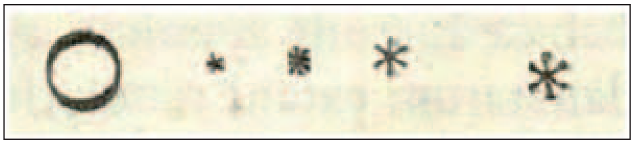
Seismic of tomorrow: configurable land systems

Regular *First Break* contributor Bob Heath* takes a hard look at what is required for land seismic acquisition systems to meet the requirements of securing natural resources responsibly.

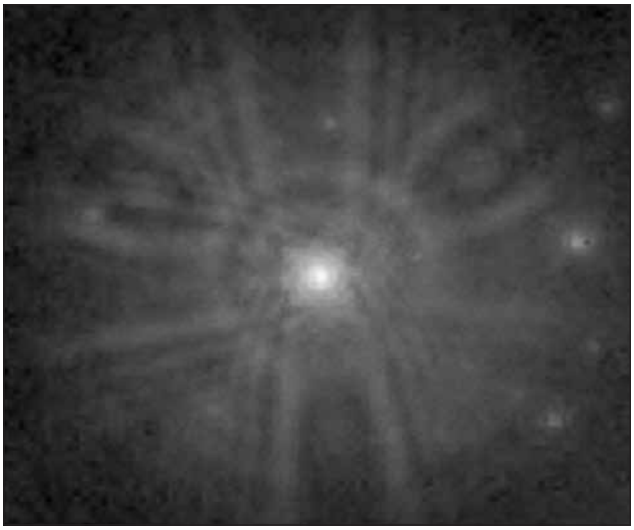
Early in the year 1610, Galileo turned his newly improved telescope to the night sky and made a discovery which was to shock him and the known world. He saw not one source of light where Jupiter was supposed to be but five. He looked again over the next few nights and noticed that four of these bright spots were moving fairly quickly with respect to each other. He realized that they were moons of Jupiter and gave them names of some of the lovers of Zeus - the Greek equivalent of the Roman god Jove. Galileo was not the inventor of the telescope but he had improved on its basic design to make these observations possible and in the process turned astronomy on its head.

Even though Galileo had made a tremendous breakthrough his observations were hampered by the quality of the hardware at his disposal. One such limitation was that his telescope relied on refraction rather than reflection of light waves to form an image. Once reflecting telescopes were invented – most think Isaac Newton should take the credit for this – less distorted images were available to any who could afford these devices and who were interested in the heavens.

Fast forward to today's stargazers who obviously have far better technology at their disposal and, as a result, the images are stunning. Thanks to hardware ranging from unmanned missions to the gas giants and the Hubble space telescope (after its teething problems), we now believe there are at least 63 objects orbiting Jupiter. We stopped naming them after Zeus's girlfriends, probably in an attempt to spare him further embarrassment.



Galileo's sketches of Jupiter and newly discovered moons.



Hubble trouble. Bad imagery from badly adjusted equipment.

Doing experiments

So what on earth (literally) does this have to do with looking for oil? The answer is rather simple: no matter what 'experiments' we want to do in science, whether we wish to study the cosmos or discover new hydrocarbon reservoirs, hardware places strict limits on what we can achieve. If you have ever tried to find the Higgs boson without a sufficiently powerful Hadron Collider, you will know what I mean. The limits in our own field of endeavour are related not just to an understanding of the underlying geophysics but also in terms of inherent restrictions in how seismic hardware can gather data to produce imagery of sufficient detail – to say nothing of how equipment dictates the cost and safety with which we can carry out our practical science.

However, in geophysics, just as in other branches of science, there are some who may not completely understand how these limitations arise. This is of course not intended to offend anyone but as it is our field which has the responsibility of securing natural resources for the benefit of the planet, I think we owe it to mankind to carry out our work as assiduously as we can.

The first recorded geophysical data gathering experiment was undertaken in Ireland in the mid-19th century by a Dubliner, Robert Mallet whom some now consider the founder of modern seismology. Mallet believed that energy in earthquakes was carried in waves, and he set out to measure their velocity. He buried a few pounds of gunpowder in the sand, stepped off a distance where he then placed his recording system. This consisted of a bowl of mercury on the surface of which he hoped to see ripples caused by the energy of the blast transmitted through the ground. He got out his watch and indicated to his son that it was time to take the shot. Mallet was pleased to see the ripples he expected and calculated a few velocities. Some consider that this experi-

* *rgheath@btconnect.com*

Use of Sigma system in South America. Courtesy Dan Braden.

ment was a failure as the velocities were rather incorrect. I think it is a bit unfair on Robert to expect him to have got things perfect straightaway. After all, the first instrumented attempt at measuring the speed of light was out by 25%. Coincidentally, Jupiter was involved in this task too.

I think Mallet's whole episode was a great success as he set out to do some novel science, invented the equipment to do it, and inspired others to go further. In fact, modern recording instruments are based on his architecture: they have a source and source controller, a timing device, and recording system. Indeed, ignoring the HSE concerns of having gunpowder and liquid mercury in close proximity, Mallet's equipment was more flexible than some in use today as it was so easy to modify!

Seismic yesterday

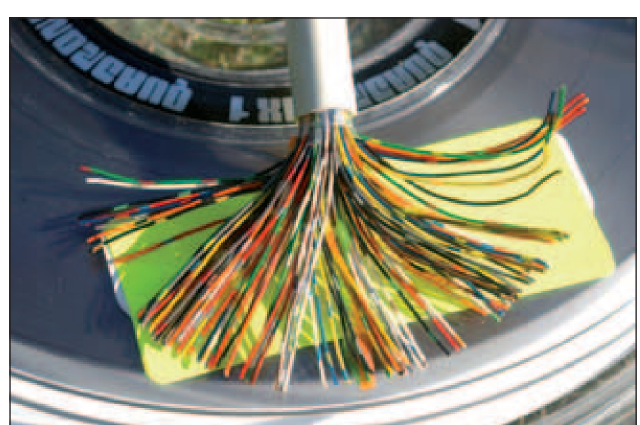
Let us do another jump in time to the era of 2D geophysical 'experiments', i.e., seismic surveys and the CMP digital era of the mid-1970s. A few basic calculations reveal that to do the job properly – to produce data of the highest quality and greatest daily productivity – we need at least three things. This first is electronic equipment of sufficiently high specification in such things as distortion and dynamic range, and the second is to have enough separate recording channels deployed so that signal and noise spatial sampling and offset criteria are met. As economics play a major part in such 'experiments' we also want to perform the work with maximum efficiency, so the third necessity is to have a couple of thousand channels at our disposal. But in the 1970s we did not have this luxury; we were lucky to have a hundred. Fortunately, hydrocarbon reservoirs were larger then, so despite our equipment and our badly under-sampled data, we still found oil.

This does not mean we were unaware of instrumental limitations versus theoretical and economic requirements, it just meant that we had nothing better to use. The analogue signal from each separate string of geophones had to travel in non-multiplexed solitude along its own dedicated pair of conductors to arrive at the recording truck where all the digitizing electronics were housed. Instantly we see a few problems which had to be dealt with if we expected ever to have more traces available: trucks would have to get a lot larger to house more electronics and, if each seismic channel needed its own pair of wires, then thousand channel recording would require cables with the thickness of your wrist. That is, unless some alternative approach could be found.

Nowadays we are regularly forced to consider the weight of cabling in seismic equipment, usually in terms of kilograms per kilometre. But for historical purposes this is not an especially useful figure unless you know how many seismic channels that piece of cable is carrying, so it is more valuable to think about the weight per seismic channel per kilometre. In analogue transmission, which utilizes one pair per trace, this value remains rather unchanged no matter how many pairs of conductors are used. To give this some perspective, a 48-channel cable, which comprised about 100 single conductors, came in approximately at 5 kg/ch/km. It would be little changed with a cable of 500 conductors.

In order not to end up with unmanageably massive trucks and thick cabling, more innovative alternatives were found which involved housing the digitizing circuitry in little rugged boxes and placing these along the seismic line, thus distributing the hardware out to the spread. This also meant that the output of the boxes would be digital information rather than an analogue signal. And since technology already existed to mix multiple streams of digital data onto one pair of wires, the number of conductors could actually reduce markedly. In this way, the seismic telemetry system was born. In rough figures, the cables used in the first such instruments, assuming a typical sample rate, could carry one multiplexed channel at around 0.3 kg/ch/km – more than an order of magnitude improvement.

This tremendous leap allowed scientifically significant changes in how geophysicists could improve image quality. This new technology could also expect a reasonable period during which it could be enhanced and further developed



1970's technology. Experiments limited by cabling.

before it would inevitably run out of steam. Within a decade of the first digital telemetry recorder becoming available, the industry saw 1000 channel operations become viable, with cable weight down further to under 0.1 kg/ch/km. I am sure there is no one in this business unfamiliar with the benefits of 3D acquisition, but it was only made possible by a series of improvements in hardware, one of the most crucial of which was reaching this weight per trace figure.

Just as with the early years of 2D recording when geophysicists knew quite well that equipment was not capable of doing the job properly, so there was awareness at the birth of 3D that what theory said we needed and what equipment allowed us to do were two very different things. Everyone understood we were under-sampling now in three dimensions instead of just two, and that the range of offsets and azimuths being recorded was far from ideal. Once again, it would be a matter of waiting until technology caught up while we did things the best we could under the circumstances.

However, this time the change had more to do with overcoming the economical and logistical issues associated with handling increasing 3D channels counts rather than any instrument feature. The problem was that the digitizing electronics boxes spread out on several square kilometres of survey were each rather costly and not as reliable as we'd like, so advancement was hindered.

The reliability issue was, and remains, a serious one in ever larger land cable recorders as they are serially dependent systems. This means full functionality of one piece of hardware can only be achieved when all other bits of equipment to which it is connected are also working properly. The failure of one bit means, like a house of cards with one removed, everything falls over. The likelihood of system failure of n identical elements is given by

$$P_{sf} = 1 - (1-P_{ef})^n$$

since $0 < P_{ef} < 1$, as n gets larger, e.g., number of channels, connectors etc., so P_{sf} tends to 1, = system failure.

Long range cablefree communication.

As an example, any single bad connector, damaged cable, or compromised ground unit on a line means that none of the channels behind the dodgy cable/connector are available to record. We do not lose one channel, we lose so many that we have to stop and fix things. Engineers in most other disciplines go out of their way to design out serial reliability for obvious reasons but the main attempts made to mitigate this vulnerability in a cable system just meant adding even more cabling.

Seismic today

The limiting factor for 3D a couple of decades ago was not so much the cable but the electronics. Fortunately, geophysics eventually could move to a higher gear thanks to changes in digitizing technology: away from IFP systems which required large numbers of individual and expensive components (such as analogue filters, floating point amplifiers, and successive approximation convertors) and on to one which could do everything on just one or two integrated circuits, thus increasing reliability while reducing cost.

The new-to-seismic technology was that of oversampling, sometimes called delta sigma conversion. Some felt that such devices, which on paper had much better figures for the things that geophysicists think are important such as harmonic distortion and dynamic range, directly produce images of better quality. But this view was not shared by everyone. The enhancements which started to come from oversampling convertors were more to do with how we could now afford to use much larger numbers of channels. In reality it was not the geophysical industry which came up with the idea of the oversampling convertor at all, which may be apparent in how their use in our type of experiments brings with it some drawbacks.

This is because active surveys use sensors close to the source which are subjected to signals many orders of magnitude larger than those at the most distant parts of the spread. Yet when using oversampling convertors, the same gain is usually set for all channels, and this is generally determined by a level which will just stop the digitizers nearest the source from being swamped with too high an input voltage – called overscaling. The benefit of this is that the full dynamic range of the convertor can then be used near to the source. However, the disadvantage is that as the digitizers get ever more distant they will use less and less of their available dynamic range. In contrast, the old IFP-based systems adjusted gain on a sample-by-sample basis and the full dynamic range of the convertor was always used. So nowadays, geophysics would be better off thinking about 'averaged utilized dynamic range' than a theoretical instantaneous dynamic range which mostly is not used. The move to oversampling converters is an example of a change in instrumentation giving with one hand while taking with the other. The short-term advantage was definitely worth having but let's not fool ourselves that 24-bit delta sigma is the ultimate in geophysical instrumentation and always leads to the best possible experimental results.

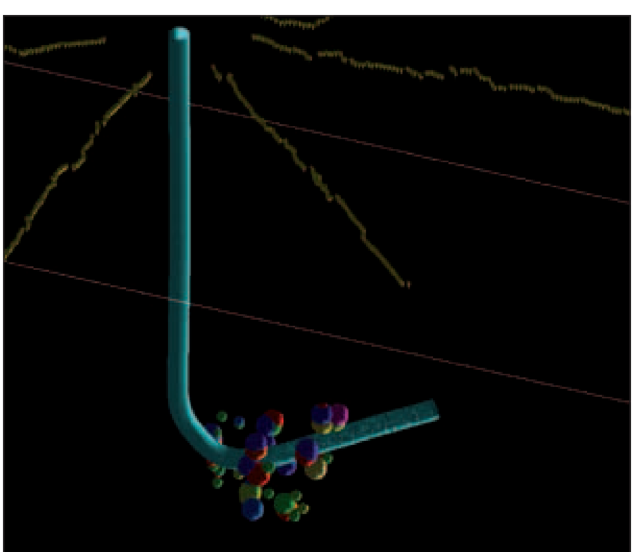
24-bit oversampling convertors have been used on land for about 15 years and only now are we getting around to trying to claw back some of the average dynamic range we lost, which is being done by use of 32-bit convertors. The value of such technology is not that you get eight more bits of data because this is not the case. It is that the average bit utilization can be better, the range of input signals larger, and, being more modern technology, use less power which is especially advantageous. And it appears that 32-bit has come in the nick of time because passive recording, or any experiment where precise values across a spread are important, benefits significantly. Some hold the view that the industry needs to develop low noise, gain ranging-based digitisers to take our experiments to the next level but I am not holding my breath.

It is ironic that the seed of cable systems' demise was planted when 24-bit convertors became readily available. Crews could be brave enough to put out larger channel counts, but they then also found themselves with onerous amounts of telemetry cable and began to pressure manufacturers to find ways to reduce the total weight. But the way to make a cable lighter is to reduce the numbers of conductors and limit the amount of plastic in the jacket, both of which are at odds with reliably operating with more active traces. So this was writing on the wall for cable telemetry as the future approach to all geophysical experiments. To enable some types of ultra-large channel count experiments, it is possible to use fibre-optic cabling which is light (<0.001 kg/ch/km) and really can carry huge volumes of data traffic. But this hardware is not likely to be used as general purpose instrumentation as its maintenance does not lend itself to most field conditions. This does not mean that it is impossible to make cabled systems works with tens of thousands of channels. It just means that mega-systems based on such technology will increasingly be seen as rather specialist and expensive. They also tend to require significant numbers of line crew to keep them up and running compared to the alternatives.

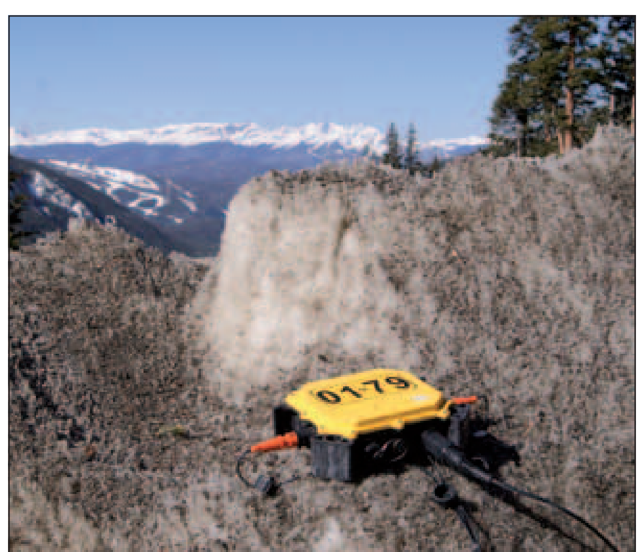
In summary so far, progress in the practical side of our science has been made by different kinds of technology being bent to our needs. The advance which allowed us to jump from under-sampled 2D's to the possibility of properly sampled 2D surveys required taking electronic hardware from a centralized location and spreading it around, along with the data telemetry systems which linked it all up. Then, improvements in that basic technology permitted a move to simple 3D acquisition. Finally, a change in electronic componentry allowed 3Ds with scientifically meaningful numbers channels, even if it reduced dynamic range in some parts of the survey. So what is the technological leap which will let us make the next step?

It seems most unlikely that digital telemetry cables will play much part because cable weight, in terms of the all-important kg/ch/km figure seems to have decreased as much as it can. This is demonstrated rather well by how almost all cableless systems on the market, even though they are for the most part new products, are lighter than almost every mature, cabled system for most applications (Heath et al., 2010). But we would be missing a trick if we thought that our next technological leap will be based solely on how light it is.

Nowadays seismic instrumentation can benefit more than ever from hardware developed in other industries, so it is essential to ask geophysicists what they require for their experiments of tomorrow before we put all our eggs into one technology basket. But there's the rub: we now live in an industry already replete with new ideas which people want to try, but no one wants to buy several different types of instrument to undertake it all. So from now on we must think about equipment which can be configured to do



Monitoring fracing with surface arrays. Courtesy Geogiga.



Configured instrument technology for tough terrain. Courtesy Scott Burkholder.

almost everything imaginable: properly sample noise and signal in 2D and 3D whether for shallow mineral surveys or deep hydrocarbon exploration, acquire all the offsets and azimuths we need, rapid deployment and permanent 4D operations, micro-seismic and frac monitoring, ReMi, experimental and engineering geophysics, mine planning and earthquake seismology. In other words, we're talking every type of active recording as well as passive, and mixtures of the two. In fact, the needs of the passive experiments are generally greater than those of active recording while combined active/passive is a major growth area.

Seismic tomorrow

Being able to undertake all these types of survey with one piece of hardware will not be possible if we build systems the way we have before and, with the exception of some niche markets, it is no longer good enough to develop instruments which cannot multi-task. The solution lies in the notion of component-based configurable geophysical hardware. It is an idea we can borrow from other industries. For example, hi-fi fans tend to buy a pre-amplifier from one supplier, a power amp from another, loudspeakers from a third, and so on to configure the ideal system. If you build your own PC, you can buy motherboards, processors, hard discs, graphics cards etc., all from different suppliers to optimize performance. In both cases, these bits plug into each other because there are standards. Major sub-assemblies are made with a sort of irreducible complexity, and there is no reason why geophysical hardware cannot evolve this way too. Then, a universal system with an ability to undertake the widest range of experiments simply requires putting together the right parts.

Let us compare this with modern land cable systems. Here, the distributed channels are essentially an integral part of the central system. One cannot work without the other, so when one bit stops working, due to the serial dependency of such hardware, the whole thing tends to grind to a halt. As if this was not restrictive enough, things are worsened by the way the source control is often tightly integrated with the recording system, making the whole shebang one great big piece of hardware. Superficially this looks like it has advantages but it rather depends on how easy that one big piece of equipment is to adapt when you want to do something it wasn't initially designed for. It is rather difficult to take just a part of it and make it work side by side something else to perform some new task. Therefore, current systems, like dinosaurs a long time ago, find rapid adaptation awkward, making new approaches to exploration more difficult and, therefore, less often undertaken. This phenomenon may also stifle the imagination of the geophysicists who can envisage new experiments, but because the hardware cannot keep up, why should they bother?

Configurable systems do not impose their will on the user. Such equipment considers each recording channel or group of channels as separate to the next group, so there is little problem of serial dependency. The central recorder itself (not that a configurable system always needs one, a properly configured iPad could work just as well) is comprised only of appropriate parts as determined by the experiment in hand, and all independent of the remote channels. The source controller also comes with different options depending on how many sources and what type, communications, navigation and QC issues, etc. And none of this is a hindrance to high levels of integration or performance, actually the opposite is true. To a large extent, it is all plug'n'play. We can go even further to consider line equipment and how it should be broken down to provide even more flexibility.

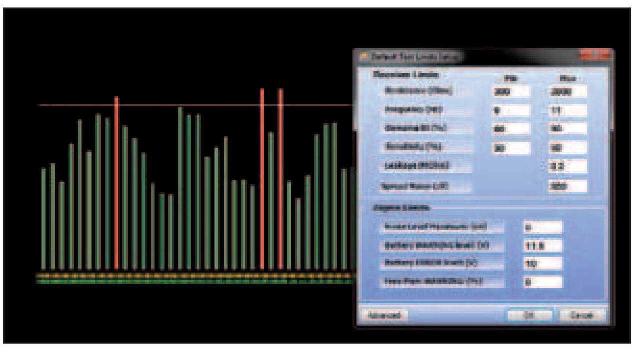
Microseismic monitoring. Courtesy Spectraseis.

Starting with digitizing units, these need to come with various input interfaces enabling a range of single or multi-component sensors to be used, either powered or not, and if powered, then they must enable control of that power. Ground stations may offer different numbers of channels per unit, to allow for everything from point receivers and standard geophone arrays, through 3C and 4C. Next, the user must decide if it is appropriate to use telemetry cables or do without for all or part of the survey. If working without cables, this should not mean the operators are is forced to record blind. They should, if desirable, be able to choose some wireless technology which allows cableless connectivity at some level.

As varying wireless communications systems have rather different characteristics in terms of licensing, range, bandwidth, and so on, users may select what they think is most appropriate to permit, for example, health check, QC, noise, and status monitoring of channels, or the return of the full seismic record. The same technology would allow remote control of deployed channels. Low bandwidth technologies include mesh radio networks and cell phone interfaces while higher bandwidth possibilities come from using some form of

iPad vibrator application.

Cellphone interface to Sigma system. Courtesy iSeis.



Cableless noise monitoring using only mesh radio technology in a configurable system.

VHF timing configuration for when GPS timing not available.

2.4 GHz Wi-Fi, or appropriate forms of compression exploiting any space-time coherence of data (Savazzi et al., 2011).

Next is the essential issue of data time-stamping. Cable telemetry systems tend to handle timing by sending out synchronization information along the cable. Cableless systems must cope differently – most employ a GPS receiver in each ground unit and this works well most of the time. But there are times when GPS is intermittent and those when it is non-existent, so if users think this is going to be the case they would first select some method of inter-ground unit communication which can warn when GPS was not available. They will then want timing alternatives up their sleeve, such as a more stable internal clock and the options of VHF radio frequency-based timing. There are other methods of timing too which allow, for example, use of cableless systems under water based on a series of repeated shots for synchronization and to convey operational commands.

The transmission of large volumes of real time data wirelessly remains technically challenging, so what can be bolted on to the basic universal system chassis to achieve this? It is important to understand how things like terrain will affect the technologies which may be called into help here, so there can be no single solution. Generally, the only licence-free option for real-time is to use the 2.4 GHz band and, while this is often very difficult to make work well in tough conditions, it is possible to use this band in different ways to help overcome the problems with each type of location. This is why a variety of Wi-Fi subsystems must also be selectable by each operator.

Armed with an understanding of what each real-time recording mode offers, users can decide how much of the spread they want with this feature because high bandwidth always comes at a price. This implies that the universal system must be capable of being used in different modes in different places on the same survey. Further, operators may ask for real time data return but sometimes only want to be sure that equipment is working and this level of communication can be achieved with technologies such as mesh radio networking. The important thing is to have the choice and know the advantages/drawbacks to the geophysical objective of making that choice.

Next we must consider how to get our hands on the data if it is not transmitted wirelessly straight to some central location, the so-called harvesting process. Unless we want to incur greater than necessary expense, this task should not interrupt acquisition, i.e., recording into a channel must be able to continue while data is being taken out of it. As some experiments may want to record large volumes of data before the harvesting process commences, this means that memory capacity must not be a limiting issue. Large internal memories as well as significant ruggedized USB-connected external memory capacity should be options. However, in recognition of the fact that one location can differ very much from one just a few hundred metres away, different means of harvesting must be on the options list. No Wi-Fi protocol was designed with seismic data harvesting in mind and one can encounter surprising limitations in transfer rate in some circumstances, especially when attempting to connect to multiple boxes at once, with data rates potentially dropping well below what one may expect from the basic 80211 specification. So, once again acknowledging the potential problems with Wi-Fi connectivity for harvesting, the data collection choices should include a simple connection between ground unit and harvesting computer by a small hardwire link such as an Ethernet cable as well as Wi-Fi. The toughened external USB memory can also serve as a very rapid and WiFi-free method of harvesting and is already a favourite of some bird dogs on recent operations.

It appears that some modern systems have come to find themselves rather a little too dependent on Wi-Fi. This technology was the natural choice for cableless kit because it was already well developed and mostly licence-free. However, the price to pay for this convenience is the need to operate at 2.4 GHz – the frequency of microwave ovens, and the wavelength at which most energy is absorbed by water. So the idea of using a radio frequency (actually a radio band about 83.5 MHz wide) whose main claim to fame is that water molecules soak it up, and is only useable with a very low power level when it comes to radio communications, does not necessarily bode well for the universal seismic instrument. This is why there must be a variety of ways in which this frequency can be used in the configurable system whether for real time transmission, status/QC-only types of work, or for harvesting.

VHF timing configuration for when GPS timing not available.

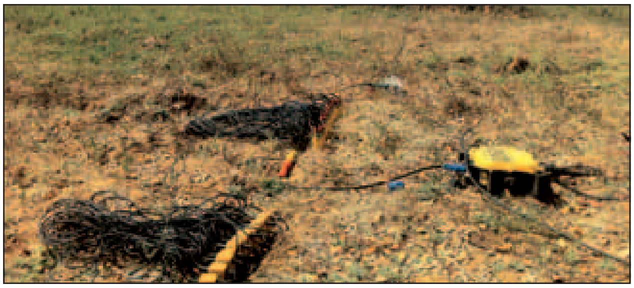
Cableless noise monitoring using only mesh radio technology in a configurable system.

Even if sceptical about digital telemetry cables as the main approach to geophysical experiments, these cables do not have to be thought of as being in a *cul de sac* of seismic technology. They may still have a part to play if they show some signs of greater flexibility or become part of a mix of other methods. However, the era when cables can only be run in straight lines, meeting at right angles to other lines of cables which end up at the recording truck, must hopefully soon be behind us. If cables are to join the ranks of the components available in tomorrow's systems and feature in tomorrow's experiments, they also need to be useable in small or large local area networks, which themselves can be communicated with by other methods, perhaps cell phone interfaces or directional Wi-Fi.

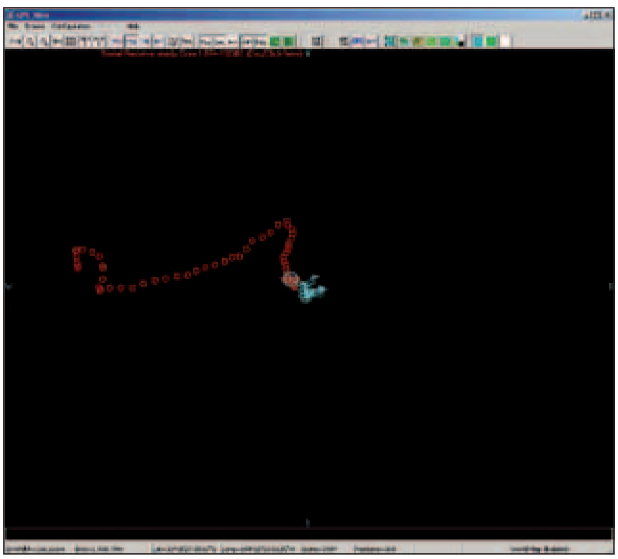
A natural place for any configurable system is to work side by side other technology, for example, with the rigid lines of cables just referred to, in order to add versatility to the operation. But whatever cabled system you favour, you will still appreciate the flexibility of the component approach with its options in timing, monitoring, harvesting and so on. Here, one has to exercise some caution, as ideally the result of the recording will be one set of data tapes not two, and all data having the same filter response. If the cabled system to which the configurable system is partnered can only output SEGD, then life can be made unnecessarily difficult as SEGD files can only be completed once all data is available for each shot, which is not always convenient with cableless acquisition. SEGY still seems to be the preferred format of most data processors as well as the most-user friendly for configurable systems, but in deference to all experimenters, a configurable system will output SEGY and SEGD.

But the capabilities of such recorders do not stop at helping cable systems show some overdue versatility, they can also be used with any cableless system which did not come with all the configurable bells and whistles one may have wanted. For example, some cableless kit forces the user to shoot blind, which may have advantages in some places but elsewhere not so much. Configurable systems can add vision and security to shoot blind systems when the two are mixed on the same spread.

A major issue nowadays, as hinted above, is that one may operate in areas where hardware goes missing if no one is there to keep an eye on it. If the ground equipment happens to have a lot of important unharvested data still in it, such theft is much more costly than simply the loss of the hardware itself. Fortunately, there are quite a few options for security and theft prevention, both off the shelf and bespoke for the plug'n'play configurable recorder. The main priority is to be alerted as soon as there is unauthorized movement of any equipment rather than find out much later. This may easily be done by use of technology; for example, the mesh



Scorpion and Sigma system dual operations. Courtesy NGRI India.



Tracking equipment remotely. Configurable security.

radio can, within limits, tell the operator where the ground unit is at any time, and whether it is on the move.

The right tool for the job

Whichever type of experiment we want to do, and whether we have to work on easy gravel plain desert or much more challenging environments, the hardware must be appropriate. Given the cost of geophysical equipment, most users do not purchase more of it than they have to, or a lot of different types, so they are forced to use the same technology over and over again no matter what the experiment is. This is rather like buying a 30 year-old family saloon car and expecting it to do as well across all terrain as a modern 4 x 4 and compete with a Formula 1rqacing car. Operating in mountains requires equipment with different characteristics from the ideal jungle system. Operating in mountainous jungle needs something else again. The modular system can be configured to work equally well, doing any types of survey, in all conditions, on land and shallow water/TZ.

Future source control

It is not just in the recording that we want flexibility. Sources and source control, and all that goes with them, are in need of an urgent face lift too, along with the QC and communication part of the hardware set up.

Shallow water operations. Courtesy Eagle Exploration.

Starting with Vibroseis, there are plenty of different types of operation – from single fleet, through much more sophisticated sweeping where sources are separated in distance or time; phase-encoded sweeps, and on to 'free for all' types of acquisition, plus the QC and navigation that goes with all of this. Even some of today's most modern equipment is surprisingly lacking in a few of the simpler tools, for example, in how similarities can be undertaken, or limits in communication with large numbers of independent sources. All these issues can be rectified by taking an open architecture approach.

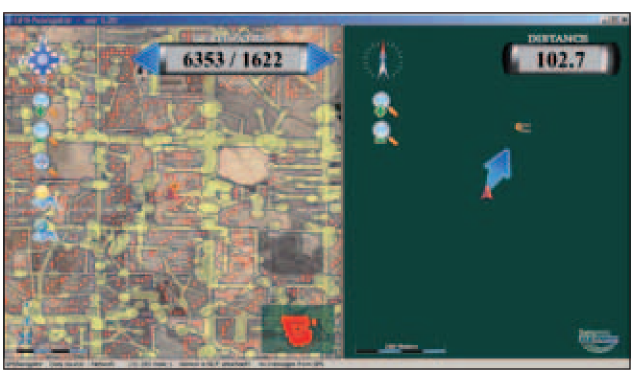
Yet, relatively few vibroseis crews use all the source testing and productivity-increasing tools already available to them. Most acquisition is based on the premise that the energy going into the ground is related to the weighted sum ground force signal, but rarely do crews actually check what vibrators are really doing, for example by use of load cells or more advanced testing techniques. Merging load cell data with the active files, and especially into 4D data sets along with better integration of larger numbers of auxiliary channels, has already been made possible by the configurable source control approach. As well as recording additional important attributes of the vibrator, plus those which are in the process of being defined by researchers, using Vibroseis for 4D often requires far higher accuracy in position and much better navigational tools. Such experiments look for very tiny changes in the response of the reservoir, yet often do not bother to record all the far larger changes in the behaviour of the source itself. Configurable source controllers address this.

Controlling the vibes is one thing and monitoring them is quite another. The first requirement of the configurable source controller is that it does not restrict us as to the number or type of recorders that can be used. Maximum flexibility in source control comes from being able to perfectly adjust recorder for the acquisition in hand. The next issue is that communication between vibrators and recorder can only be improved by taking a different approach to how radio channels are accessed, allowing any radio to be used including older but higher power analogue radios and repeaters. This is made much more difficult unless the hardware architecture is open enough.

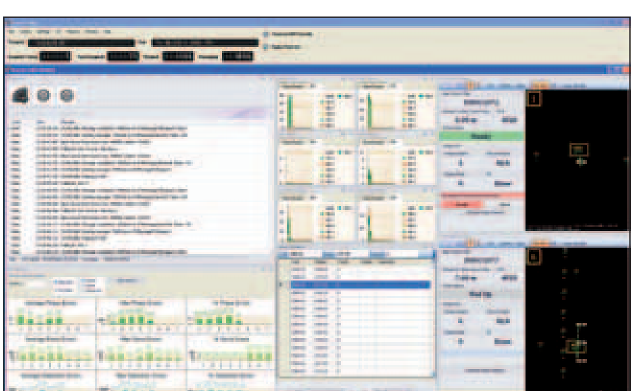
I suspect that it will be the source side of our business which attracts the most research in the coming years because we have already hit a number of limits. Sources have reached the stage where analogue cabled systems were more than 30 years ago. To improve things we were looking for recording trucks to get bigger and cables to get much thicker so we could handle more channels. But just as recording technology found a different way to progress, now it is the turn of sources. Vibrators are already as heavy as they can reasonably be and productivity levels of 50,000 VPs in a 24-hour period may be difficult to improve on. It is time to get smart.

All sources are inefficient in the conversion of primary energy into the seismic signal. Dynamite is only 2–8% efficient depending on depth, charge size, and ground conditions and vibrators have nothing to shout about either. By increasing the efficiency of conversion more energy can be transferred to the seismic wavelet giving a higher signal strength for the same level of energy input. In order to do this, we firstly require a better understanding of the vibrator or impulsive source mechanism and its interaction with the ground. This improvement in knowledge is not likely to come over night, but it is actively being worked on and source controllers need to be able to change quickly to adapt, once again meaning that configurable systems are needed.

Getting smart with vibrator test and performance research.



Advanced navigation control for increased accuracy on 3D and 4D.



Impulsive source control, configurable features for safety, source source type, etc.

Conclusion

This industry has a poor record of adopting new technology, and even being able to adopt new technology. For example, when PCs first came out, some of the major manufacturers considered them little more than toys as PCs did not fit in with those manufacturers' way of thinking. We have the smaller system developers to thank for getting the industry to see their value. The industry was also slow to buy into cableless systems, seeing cable as having to take the starring role for decades to come. However, given the historical cost of a recording system or the profits to be made by a successful hardware manufacturer, it is no surprise that product developers try to hook contractors into their particular system approach. And it is no shock that contractors want to make the most out of whatever they've invested in and will bid such hardware for any and all work possible. After all, being a seismic contractor is not often a profitable business, at least not compared to being a successful manufacturer. Open architecture configurable equipment in exploration geophysics, something we have long enjoyed in the hi-fi or PC world, helps to make geophysical life much less risky for all involved.

Therefore, the good news is that every section of this business can win with the configurable system approach. Any manufacture can choose to make one component or all and such competition can only accelerate our science's progress. Contractors can purchase the basic parts plus the functionality they want in order to do the type of acquisition they specialize in, and when they want to do other things they do not have to buy a whole new system. When it's time to advance, they only need to upgrade the part that is then reaching obsolescence. Survey planners and data users, as long as they understand all the options on offer can design their acquisition knowing that the hardware is no longer the limiting factor, and then go out to tender to all the companies who offer the right bits of the system to pull off the survey. The even better news is that this is not science fiction but already happening. Naming no names there is at least one recorder and source system that has all the attributes of the equipment described, and can rightly claim to the be first technology in the world with the flexibility to take on almost any experiment anyone can dream of. Robert Mallet would be pleased; he would recognize such instrumentation, like his, as equipment which can be used to take the science further

Seismic system optimization. The shape of things to come.

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