Exceptional Data, Swift Turnaround, Reduced Exposure

by Marc Rocke, Geophysicist, Polarcus

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New technology often comes at a premium. Development and marketing costs, upgrades to manufacturing infrastructure and the overall hype surrounding a new product entering the market usually translates into a price uplift for end-users. Improved data quality, along with increased safety and efficiency, can sometimes rationalize the extra costs. However during an industry downturn these justifications are less likely to be accepted, motivating service providers to become more creative with technology that is already available in order to surpass project objectives.

XArray is one example of such innovation which, through harmonious integration of currently available technologies, provides a tailored solution to survey design. The result is increased efficiency of up to 50% along with significant improvement in data quality. As it uses technology that is already available and deployed in the fleet, it comes with no additional capital outlay, HSE exposure, or cost uplift to clients. This improved efficiency and data quality derives from leveraging dense shotpoint intervals and multiple sources to improve crossline sampling.

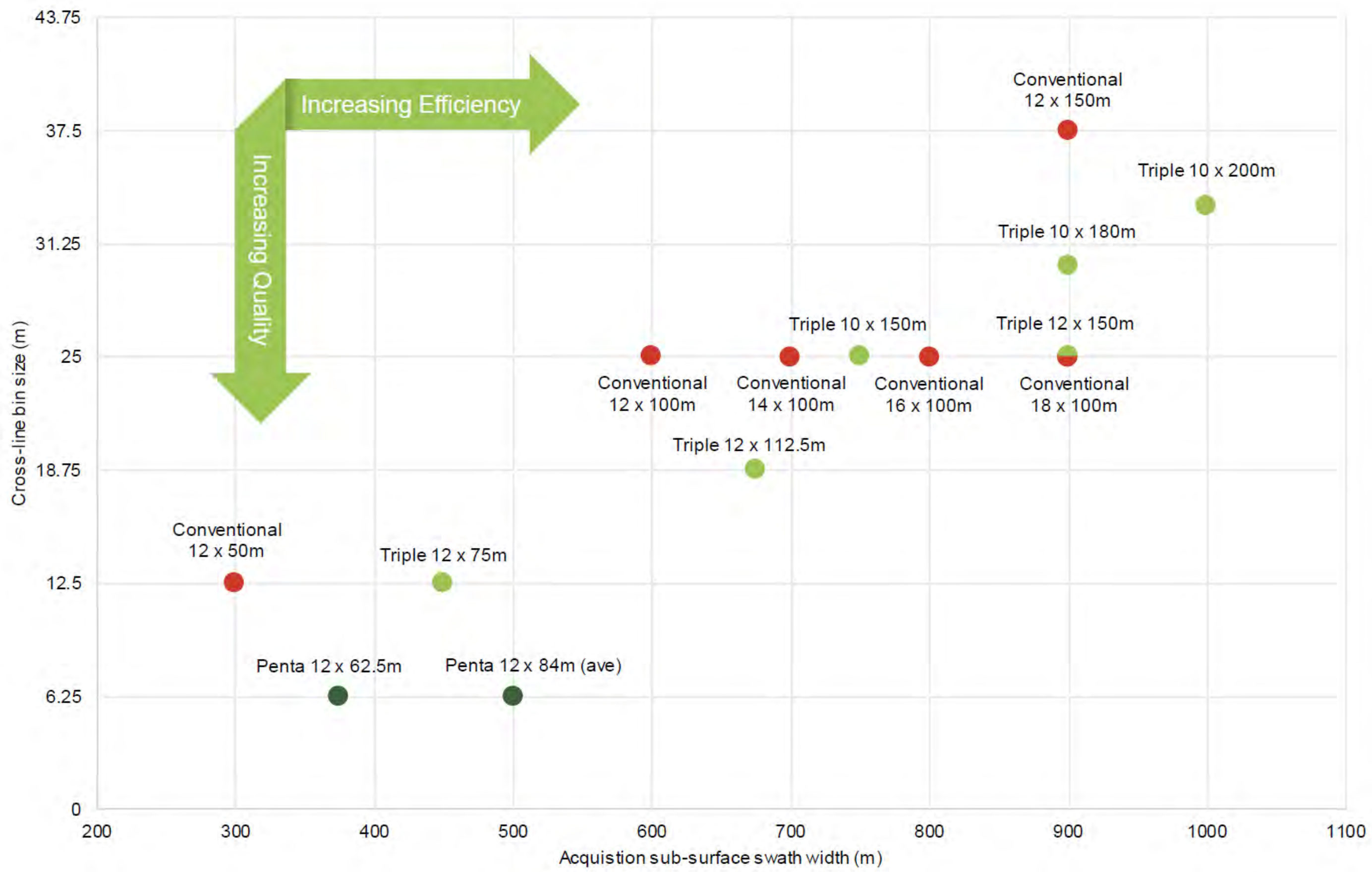
In towed streamer configurations, inline sampling is calculated by halving the distance between receiver groups on the streamer. The industry standard streamer receiver group intervals of 12.5m achieves an inline bin dimension of 6.25m. Crossline sampling on the other hand is the result of the streamer interval divided by twice the number of sources used. In the case of dual source acquisition, the crossline bin dimension is one quarter the streamer interval. In the case of XArray, crossline sampling is one sixth when three (Triple) sources are deployed and one tenth for five (Penta) sources, resulting in a considerable increase in crossline (CMP) sampling while using the same amount of in-sea equipment.

Several benefits become evident from this initiative. Apart from the resolution uplift that is achieved leading to enhanced imaging, XArray Triple works without restriction to spread width so high quality data can be acquired without increased acquisition time. Additionally with square bins at 6.25 x 6.25m, in the case of XArray Penta, it is no longer necessary to define line heading by the predominant direction of structural dip since sampling is equal in both inline and crossline directions. The survey azimuth can be chosen to maximize operational efficiency, adapting to survey geometry and operational restrictions. We have seen several cases where the survey economics are drastically improved, sometimes making the difference between a viable survey and not shooting at all.

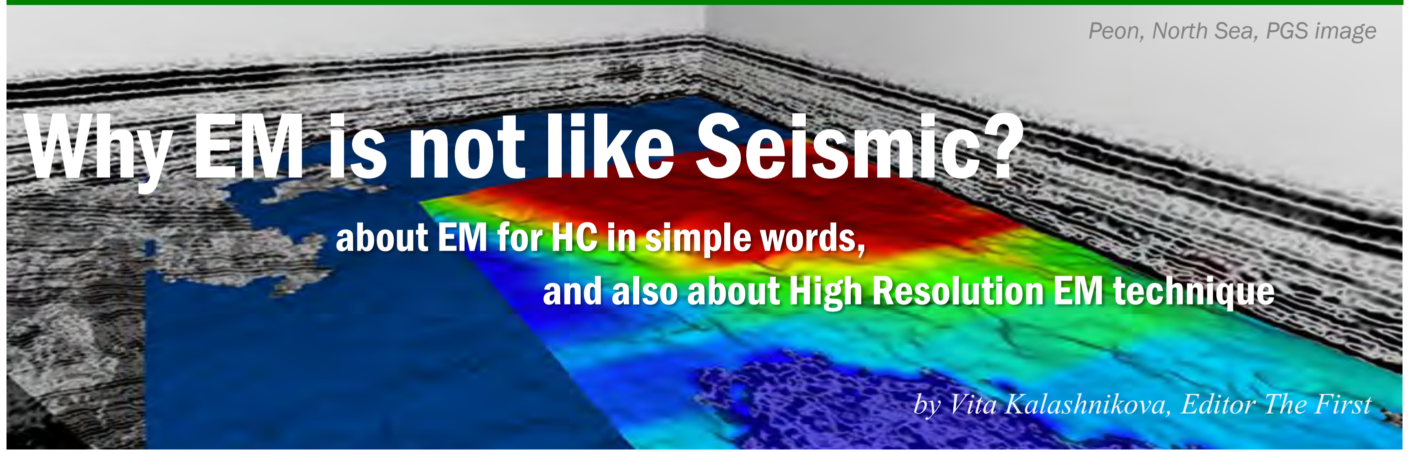
Shot de-blending is the most cutting edge of all the elements of XArray. Blended marine seismic acquisition emerged in the late-1990s and allowed shot interference (by means of continuous recording). However the blended data obviously needed to be separated in processing and the attempts to de-blend effectively have come in various flavors over the last ten years, driven by the general consensus that it will be an integral part of seismic acquisition. Recent technological advancements have made the process become a practical routine.

XArray uses what is more accurately referred to as 'near simultaneous shooting' (Berkhout et al, 2008) where shots are fired in distance mode according to a dense pre-plot of regularly spaced shotpoints. Although shot locations are regularly spaced in distance, there is a natural randomization in shot times that results from small variations in the time it takes a vessel to travel from one shotpoint to the next. This natural randomization of firing time is exploited to allow for effective separation in the de-blending process.

Combining the use of continuous recording technology, dense inline shotpoint intervals and multiple sources, Polarcus has leveraged survey design and de-blending in processing to provide tailor-made seismic solutions under the banner of XArray. The component technologies are well accepted in the industry and utilize equipment currently available onboard our vessels and familiar to our crews. The flexibility gained by the XArray method allows for reduced turnaround time from first shotpoint to drilling, reduced HSE exposure and improved data quality. Polarcus has acquired over 40,000 km2 of dense shotpoint and XArray data to date, and there remains growing interest in applying the method in basins around the world.



Plot showing efficiency and data quality comparison of common dual-source, triple-source and penta-source geometries. This is just a small subset of examples. The range of geometries that can be achieved on the quality–efficiency spectrum is limited only by the creativity of the survey design process.



Why EM is not like Seismic?

about EM for HC in simple words, and also about High Resolution EM technique

by Vita Kalashnikova, Editor The First

It is been a decades like EM methods tried to prove its deserved place on HC exploration market. Proved original techniques caused diverse opinion when it comes to the Norwegian explorations sector: from *"how brilliant it is!"* to *"it is totally failed on Norwegian shelf"*. Why are experiences so different? What makes disappointments as frequent as success stories - lack of explorationists experience in EM or may be absence of appropriate interpretation tools? The Editorial team of The First tried to understand and presenting here the challenges of EM exploration and precaution of what has to be taken into account when exploring with EM.

EM for Hydrocarbons Exploration

Electromagnetic (EM) methods are well know in implementation for geological structure investigation (from 1910) and ore exploration (1920s). First methods for hydrocarbons exploration were carried out in 1928-29.

The first use of **marine electrical prospecting** for oil and gas exploration dates back to the early 20th century (Schlumberger, Schlumberger and Leonardon, 1934). Late 1970s and the late 1990s of the 20th century are the turning points in the development of marine methods of electrical geo exploration [1]. In the late 1970s, the US military had to assess the resistance of the oceanic lithosphere to create radio communications with submarines. The development of a sounding technology, known as **Controlled-Source Electromagnetic (CSEM) method** [2] began with the financial support of the military departments at the Scripps Oceanographic Institute in the United States. This method had a huge impact on marine EM exploration. Until the late 1980s, studies of the EM properties of the lithosphere, carried out by western academic researchers in the framework of scientific projects. In the 1980s, Exxon explored possibilities of EM exploration for hydrocarbons detection (US Pat. No. 4,617,518 A, 1986). The beginning of mass commercial application of the method was related to the end of the 1990s, when oil companies began investing money in the development of the theory, equipment and methodology of **CSEM** due to high hydrocarbon prices and the start of deep sea drilling in the Gulf of Mexico. Since that time, the industrial application of electrical exploration in the oil and gas industry begins, and CSEM became the leading electro-prospecting method. After the global EM crisis, which erupted in 2008, the overestimated expectations for marine electrical reconnaissance have being corrected [3].

Introduction to EM techniques

EM exploration is a part of geophysical exploration aimed to study geological structures with help of electromagnetic fields. It allows solving many problems from shallow surface civil infrastructure needs and archaeological studies to deeper geological structures mapping including prospecting of ore deposits, geothermal resources and hydrocarbon resources. The most deep ground penetrated techniques allow studying conductivities zone in Earth crust and upper Mantle, and monitoring EM fields to study the process going in the Earth (e.g. Earthquakes).

Some of main physical groups for methods can be presented like:

- ***Resistivity*** methods use a constant EM field to determine resistivity (ρ)
- ***Low frequency*** methods use natural or artificial low frequent EM fields to determine resistivity (ρ) and in some cases electromagnetic permeability (μ)
- ***High frequency*** methods are based on high frequent EM field to determine dielectric permeability (ε) as well as ρ, μ
- ***Geoelectrochemical*** methods are based on secondary fields arising in two-phase media. The source of those fields is caused by natural electrochemical activities or polarization in the media and is depended on resistivity (ρ) in the Earth.

Acquisition can be conducted onshore, offshore, air, mines and boreholes.

In the theory of electrical prospecting, the main goal is to define and solve firstly ***direct*** **and** then ***inverse problems***. Simply speaking a ***direct*** problem of geophysics is to find a field for a known object with given physical properties; ***inverse*** is to find the parameters of the object using a given field. **The solution of the direct problem is unique, but this is not unique for inverse problem which is ill-posed.** Solutions can be found by solving the system of Maxwell's electrodynamics equations.

$$\operatorname{rot}\vec{H} = \vec{j} + \frac{\partial\vec{D}}{\partial t}$$

$$\operatorname{rot}\vec{E} = -\frac{\partial\vec{B}}{\partial t}$$

$$\operatorname{div}\vec{B} = 0$$

$$\operatorname{div}\vec{D} = q$$

Where, ***E*** and ***H*** are the electric and magnetic fields, ***D*** and ***B*** are electric and magnetic inductions, ***j*** is the density of conduction current, and ***q*** is the electric charge density. In addition,

$$\vec{j} = \sigma\cdot\vec{E} \quad \vec{B} = \mu\cdot\vec{H} \quad \vec{D} = \varepsilon\cdot\vec{E}$$

Where σ, ε and μ are the electromagnetic properties of the medium: electrical conductivity, dielectric and magnetic permeability. The first equation is Ohm's law in differential form.

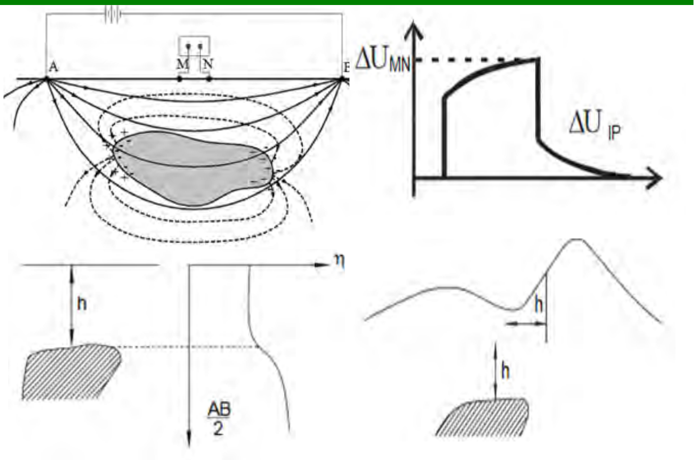
The main difficulties of EM studies compare to e.g. Seismic exploration is that in majority cases it is necessary to use algorithms for solving a direct and inverse problem corresponding to particular EM method with particular acquisition and configuration. While in Seismic, the method and configuration do not really matter for imaging, it is enough just to know acquisition geometry and configuration. **It is also important, that a chosen EM method will be always seen in context of the exploration problem.**

Various EM equipment for acquisition as well as mathematical algorithms for processing and interpretation have been developed quite extensively for onshore exploration. Last 15-20 years, there was a tendency to make recording equipment universal. There are several software companies on the marked today suggest software packages applicable to different EM methods. This software aims to solve ***inversion problem***, e.g ZOND[1], Interpex, KMS Technologies software, SCRIPPS Mare2DEM and others. It also possible to find online free software to conduct studies, e.g TDEM Geomodel.

Land and marine EM it is a different stories. Land data allows to work with high frequencies giving better resolution, while in water (in case of streamer acquisition), high frequencies have a tendency to be strongly attenuated.

There are several EM methods used in marina environments. The most practical became **CSEM.** This method measures resistivity, thereby the methodology is optimized to measure it as precise as possible. Typical **CSEM** used frequency range from 0.1 Hz to 5 Hz. Another method is **IP** (Induced polarization). It implies, that if there is a conductive body in the rocks, it can become polarized when the electric current goes trough it. In this case, a double electric layer forms on its surface. As a result, the body becomes a source of secondary (induced) currents. After switching off the current source, the secondary charge is released. Its measurement allows to evaluate not only resistivity (like in **CSEM**) but also bodies polarizability, Picture 1. **CSEM** tries to avoid IP effect to improve resistivity quality by using continuous alternated source signal and long source receiver offset.

There are a number of causes for IP effects documented, ranging from pyrite, presence of organic matter, hydrocarbon pollutions (environmental geophysics), to changes in clay properties and changes in grain size and etc. The **IP** marine method (e.g. DNME (Differentially-Normalizes method of Electrical Prospecting, used by ORG Geophysics), is used to detects **IP** anomalies of pyrite footprint somewhere above the reservoir in several layers. The method was very well proven in former Soviet Union firstly offshore (Baltic, Caspian, Black and Azov seas), later, got high success rate on land as well [4].

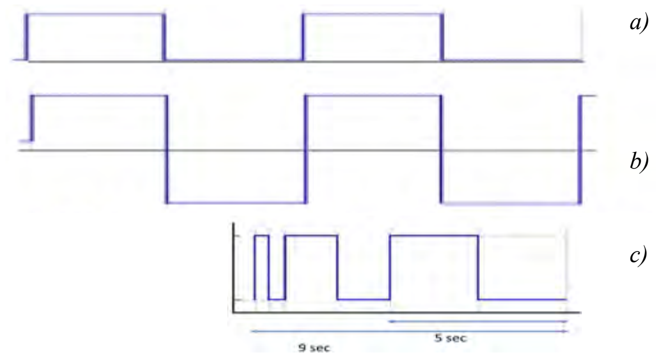


Picture1. One of the EM scheme.
a) Scheme of EM field caused by IP and its observation technique.
b) Impulse measurement of IP with Polarization effect

If ΔU_{MN} *- measured potential difference,* ΔU_{IP} *- induced potential difference, when current is off, then Polarization is estimated as*

$$\eta = (\Delta U_{MN}/\Delta U_{IP})*100\%$$

Estimation of the body depth ~AB/2 or a distance h from source electrode to inflection point



Picture 2. Simplified different sources of EM signal. a) IP source with constant On and Off current and period, b) Alternated polarity continuous current signal, used in CSEM. In practise, more advance waveforms are used [5], c) IP source with different harmonics to get wider frequency range and higher resolution (land).

Shape of the source signal is important part for EM exploration. For easier detection of IP effects, the source must be OFF for a certain time between pulses, while for **CSEM** the source must be ON all the time, to maximize transmitted energy, Picture 2. Picture 2*c* shows changing source period—modulated signal. One on the way to get additional frequencies.

According to Daniil Shantsev, Senior Scientist at EMGS, an optimal source waveform is shaped to focus most of the available source power on the optimal frequencies determined during the sensitivity modeling [5]. The latter takes into account the geological settings, type of potential targets, water depth, environmental and hardware noise levels etc. Typically, the optimal frequency band covers approximately one decade: *higher frequencies are attenuated too fast, while lower frequencies give too poor spatial resolution.* Within this optimal band EMGS usually chooses 4-8 frequencies and aims at distributing source energy more or less evenly between them. Using more than 6-8 frequencies within the optimal band does not provide much new information since the frequency coverage is already quite dense, but gives an extra computational load when running inversion. Besides, focusing all the energy on only few frequencies allows one to achieve higher signal-to-noise ratio and use longer source-receiver offsets.

Allan McKay PGS EM Manager, shares that PGS Towed Streamer EM source current waveform, and consequently frequency response data, is rich in frequency content as well as having a large frequency bandwidth typically covering at least 2 decades of frequency (e.g. 0.2 -10 Hz). PGS normally uses a specially coded broadband source current waveform that is tailored to the survey objectives. The benefits of frequency bandwidth, and multiple frequencies covering a given band -width, are recognized as necessary in the CSEM community to determine anisotropic sub-surface resistivity reliably [6,7]

According to *RALF 1* inversion software developer for HRES-IP[2] method Vadim Chernov, acquiring data with modular signal (Picture 2*c*) allows to increase EM resolution. **Using modular signal in CSEM and free RALF 1 for inversion will give high resolution EM image in marine exploration as well.**

HRES-IP technology (land) has advantages of studying a non-stationary process of high resolution of the geoelectric section and measuring the phase parameters of the harmonic field in order to obtain information about the anomalies of the induced polarization related to hydrocarbons.

[1] *One of the World leaders in EM software with strong physics background and top notch mathematics, providing high quality solutions for EM exploration techniques.*
[2] *High-Resolution Sounding with Induces Polarization.*