The Cableless Seismic Value Proposition

Where extra caution is required when selecting nodal equipment

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Introduction

For more than ten years, most of the articles in the geophysical press about land exploration have made some greater or lesser reference to the subject of nodal seismic recorders. Rather than clarify all the pros and cons of this technology, some of these pieces have unwittingly served to increase confusion as to what nodal seismic is, concentrating only on its advantages. Few publications have covered the potential risks of such recording or made reference to the caution which must be adopted when choosing any particular type of hardwork.

It does not help that there is no universal agreement as to the precise definition of "nodal". So, herein I will go along with what I think is most commonly accepted - a seismic recorder whose line boxes are not connected together by digital telemetry cables and which can operate autonomously. Essentially, this means each ground box is an individual unit, neither aware of nor dependent on any other piece of line hardware to record seismic data. Most nodal recorders operate in this entirely autonomous way but there are also more advanced devices which have the option (though not the necessity) to become part of a wireless communication chain when needed. They do not need this wireless link to operate but can greatly benefit when it is there; such a communication link has many advantages to nodal acquisition. There are also some cableless seismic systems which (on the basis of this definition) must be part of a comms link or they will not work at all, which can be disadvantageous whenever there is a problem with the comms link. We thus see when referring to these devices that the word "nodal" is mostly equivalent to "cableless", "cablefree" and "wireless".

Some articles have made a big fuss about differentiating one nodal product from another in terms of whether it is literally cablefree, cableless or has wireless communications. This seems to have been done in order to attempt some competitive gain. It is indeed correct that the many systems on offer can differ amongst themselves significantly and that they may each be more accurately described by use of one term rather than another. However, given the increasing experience of nodal recording, it is becoming ever more apparent that the major differences between these products have little to do with which word or phrase most accurately describes how much wire is connected externally to each node. This should be stressed. The reality is that this technology is most important advantages and are not at all simply related to whether ground units have no or few conductors outside the ground unit housing. These words are thus a serious distraction from what is essential to understand with nodal recording. This is in terms of the benefits each different type may bring as well as the risks that each

Fig. 1: Value proposition for cableless recorders. Must offer maximum flexibility for best data quality at lowest price across all environments. Here Sigma unit recording 3C data, using simple motorcycle battery, real time QC.

presents, and so the cautions that must be taken when choosing and operating the hardware.

This author has been coming to India for more than twenty years to discuss new recording technology and has long been a major advocate of the cableless approach. I was almost certainly the first to bring the nodal concept to India by means of magazine articles and by papers given at SPG conventions, and I believe the local industry could significantly benefit from the wider adoption of suitable nodal hardware. However, to imply that this technology has no risk is irresponsible. There are various warnings and problems which all users should be aware of and operators new to this should be cautious. Caveat emptor.

Therefore, unless otherwise stated, this article will deliberately use these words synonymously but with a preference for "cableless" which more fairly encompasses all such recorders (in that they ALL have less cable than a telemetry cabled system) and tries only to show bias towards a certain cableless approach when it has demonstrable geophysical advantages. The word "nodal" will also be used in a generic sense where it is interchangeable with "cableless". The use of just these two words herein will help to demonstrate just how unimportant and unrelated to the real issues of land exploration it is to describe hardware by mere reference to the amount of external wiring they use.

The Value Proposition

Seismic data recording is almost never about getting the very best data that is technically possible. Instead it is about acquiring data adequate for the job at a price that is affordable

- the ratio of acquisition cost to acceptable data quality. It is easy to design surveys with very high fold, greater offset and azimuth ranges, much increased source effort, smaller and better populated bins and so on, but in most cases such operations are not affordable and so compromises are made. Every survey is different and geophysicists never have the luxury of simply considering source rock geology imaging, surface complexity, target depth and reservoir thickness. Survey planning must include allowance for varying noise problems, differing environmental and security challenges, hazards and obstructions (manmade and otherwise), and other issues affecting quality. Nowadays, just as medical doctors need to know the difference between imaging equipment such as MRI, CTscan, PETscan and ultrasound, geophysicists can be called upon to offer advice on how each recording technology can cope with the problems such as those listed above. As significant generic information has not been made widely available covering these differing operational capabilities, this piece should be of some use to them also.

Fig. 2: Operating Sigma cableless system in difficult urban area with high degree of vegetation. Essential to have real time QC to monitor noise and GPS reception, system health and batteries etc. Observer set up desk in convenient location, to monitor line, control sources and harvest data. Survey would have been uneconomic and almost impossible from environmental perspective if large recording truck or harvesting trailer required. Courtesy GSL Seismic Services.

It maybe this sort of detail has not been widely distributed because some recorders seem to have only been designed with certain acquisition niches in mind, i.e. where they do well at dealing with just one or two typical exploration challenges. Perhaps a system may excel in sparsely populated, open areas where data quality is inherently good and the only risk to the data or equipment may be from, for example, wild animals. But the hardware which does well in such locations will probably not excel where data quality is inherently poor, terrain difficult and a variety of cultural issues have to be handled. Therefore, if an operator feels he will be dealing only with one or two easy challenges, it makes sense to research the most appropriate product which does very well in just those few niches. However, it is rare that an exploration company encounters only a few types of problem across all the locations for which it is responsible. In this case, the choice of recorder must be made much more carefully so that the best quality data can be acquired over the widest range of environments. The choice of non-niche recorder is then a much safer bet.

This is the simple value proposition when it comes to nodal hardware: the best system for the best data quality across the widest range of surveys which are likely to be encountered. This implies, where the environment changes significantly, the most appropriate hardware must have sufficient built in flexibility to handle multiple types of acquisition. It is a very different type of arrangement to that understood with cabled systems which offered (in relative terms) almost no real choice and thus its value proposition differed little between one product and the next. As choice of nodal recorder is so critical to how effectively an operation can be conducted, it probably helps to know something of how the industry came to this point and where all this new choice came from.

Technical Background

In the 1990's the industry started to put effort into finding ways to reduce significantly the cost of surveys, and/or record better quality data for the same cost. That is, it wanted to improve the land seismic value proposition. It had a couple of big ideas. One of these related to regulating field effort according to the quality of data being received in something close to real time. The other idea concerned trying to reduce field effort by a change in hardware and this went on to be seen as the cableless approach; only later began to called “nodal”. At the time these concepts were seen as separate approaches and this author was involved with both. As technology progresses we are seeing that there is a desire to amalgamate the two to bring even greater benefit to those charged with getting the best data at the lowest price. Therefore, any article discussing the caution that should be applied in recorder choice needs to cover both approaches.

The first idea, that of regulating field effort according to the quality of data being acquired virtually on a shot by shot basis, was referred to as “quality controlled acquisition” - QCA. At the time, it was conceived that QCA would only apply to cabled systems because at least some quality attributes in real time would be required; it had not by then become clear how such QC attributes could be transmitted without telemetry cables. The idea for QCA was to start as usual with a survey model describing source and receiver effort, but QCA functionality would then allow changes to either source or receiver effort to be made as data was analysed in real time while acquisition proceeded.

For example, it may be on a vibroseis operation that the initial model called for six sweeps of 12 seconds from four vibrators, on the basis that previously this much energy had been required to provide sufficient signal to noise ratio to illuminate the target clearly. But supposing it were possible in the field to assess that data quality was sufficient after only four sweeps. In this case productivity could significantly improve by using the lower number of sweeps or fewer vibs. Conversely, if after the originally planned six sweeps data seemed so poor as to be potentially uninterpretable, then more source effort could be increased or more channels deployed so that at least some useable data was recorded.

Amongst those companies who were aware of this concept there was great excitement at the time. However, there were two main reasons QCA appears then not to have taken off. One related to the ability to estimate the necessary quality attributes quickly enough to make rapid decisions affecting recording effort; in-field processing of sufficient capability was then not widely available. The other was that most operators felt safer keeping to the pre-plan, even if it meant more expensive or poorer quality data. We will return to QCA later as future major improvements to the value proposition will need to incorporate it.

The second approach was to develop seismic recorder technology which would inherently be lower in cost to use due to some particular beneficial product characteristic. To most of this simply meant reducing the weight of line equipment in the expectation that lighter hardware leads to lower operational cost. Since telemetry cables were generally the heaviest single component of a cabled system, that was the target to aim for, so was born the notion of cableless recording.

As one who was in at the genesis of the cableless system era, I remember distinctly that the “cable” here referred to the spread cable which sends commands in one direction out from the central system to deployed grounds units and receives high bandwidth digital data back. This cable was/is more formally known as the digital telemetry or spread cable. This was the cable we wanted less off in cable-less acquisition.

This does not mean that there was no discussion about minimising other types of cable. But specifically what the new technology wanted to save us from were the drawbacks of spread cables as they related to the value proposition. Certainly no one wanted any move away from digital telemetry cables to increase the risk of poor data and worrying about geophone cable was on no one's agenda primarily because of those involved at this time, understood the on-going importance of geophone arrays for acquiring data of the highest quality in most circumstances.

It subsequently became very clear that to concentrate only on ground equipment weight as a way to reduce cost leads to some entirely false, expensive and dangerous conclusions about field operations whether cableless or cabled. For example, in some cases, nodal recorders are still heavier than cabled systems, but they nevertheless offer lower cost acquisition because they do not rely on any serial dependent architecture. It is also not an easy matter to define the actual weight of many nodal systems and how they affect operating costs. They can have line boxes which are relatively light but they may simultaneously hugely increase the amount of equipment needed elsewhere, including very large trailers for data harvesting and/or battery charging, electrical generating and air-conditioning equipment which cable telemetry systems did not need. We see that line equipment weight as the main measure of cost reduction capability is useless - just like the amount of (non-digital) external wiring in cableless acquisition is not correlated to the value proposition.

Other reasons for doing away with telemetry cable included their initial and on-going cost, the unreliability they brought to acquisition and perhaps the greatest reason of all to do away with them was related to the already referenced serial dependency of this method. Here, the failure of one cable or ground unit usually meant the loss of so many channels that the line had to be fixed before acquisition could proceed. Many crews would simply spend large fractions of the day in “bringing up the line” before they record a single shot, and then replacing cables as they failed during the day. There thus have to be characteristics of nodal recording apart from weight which lead to the best value proposition.

Spoilt for Choice, or Spoilt by Choice?

In the 1990's some of the organisations behind a new value proposition included BP in the UK and the Italian Oil giant AGIP, now ENI. There were at the time internal documents from a variety of companies covering what such new technology would need to look like. For example, what cableless design would be the best to cover the issues of batteries, realtime access to data, system security, flexibility to take on multiple types of surveys and so on?

Fig. 3: GPS reception must be available in all location or otherwise reported immediately to operator.

It is fair to say that not all the possible problems which certain cableless approaches might inflict on users were then appreciated. However, the most important were considered and still seemingly ignored by some manufacturers. This is apparent by reviewing some of the public domain documentation. For example, "Seismic System 2000" (which this author later updated in "System 2000 Revisited") and ENI's excellent comparison piece presented at SEG 2012 (Pellegrino et al) which concludes that greater market penetration of cableless systems requires them to have certain minium capabilities, one of which is the ability to report QC data in real time. Another is a capability for non-centralised data harvesting. As would be expected, most early opposition to nodal recording came from the companies who made digital cable telemetry systems. They were quick to explain that these recorders always had access to QC information (or at least they did when the telemetry cables were working) and to real time data. It is interesting that such companies either now actively market their own nodal products (some of them having no easy-to-deploy real time comms capability) or are no longer in the market.

There are now more than ten cableless offerings vying for our attention. There have been four new nodal recorders announced, including major upgrades to existing systems, in

Comparison in varying cableless seismic acquisition technologies

- Shootblind and non shootblind.
- Non-shootblind with assurance of communication and those offering no assurance.
- No. of channels per ground unit.
- Batteries: internal or external (or both).
- Battery chemistry choices available, or forced.
- Ability to work on water.
- Suited to wide range of passive/ permanent.
- Suitability for analog 3C.
- Ease of deployment.
- Ability to use multiple different passive and active sensors.
- Multiple types of harvesting methods, or only 2.4 GHz-based.
- Serially dependent comms architecture or other.
- Recording to stop during harvesting or recording continues.
- Full support for SPS, SEGD, SEGY.
- Levels of built in hardware and data security.
- Ability to work side by side other cabled recorders, or none.
- Ability to add sight to other cableless recorder, or can only be used on its own.
- Configurable system, for optimisation in different environments or non-configurable.
- Price to purchase, including all initial software and peripherals.
- Price to operate, including software upgrades.
- Level of source control integration

Fig. 4: List of capabilities that may need to be compared between differing nodal systems.

the last twelve months alone - three of which have paid attention to the original design directive of having an ability to transmit QC data in real time. Incomprehensibly, given how much it diverts attention away from the important issues, a comparison which still tends to be made as each new product emerges covers how much external wiring is required. This makes no sense. It is quite clear that not only was this not considered important at the birth of the technology, but other system attributes have significantly more affect on whether this recording hardware can give us better data at lower cost. Far more important are details such as the ability for ground boxes and control system to support some minimal level of two way communication, data and system security, limiting battery numbers and chemistries, flexibility in harvesting recorded data. All these issues are potentially essential parts of a more detailed value proposition for today's land seismic, and to improve this proposition for tomorrow needs the combination of both the original ideas, that of cableless and QCA.

The Unusual value of Limited Competition

For those who were not keeping count, it is worth pointing out that the number of viable and internationally marketed cable telemetry systems was rather small. In fact they could be counted on the fingers of one hand. Although at the time we tried to make a lot out of the differences in functionality between these few offerings, compared to what is available in nodal systems today, digital cable telemetry systems were mostly much of a muchness.

For many users, they seemed to provide superficially identical levels of data quality and system testing. Weights and power consumptions did not vary much, similar levels of deployment effort for ground units and batteries were required, and so on. Therefore, one recorder had little chance to improve the value proposition much more than the next one. There were some types of functionality which certain recorders tended to be better at. However, such benefits were not always apparent from the simple product comparisons which usually were made and they did not always filter across to the people who actually had to make the best use of the equipment. Had there been the opportunity to make more detailed comparisons, perhaps the more imaginative acquisition geophysicist could have used the more flexible cabled system to gain commercial or data quality advantages. But this did not often happen probably because there is rarely complete freedom by operators to choose the most appropriate seismic hardware. Perhaps it also did not happen because where there is the innovation leading to increased system flexibility, it tends to come from the smaller manufacturers and they are usually the last ones to be chosen.

However, there were clear benefits of so few options. For example, buying Cable System A rather than Cable System B or C, as is still seems true with cable systems today, mostly did not doom the purchaser eventually to having major regrets that its choice could have been so much better. Compare this to current cableless technology and we see that this comforting "I cannot really go wrong whatever hardware I choose" approach does not apply. We find in nodal recorders that we need the fingers of both hands to count them. We

Fig. 5: Real time noise display from Sigma system integrated with shootblind nodal recorder. This addon mesh radio based functionality is unique to Sigma but is increasingly required to assure data QC and system status in nodal acquisition.

quickly see that there are significant differences in functionality between them which are enough to make some very much better at performing in a wide variety of operational circumstances than others.

This may be more simply put: some nodal units seem designed to be exceptionally good at certain niche applications (which was rarely the case with cable telemetry systems) whereas others have much more general usage. In fact, some of the more advanced nodal instruments are actually configurable to be optimised for a wide variety of acquisition, including passive, active and combined, stand alone or with other systems, on land and shallow water and in every type of environment from desert to town and jungle, and do not need to shoot blind. (Strictly speaking these products are now increasingly referred to as hybrid rather than cableless, but nodal cableless can be considered as a subclass of hybrid capability.)

Any seismic contractor who chooses a niche nodal system needs to be very sure that all its planned surveys can be carried out without risk to data quality, personnel, cost and the environment. Sadly, there are operators in every continent I have visited recently (Europe, North America, Australasia, South America and Asia) who have regretted the choice of hardware they made, originally believing that there was not much to differentiate them, then only later finding out to their great cost that there is. In most cases this relates to lack of QC capability but is not always limited to this feature. In several examples, contractors are now adding cableless systems with a guaranteed real time QC monitoring capability to work side by side their shoot-blind nodal systems to ensure data quality does not deteriorate any more.

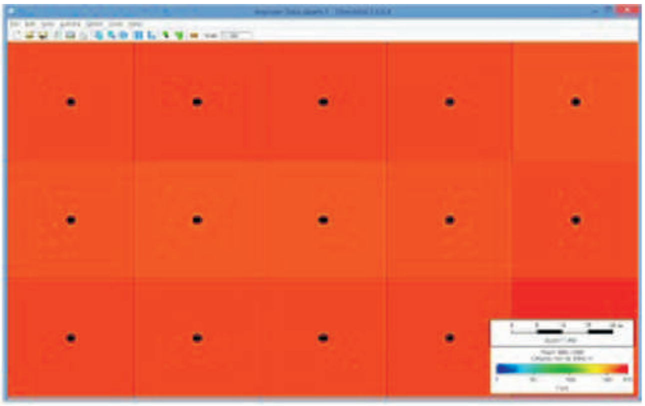
Fig. 6: Sigma hyMesh high bandwidth option used to transmit complete seismic record. This also can be used to radically improve performance of any shootblind nodal system. There is growing demand for this add-on full bandwidth real time functionality.

Thus, whereas it is usually a good thing to be spoilt for choice we can conclude in this instance that variety in land seismic cableless technology has a risky downside. If a company previously only experienced with cabled recorders now plans to use this hardware, it should make itself very aware of all the risks and benefits of each nodal approach. If that company has any doubt, my advice is either to remain with cabled systems (the devil you know), shortlist those nodal systems which offer at least some minimal level of QC and hybridisation (there is already a small handful of such products) or choose a few hundred channels from a variety of nodal products which are all flexible enough to work side by side the cabled system already owned, to gain experience of what features are most valuable. By this approach, an operator is far less likely to find himself in the position of having regrets.

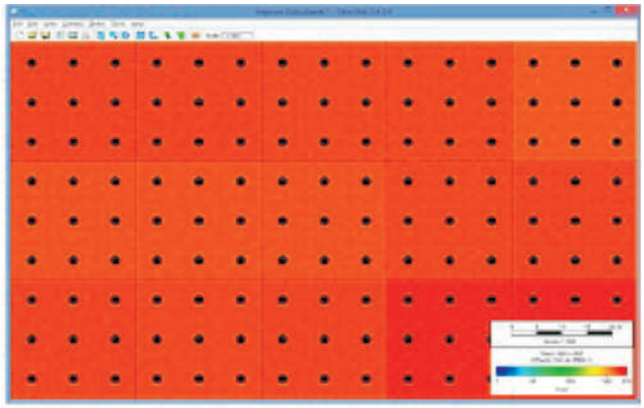
Making Choices, Exercising Caution

When reviewing differing recorders ideally one should consider all different aspects of the technology. A list of features which are worth comparing is in Figure 4. However, given space limitations we will concentrate on those most closely relate to achieving the best data in the maximum number of environments for the lowest operational cost. A new system which does not score well in this is useless according to the value proposition. Further, it is a poor investment to buy something new which cannot perform adequately if existing/currently owned hardware can already provide higher quality data. There are various specific quality and cost issues which cableless systems should make us consider, most of which did not worry us when using cabled systems.

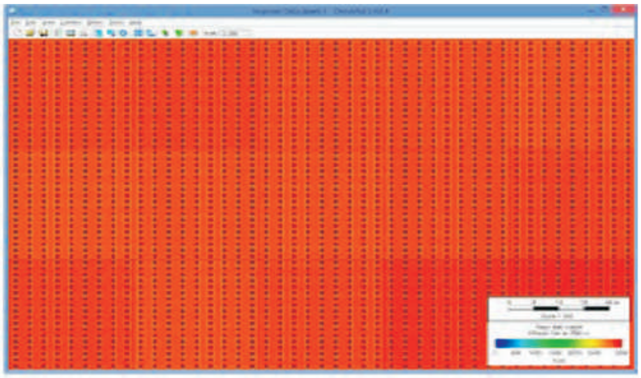
The first relates to GPS. In almost all nodal products the receipt of a GPS signal is necessary to time stamp seismic data. If the ground unit cannot receive GPS signals, sooner or later the data may be useless. Various products take different approaches in this regard. Some units can receive only the American GPS system while others can pick up signals from Glonass too. It is wrong to assume that GPS signals can be received everywhere and all the time. I have been in situations where there is clear blue sky above and still could not pick up GPS for almost an hour. When there are operations in jungles, sometimes the GPS will not penetrate to the jungle floor making GPS reception unreliable or non-existent. Some manufacturers advise burying the ground unit either to avoid it being stolen and/or to get adequate coupling since they are relying on the single geophone (installed inside the node's housing) to sample the wavefield. Burying the node, especially in wet jungle conditions may give rise to on-



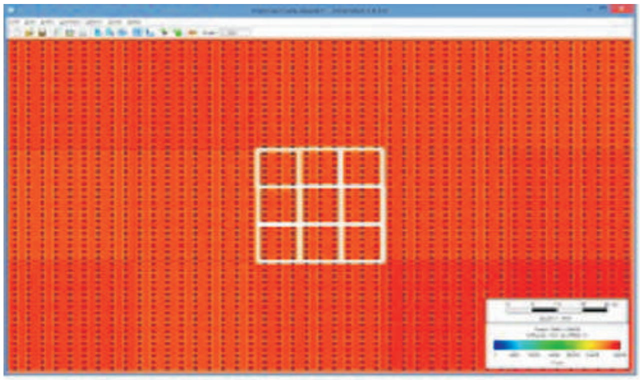
Data example 1. Courtesy Mustagh Resources.



Date example 2. Courtesy Mustagh Resources.



Data example 3. Courtesy Mustagh Resources.



Data example 4. Courtesy Mustagh Resources.

going issues of poor GPS reception. It is important to investigate whether the system can quickly report loss of GPS signal and what the hardware does to maintain data integrity when GPS is lost.

This next data quality issue is that of sensors. All digital cabled telemetry recorders even in their most basic form allow attachment of almost any configuration of geophones to each channel input: singles, small strings, multiple strings (e.g. to form an aerial array), different sensor sensitivities and natural frequencies. This ability to use the right sensor approach for the job is no less essential in nodal recording too. It is true that some cabled systems enable the user to work with inherently single sensor devices such as MEMS. However, the point receiver nature of this technology also makes it a niche recording application - which may explain the limited market penetration which MEMS hardware suffers from. Most of the groups I know which regularly employ point receiver cabled systems use them for relatively unique applications employing very large channel counts in simple terrains. In fact, almost all the remaining cabled systems market themselves as being capable of hundreds of thousands of channels and that this capability is to support the claimed geophysical benefits of point receiver. This implies, unless planning to buy huge numbers of channels, that the very minimum caution to be taken with nodal systems should be that are capable of more than just single sensor deployment. In other words, if cable systems market their single sensor capability as valuable for high channel counts, then surely from the point of view of geophysics the same applies to cableless. Lower channels counts (maybe ten/twenty thousand channel or fewer) imply the use of arrays.

Nodal Acquisition in Noisy AREAS

The ideal land survey is sometimes said to be point source and point receiver, but this is dependent on the number of source and receiver points. When neither figure is very large then quality data is unlikely to be the result. Basic physics confirms that receiver intervals must be chosen to provide proper sampling of apparent wavelengths of reflected and diffracted signals.

However, few surveys record only desired signal - land data generally has various noise modes with a wide range of wavelengths, often far beyond the spatial spectrum of desired signals. Ground roll and surface waves tend to contain longer wavelengths which usually overlap the shorter wavelengths of the signal to be captured. Chaotically scattered surface waves create broadband noise which includes short wavelengths, and such noise requires adequate spatial sampling in order to avoid aliasing of noise modes into desired signal bandwidths. Cabled systems all allowed the use of arrays to provide the function of spatial sub-sampling.

Some think that such arrays were only useful to attenuate groundroll but an array designed to protect signal is generally too short to provide enough ground roll attenuation, while for example a 6-element array pushes the sub-sampled Nyquist to a higher wave number and summing of array elements helps suppress some high frequency noise. In areas of poor data quality, or where it is difficult to acquire data of high frequency content, single sensor is likely only to make this worse unless at least very high spatial sampling is being planned, perhaps trace intervals of 5-10m. For example, short wavelength noise sampled once every 20m with a point receiver will alias into signal bandwidths many times, and remove almost all possibility of acquiring quality data. Add this poor quality of data being acquired due to incorrect spatial sampling to the situation where cultural noise cannot be monitored in real time (especially important just before any dynamite shot is taken) and there may be a perfect recipe for data of very limited bandwidth, bad signal to noise ratio (poor dynamic range).

This may be easier to see using plots of mid-point scatter (which can also be called "spatial sub-sampling"). Data Example 1 is the result of point-receiver and point-source in a design intended to focus midpoints. Data Example 2 is still point source and point receiver but using a design intended to produce mid-point scatter signal using a triple-stagger design. Data Example 3 shows the actual midpoints for each individual source and receiver point assuming an array of six receivers distributed over 1/3 of a receiver interval and 3 sources distributed over 1/3 of a source interval. This shows the effective spatial sub-sampling achieved by the use of triple stagger and short arrays (the arrays must be kept short so as not to attenuate desired signal wavelengths). Example 1 yields spatial sampling sufficient to capture the long apparent wavelengths of reflected signals in most cases. However, chaotically-scattered source-generated noise contains all wavelengths (long, medium and short). This fine sub-sampling is especially important when a strong level of this type of noise is present. Short wavelength noise has the ability to eat up the long-wavelength signal elements if not properly managed. Technically, the delta-x in spatial sampling determines the Nyquist wavelength (2 x dX). With a large delta-X such as in Example 1, the short wavelengths will alias and contaminate the long-wavelength signal. The use of triple stagger and arrays provides a smaller delta-X (separation of individual geophones within the array) which extends the sub-sampling Nyquist to shorter wavelengths and reduces aliasing. The summation of the elements in the array (demonstrated in Example 4) as the points which are averaged in the field, without NMO or statics processing, to produce the recorded traces represented in Example 3 forms a wavelength filter that suppresses the short-wavelength noise before it aliases around the Nyquist formed by the new sample interval (this is the green filter response shown in Figure 7).

It is often clear, therefore, that the ability to use hardwired arrays is essential for good data quality unless intending to use huge channel counts. Hardwired arrays of course requires some external (to the node) wiring so this clearly makes the point that choosing a recorder by how much it has minimised external conductors is not generally a sound way to make a system selection if data quality is high on the agenda.

There are admittedly some claimed benefits to point receiver recording and processing each with NMO and statics corrections before summing or migration (even this may not be universally true since offset and azimuth differences across array components is very small and therefore in the majority of prospects it is not likely that processing of individually recorded elements will be beneficial). However,

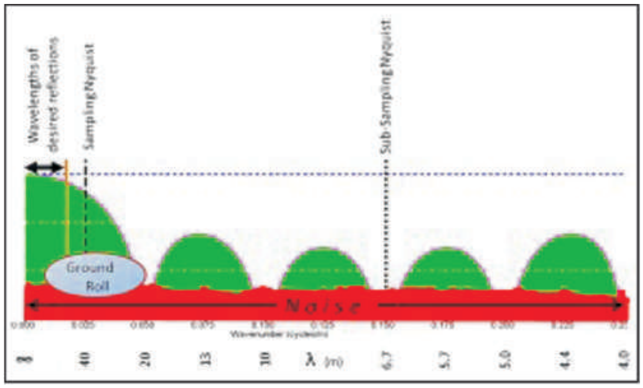


Fig. 7: Array filter response. Shows importance of geophone arrays.

these almost entirely only come from those who are advocating enormous channel counts which is only logistically feasible in desert environments. Elsewhere, smaller channel counts and trace intervals greater than 5-10m are the norm, and here an array is almost always the far superior approach. Thus, any recording system must offer sufficient flexibility to cope with this or data quality is automatically and irretrievably limited. No one would have accepted a cable system which inherently limited data quality so it makes no sense to use more modern equipment with less capability.

Data quality is also fundamentally dependent on the coupling of the sensor to the ground. This is another good reason to use an array as one poorly coupled geophone on a string will still leave other well coupled transducers to provide signal. The single sensor approach, especially where that sensor is itself now encased in a large housing, may offer new challenges to deal with. The cableless recorders which adopt this approach usually recommend some level of burying of the ground unit, which itself may require significant extra effort in anything but the most accommodating surface conditions compared to deploying a geophone string. However, as well as the inconvenience and cost of having to bury and then pick up such large units for data harvesting, re-burying them in the same location (which may be the temptation in difficult areas) may also deteriorate data, especially as higher frequencies, see Figure 8.

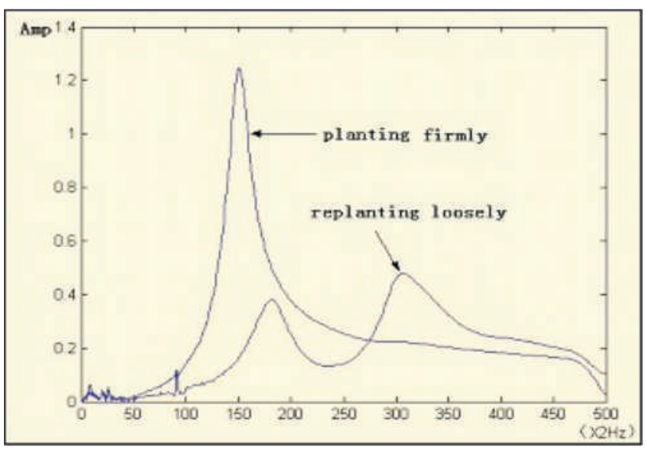


Fig. 8: Potential data deterioration from replanting single sensor. All signal can be affected with greatest harm at higher frequencies. Courtesy Jidong Wei.

Quality Monitoring

Obtaining the greatest bandwidth data is of course essential for many reasons buthigh recording frequency data can present special problems. Let us briefly go back to basic physics to understand how differing instruments may help or hinder this process.

Data processing depends on deconvolution to recover weaker parts of the reflection amplitude spectrum. In some cases, decon may reach down as deep as 50 to 70 dB before deteriorating signal to noise ratios limit its effectiveness. This depends largely on noise conditions, so obtaining the highest quality (lowest noise) data is essential.

As waves pass through the earth, energy is lost to absorption with each oscillation (or each period of each Fourier component of an impulsive wavelet). As a very rough average in sedimentary rocks, the amplitude of each cycle is about 94% that of the previous cycle. This greatly generalised figure of 6% loss is about 0.2 dB. If each successive cycle is 0.94 times the amplitude of the previous cycle, then after 100 cycles the amplitude would be 0.94^100 = 0.002 times the amplitude of the initial signal. This is 20 x log (0.94 ^ 100) = -54 dB. If factors are included also for transmission losses and spherical divergence, generally any signal will probably be too weak to use after 100 cycles. For a simple reflection path, that means about 50 cycles going down and 50 cycles returning to the surface sensors.

Therefore, the useful depth of penetration of a seismic signal is about 50 wavelengths (λ). As $V = f \lambda$, for 50 cycles, depth = 50 V/f where V is the average speed of sound through the rocks between surface and target. For very shallow reflections, using typical velocities we may find that frequencies above 1 kHz are recoverable. However, for moderately deep petroleum targets where perhaps V might be 3500 m/s, it is easy to calculate, as an example, that only 70 Hz may be recoverable from a reflection at 2500 m. Or we couldask what frequencies might survive to a depth of 2000 metres in a sedimentary basin with average velocity of 3200 m/s and we can rearrange the equation to solve for Fmax = 50 x V/D = 50 x 3200/2000 = 80 Hz. This obviously also explains why longer wavelengths can travel farther before they are too small to be picked up.

The one hundred oscillation figure is definitely NOT exact but it is a useful guideline. However, whereas the Earth controls how large the amplitudes are for signal it sends back to us, the ability of hardware to recognise/record very small signals is determined by many things. This includes some things in our control and something beyond our control: the amount of various types of noise in the exploration area, the sensitivity of the sensors and instrument etc. Most modern recorders, cableless or cabled, have little to differentiate them in terms of sensitivity though some are seen as having a very slight advantage over others when they have 32 bit rather than 24 bit convertors. But in terms of the value proposition it is how the instrument forces us to work to get the best data (retrieve highest frequency content)versus the cost to use that system in such a way that must be considered.

As in almost all cases, we need a well-designed array (to protect our signal from noise, to recover these high frequencies) and we need to employ nodal systems which let us deploy those arrays as cheaply as possible. Where there is short wavelength noise such as chaotically-scattered source-generated noise, the mid and short wavelengths of that noise alias into our signal and long-wavelength band. As an example, imagine a survey with 20 metre receiver interval. The Nyquist wavelength is 40 metres or 2 x Ri (the Nyquist wavenumber would be $1/(2\ \Delta x) = 0.025$) meaning wavenumbers from 0.025 to 0.050 (wavelengths from 40 to 20 metres) will alias into the signal bandwidth of 0-0.025 (wavelengths from infinite down to 40 meters). Noise with wavenumber from 0.050 to 0.075 (wavelengths from 20 down to 13.3 metres) will also alias into the same signal band, as will wavenumbers from 0.075 to 0.100 (wavelengths 13.3 down to 10 metres) and so on. Every "tile" of wavenumbers in 0.025 increments will alias into the signal band. See figure 7.

Whatever hardware is deployed every twenty metres, some sort of signal is recorded but it is not the same if a point receiver is used instead of an array. Using a 6-element array (element spacing of 3.333 metres) provides sub-sampling with a Nyquist wavelength of 6.667 metres or a wavenumber of 0.15. The summing process of the hardwired array of geophones produces a wavenumber filter such that the shorter wavelengths of noise are attenuated. They will still alias as before when we produce a recorded trace every 20 meters, but now the level of the noise which will alias and contaminate our signal has been reduced by up to 24 dB (the practical limit of attenuation of most field arrays). Thus the damage to our signal when not using arrays occurs at all wavelengths and frequencies - all of the signal is contaminated by aliased short- and medium-wavelength noise.

Obviously, if noise does not exist on any particular project, then arrays may not provide so much benefit. Most papers that document tests where data quality was not improved by using arrays tend to show data from areas of very clean data. However, when chaotically-scattered source-generated noise exists (as in many project areas) then the use of an array will reduce the negative impact of aliased noise and tend to provide most improvement for the more-easily lost high frequencies. In cabled systems, unless tempted to use MEMS, single sensor acquisition was rarely seriously considered by most crews in difficult environments. Therefore, we should not be tempted to switch to single sensor recording with cableless systems simply because it is convenient for the manufacturer to build a single geophone in to each node, or because such methods mean fewer external conductors.

Given the importance of high frequency data and how nodal systems present different choices to cabled systems, let me briefly summarise. Whereas there is no way to quantify precisely the benefit of an array since it depends on the type and magnitude of noise present in the project area, a benefit is almost always derived. Generally large receiver intervals and point receivers are probably sufficient to capture the necessary wavelengths of deep reflection signals but noise requires different spatial sampling (much smaller intervals).

The more noise that is present in an area, the smaller should be the receiver interval. The choice is either to do this with a very high density of point receivers (very large numbers of nodal channels) or smaller numbers of channels (counts in the thousands to low tens of thousands on a reasonable sized 3D) and arrays. Just because new instruments made new ways of operating more enticing, we still need to consider basic physics to know if those new ways will help of hinder.

Finally, in regard to data quality, consider again common industry experience in terms of what was acceptable in cabled telemetry. Here we would not have taken a single shot unless the QC data being sent in real time demonstrated unequivocally that all line equipment was functioning adequately. How often has an observer delayed a shot to allow wind or other cultural noise to reduce? How often has he stopped recording to investigate noisy phones or dead channels knowing that these can make an important difference? Most acquisition is performed against a preplan which itself usually presupposes that the observer will use his judgement, skill and crew resources to acquire data of the highest quality. This is especially true with dynamite recording where each shot is expensive and difficult to repeat, and where the timing of shots can often be slightly delayed to allow cultural noise to subside. No one would permit an observer with a cabled system just to keep recording aimlessly, oblivious to the minute by minute realities on the spread which affect data quality. It consequently seems strange that anyone would imagine a cableless recorder without an ability to report at least basic QC in an acceptable time frame would be an approach suited to a wide range of environments.

Fig. 9: Gathering QC data on Sigma crew can be by use of real time mesh radio or, shown here, by using line QC data harvesting device. QC data is carried to observer using ruggedised USB memory (here in blue), no need to send whole line unit to the observer offering faster and lower cost QC.

To cope with this drawback, some recorders which do not support any form of real time QC offer a form of delayed reporting. With this approach, line crew are required to walk (or drive on, or fly over) the line with "*Delayed QC"* recording devices which pick up limited amounts of QC status from deployed ground units. In most cases the observer does not see this data until the line device is returned to recording truck and the observer loads the QC data into the acquisition controller. If the observer can get his hands on this data quickly enough the potential data quality degradation may be minimised but this is difficult to do in most cases unless multiple line QC recorders are used and many people charged with the task of getting this data to the observer in good time. This is also an expensive operation as it requires large numbers of such line recording devices which, while they are with the observer, are not being used to acquire more line QC data. But trying to assess spread noise levels while those responsible for acquiring the relevant data are themselves sources of noise, also seems to be on the wrong side of the value proposition. How often have we, for example, when using a cabled system for dynamite shooting, contacted line crew to stop moving once the shot was ready to be taken? iSeis's Sigma system has a variety of low cost ways of getting this "Delayed QC" data more quickly to the observer if the user is not employing Sigma's built-in mesh radio networking real time capability. One is called the "Forward Observer" which links to the mesh radios inside each Sigma ground unit to receives QC data from one or more units over the mesh. This is already advantageous compared to other delayed QC approaches as it minimises movement on the line. But additionally, this data is written to a removable memory which is all that is needed to take to the observer allowing more QC then to be gathered. The real time mesh-based QC and the delayed Forward Observer QC can both be used in the same operation. See Figures 9 and 10.

Fig. 10: Future direction of line QC gathering. Sigma's miniature Forward Observer allows deployment on UAV/drones.

The Other Side Of The Value Proposition

Cost is the other half of the value proposition. For seismic equipment there is the cost to purchase as well as the cost to operate the hardware. For cabled systems there tended neither to be a great deal of difference between the prices at which suppliers would sell equipment nor much cost difference in operating them in the field. As we have seen, this was because the systems were essentially so similar. With nodal systems this is often not the case. There can be significant hidden cost advantages of one cableless approach over another both in terms of purchase and operations. We take just three examples of this - the costs as they relate to the batteries, data harvesting and how many channels are in each ground unit.

The number of channels which a single battery can supply via the power down cable method in a cabled telemetry system is partly dependent on trace interval. This is because most power is not used in energising the digitising channel, but in I-squared R losses in distributing power along the cable itself. A cabled seismic system of about 2 - 4,000 channels, given the trace interval that such numbers of channels would imply (30 - 50m) on a 3D crew would mean around 60 - 80 batteries. Such a quantity of batteries generally requires no special consideration. Keeping them charged for the line, safe disposal/and local replacement as they came to the end of their useful life are simple matters and able to be handled locally. Cableless systems are not like this at all.

It has often been said that nodal systems exchange the cable problem of cabled telemetry systems for a battery problem. The minimum number of batteries any of the current cableless systems need for a 3,000 channel operation would be 1,000 and this only comes with those systems offering 3 channels per ground unit. In some cases, this number of channels may need 6,000 batteries, close to one hundred times what was usual for a cable crew. Learning how to handle this many batteries is a whole new experience for any operator and should not be underestimated. To make matters worse, some nodal hardware requires lithium batteries, which then require special chargers and handling. Neither the charger nor the battery is usually available locally. Therefore, significant initial and on-going cost, compared to a cabled operation is the result. Just as most cabled systems waste most battery power by transmission losses, most nodal systems waste most power by not being able to switch the unit off once recording is over for the day. Clearly, the best way to save cost in nodal operations is by being able to use the fewest and lowest cost, locally available batteries and to be able to switch them off when required. This also has knock-on savings in terms of the trailers and power supply that may be needed to charge the batteries.

It should be added that whereas there is a superficial advantage to having an internal battery, it is outweighed by the disadvantages this brings. One is that this requires each ground unit, its recorded data and battery all to be handled as a single unit. Thus if there is a battery issue, such as having to wait in warm climates for it to cool down after coming off the line before being charged, then the ground unit is held up even longer. Using internal batteries means that their whole weight much be carried around no matter how short the survey, and still requires external batteries if the duration is longer than the internal battery capacity. This also allows no chemistry or charge duration battery choice. As so many batteries are required on nodal recording, choice and flexibility is essential to reduce financial burden.

Fig. 11: Data harvesting problems from nodal recorder with internal battery and centralised/rack harvesting. Data downloading cannot commence till internal batteries attain the correct temperature. This is one reason why it must be possible to handle batteries, data and ground units as separate items.

Data harvesting is the final area to consider in terms of cost. Recorders such as iSeis's Sigma nodal system have add-on hardware options (in this case, by attachment to Sigma ground unit's Ethernet port) to support full realtime data return even in tough environments. However, this requires some additional capital outlay and equipment deployment. If seismic data is not sent from the field via some wireless method, the crew has to go and collect it. There are almost as many different approaches to this as there are nodal systems. Some require the entire ground unit to be collected up and placed into bulky download racks. These racks can be so large as to require their own trailer(s), mains power supplies and air conditioning. These can add hugely to cost, overall weight, system flexibility and so on. If adopting this approach, the ideal would be to have the lowest quantity of ground units to pick up off the line and place in racks, which implies more than one channel per unit.

Fig. 12: Data harvesting via ruggedised USB (yellow) memory with security file. Ground units remains on the line. Rapid access to data at any time and no need for harvesting trailers etc.

Other systems offer the convenient and lower cost method of allowing the boxes to stay on the line and a portable data collector either plugs in to the unit or connects via WiFi. Finally, some manufacturers have developed the most convenient and cost effective method of data

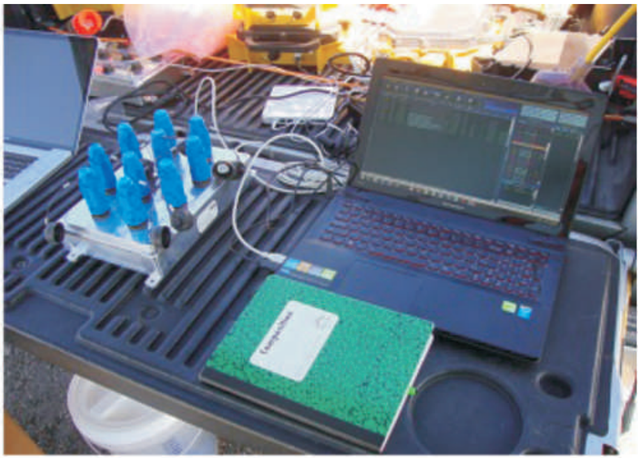


Fig. 13: Entire data harvesting equipment required for thousand channels of Sigma cableless system using rugged USB memory collection. No need for harvesting trailers etc.

Fig. 14: SI U*Node cableless system also offers ability to send QC data in real time.

harvesting. This is where a simple external memory device is attached to the ground unit (via a rugged USB connection) and data is copied from internal to external memory. The memory can be attached to the box before recording starts in which case data is sent both to internal and external memory. Alternatively, the memory can be attached to ground unit after recording starts or after it is finished and the same memory used to copy data off many boxes. This allows multiple methods of harvesting to be used on the same crew. As data collection can otherwise be so time/labour intensive and costly, it is essential that flexibility in harvesting is considered. See Figures 12 and 13.

For security, in the case of the Sigma, the external memory must have written to it a control file to command data to be copied from internal memory. This copying can even happen during seismic recording allowing acquisition to remain uninterrupted and data viewed at any time. It also does away with the need to buy extra ground equipment to cover the time when some other systems would have their ground units in the harvesting trailer and unavailable for recording. All that is then required is to take those external Sigma memories (which may be one per ground unit, or one per hundred ground units) to an interface hub connected to, for example, a laptop where data is then harvested processed and copied across to an external disc. See Figure 2 and 13. This literally can be done on the back seat of a car/pick-up, or on a simple desk, which is clearly hugely more convenient, faster, less labour intensive and more cost effective than needing a trailer, generator and so on.

The number of channels per ground unit is the final issue of cost. A reasonable measure of the amount of effort that must go into deploying hardware is the number of pieces of equipment that have to be handled. Here there is discussion as to whether a 3 channel unit is better than a single channel unit. With three channels per node, clearly the crew has to handle only one third the number of ground units, but conversely will need to add one or two geophone jumper strings where a single channel unit will not. However, the issue is more complex. Clearly a single channel unit also needs three times as many (internal or external) batteries compared to a three channel unit, and in most systems the battery is the single heaviest component. Therefore, adding up what it takes to comprise three seismic channels, i.e. box(es), battery(ies) and jumper cables, in almost all circumstances the three channel unit is lighter and requires much less handling. (Three channels per ground unit of course also allows 3C recording which may be very difficult with a single channel nodal approach, see Figure 1). Therefore, almost always the cost aspect of node deployment is also lower with 3 channel ground units as is the convenience of their use..

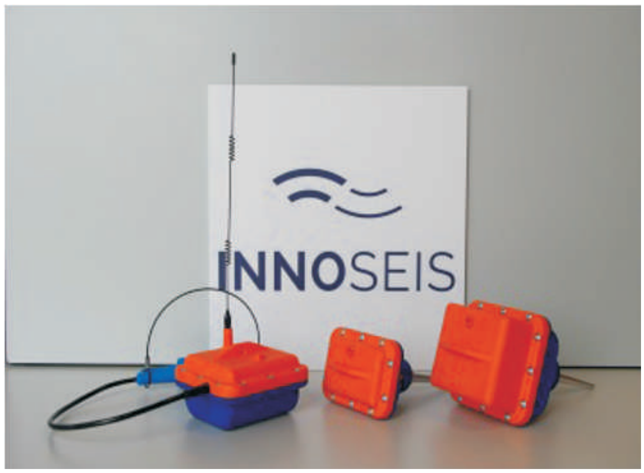


Fig. 15: Innoseis cableless recorder, first revealed 2014 Features box-to-box communication and option for external geophones/array.

Summary

Cableless/nodal systems were devised entirely to re-balance the seismic value proposition - to give us better data at lower cost. We have reviewed which issues affect data quality, with special reference to where there are (a) differences between nodal and cabled systems and (b) the differences in potential data quality improvement/ deterioration between the many nodal approaches. This piece has also looked at various items of initial and ongoing cost.

Based on the information herein presented, the only reasonable conclusion is that the best solution for cost, for crew convenience and safety, and for data quality is much more likely to come from ground units with some guaranteed form of communication, and from harvesting which does not require the ground units to be brought to a central location. It is no coincidence that both these requirements were referenced in some of the original documentation covering designs for nodal systems in the mid 1990's. It is also interesting that most systems released in the last year have the ability for QC data return and flexible methods of harvesting. It seems clear the industry is at last paying attention.

Those intending to commence nodal recording should be cautious over the full spectrum of issues that is involved in successful operations peculiar to its own environment. New technology is no guarantee of better data or lower cost operations. India is in the lucky position that it can learn from the costly mistakes made by some early adopters of the technology.

Acknowledgements

Thanks to Norm Cooper of Mustagh Resources for providing insight into where it is possible to improve data quality with less effort, and where it is easy to lose data quality if not paying attention to basic physics.

Thanks to GSL Seismic Services who have successfully used Sigma cableless seismic systems in the world's most difficult environments and the widest range of types of acquisition proving the peculiarities of the cableless value proposition.

References

Fleming, C. Flexible active and passive seismic acquisition in difficult terrain.Lessons for the Asian environment. Drilling and Exploration World, Vol 22, June 2013, 47-54.

Jack, I. Seismic System 2000. The Leading Edge, October 1996. 1127-1128.

Heath, R. Seismic of tomorrow: configurable land systems. First Break Vol 30, 93-120.

Heath, R. System 2000 Revisited. The Leading Edge, November 2009, 1314-1320.

Heath, R. Weighing the role of cableless and cable-based system in the future of land acquisition.

First Break Vol 28, 69-77.

Heath, R. Cableless seismic recording and a new problems for geophysicists. Drilling and Exploration World, Vol 21, February 2012m, 74-85.

Heath, R. Cableless seismic in difficult environments: Comparisons for explorationists. Drilling and Exploration World, November 2013, 87-112.

Lansley, M (2012). Cabled versus cable-less acquisition: making the best of both words in difficult operational environments. First Break Vol 30, 97-102.

Pellegrino, M., *et al.* Wireless and Wireline land 3D seismic in North Italy, SEG Convention 2012. ENI E&P.

Review SPG Conventions of last 16 years for author's talks on cableless recording.

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