are today and we should acknowledge the paramount contribution made by satellites (GPS) for both positioning and timing in such a simultaneous sourcing achievement.

## DISCUSSION

### Going further

What may prevent high-productivity vibroseis from achieving further improvement? Adding new fleets of vibrators seems to be an easy and cost-effective way to beat production records, while on the recorder side nothing has to change as long as you operate in continuous recording mode. However, there are still two important limiting factors. The first is the ability of the observer to monitor ever higher numbers of independent sources to be sure that they are performing as required, unless you agree to shoot blind, as in BP's ISS approach. For sure an improved radio communication range and capacity would help in better vibrator control. The second is the necessary balance between the source and the receiver efforts: it does not make sense to complete a shot grid and then to stop because the receiver spread did not move accordingly. Lighter receiver

stations, replacement of geophone strings by single sensors and fewer batteries would help in speeding up the roll-out of the spread. For such issues, the use of a cableless system may be part of the solution although each unit requires its own battery. Decimation of the receiver spread to a sparse grid (e.g., 200 m x 200 m) as proposed by BP in its ISS nodal approach also makes sense providing it is compensated by a dense shot grid and all real-time QC's will be missing. As often, there will not be any universal recipe to further improve productivity, the solution having to be tailored for the local terrain conditions.

## CONCLUSIONS

### Spatial sampling, the new paradigm

This historical perspective of the recording equipment and technologies enabling very high vibroseis productivity illustrates the many benefits of a close partnership in the seismic industry. As soon as the real-time capabilities of recorders and vibrators were made available by the manufacturers, they were implemented in the field by the contractors via new methodologies proposed by oil companies. Such quick interaction made it possible for land crew productivity in open terrain to reach unexpected levels (20 000+ VP's/day in production, 40 000+ VP's/day in test), well above what has been achieved in marine acquisition.

We should not forget that a decisive step in this evolution occurred in the minds of people, which corresponds to a paradigm shift in the way we should consider land seismic acquisition. Data quality should not only be considered from the point of view of the individual shot points but also from the point of view of the final seismic image for which spatial sampling by sources and receivers and the resulting trace density matter. Thus, even if high productivity methods reduce the quality of the single records due to the use of single-vibrator, single-sweep emissions and to the interference between overlapping VPs, we may expect the resulting dense spatial sampling by the sources to make up for this. High trace density and associated advanced processing will preserve organized noise from aliasing, attenuate random noise thanks to higher fold coverage and remove acquisition footprints. Such an achievement would not have been economical without the increasing capabilities of the recording systems and the innovative methodologies of simultaneous sourcing.

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