A BRAVE NEW SEISMIC WORLD

What are the limits of hybrid seismic recording?

BOB HEATH, iSeis

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Over the last decade there have been many column inches devoted to the subject of the differing types of instrumentation available for land seismic data acquisition. There are groups advocating the use of recorders based around digital telemetry cables, and those who cheer for hardware without cables, so-called cableless systems. The latter type of product comes in multiple favours often broadly differentiated by whether they have some built-in means of communication.

During this time, all sorts of claims and counter claims have been made for all these different acquisition approaches. Not long ago some were prophesying that the greater majority of land seismic data by now would be done without employing any telemetry cable or functionality at all; clearly such statements were a bit premature. However, in fairness to all sides, it seems currently there are winners all round. The number of cableless seismic channels sold is about one million, which is not bad for a relatively new technology while, to prove there is life in the more traditional way of doing things,

Sigma test area. Quantifying deployment effort, range and bandwidth for different set ups. Dry straw bale presents very different absorption characteristics to wet straw.

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This willingness to see the benefit in different recording approaches while finding out for ourselves what works well where, is leading to less polarised views and increased ability to investigate what more could be done for us by new hardware if we just gave it the chance. There is now enough experience internationally in the industry to appreciate what is proving to be the best tool for each job, while at the same time seeing more clearly the drawbacks each may come with. Forgetting for the moment that each manufacturer wants to sell more of what he makes, at the expense of what the competitor makes, is there a place for all comers in a brave new seismic world, do we still need equipment which can do more and more – in other words, the hybrid approach?

Sigma crew preparing for survey in jungles of Indonesia

CellSeis Geophysical

TREND TO INTEGRATION

In the first few years of this century, users made bold statements about how they wanted to see things turn out 'for the benefit of the industry' and views were rather black and white. If you ask the same group now how they see the next ten years, many will answer that we need to make use of all acquisition technologies, that each has their benefit, and that we will not see the complete disappearance of cables for a very long while. The word you hear quite often in this respect is that we need 'hybrid' acquisition where we can configure any recording technology to take on many geo-tasks.

Some would go even further and say that contractors should be able to use any bit of equipment made by one manufacturer along with any other bit(s) made by others, e.g. company A's cable system with company B's cableless system

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Sigma cableless system trials with one cabled system and two other cableless systems.

and company C's source controller. This is based on the notion that we have mobile phones and laptops which can take on multiple roles and also benefit from certain standards (software or hardware) which allow them to plug in a variety of useful external devices. There is thus the belief that seismic equipment of all colours and hues should offer the same flexibility.

To some this seems a naive concept. Many manufacturers still deliberately make as much of their equipment as possible only work with peripherals supplied by that same company. In extreme cases, some even try to organise things to be so inflexible that their hardware can only be conveniently powered by that company's own batteries. Other suppliers see the benefit of having much more open architecture, applying not just to recorders with their sub-components like tape drives or external hard-drives, but also to the source control systems which are of course just as essential to any active seismic operation.

Fortunately, the trend is towards more integration and more 'integratebility' and this can only do good to the industry as a whole because it is not long since each manufacturer trying to do everything itself led to higher hardware prices and less functionality. For example, geophysical manufacturers used to build their own analogue to digital converters; now most do not, as other industries do a better job which we can take advantage of. Similarly, seismic recorders used to come with control systems entirely constructed in-house and there was no other way to build and operate that instrument. Then computers with agreed standards became available and now everyone makes use of them. This has the great advantage that operators can, if they desire, effectively buy replacement seismic hardware from the wider electronics industry, and even perhaps from Amazon or eBay.

But the future will require much more mix-n-match flexibility than only being able to use a few components here and the odd PC there. Hybrid systems should be able to swap many more of their essential components and entire subsystems even down to some of the ground electronics. The reason will be, whether everyone likes it or not, that the electronics business servicing land seismic acquisition is minuscule compared to many other electronics businesses and we no longer set many of our own hardware standards. We expect no less from our domestic electronics - the Blu-ray player, widescreen TV, surround-sound system, and loudspeakers, all can come from different makers and all work nicely together.

The main businesses we are likely to benefit from include those oriented towards ethernet hardwired and cableless communications as they are the outfits spending billions annually around the world to improve and accelerate the passage of data. Since that is a major part of what many seismic systems have to do, then not to be able to take advantage of all that R&D is going to condemn any go-it-alone manufacturer to a very uncompetitive position. The corollary to this is that manufacturers who are happy to see the implementation of off the shelf technology, perhaps by simple plug-in, are going to benefit considerably while not having to fork out fortunes on their own developments. There are good examples of this already in our industry and it is unlikely that we will see less of this sort of thing as the next few years go by.

The types of locations where cableless systems excel are many and varied

THE HYBRID APPROACH

When it comes to hybridisation of exploration instrumentation, the ideal would be the ability to 'use anything with anything else'. For example, it is very useful to be able to employ any cabled system with any cableless system and with any source controller and not lose out on any functionality that would be available if equipment from only a single provider had been used. And one major seismic hardware manufacturer is already leading the way by building a range of equipment which can be mixed and matched with other manufacturers' products to a level which is only limited by the flexibility and openness of those other systems. However, a new level of hybrid-ness being sought is the ability to use different cableless systems together. But why does anyone want to do this? The answer lies in the need for better data quality, lower costs and even more operational versatility.

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More and more crews in the future will make use of multiple recorder types. It seems that the only place where cable recorders are going to be safe from someone wanting a cableless system to share the spotlight is in the area where two conditions simultaneously apply: where cables are logistically very easy to handle and where channel counts are to be measured in many tens, or even hundreds of thousands. The reasons for this is that where cables are difficult to cope with, for example because of weight or potential cable damage, then one tends to find a way that you do not have to handle them any more, which means turning to cableless systems. And cableless systems do not always offer simple ways to work with huge channel counts compared to the convenience of the data coming along real time in a cable to the central system. In all other places, cableless can make a good case for being at least as good as cable, if not much better.

However, cableless comes in many varieties, and the types of locations where it can excel are also many. Therefore, it is unlikely that one survey is best served by a single cableless approach, so where possible it becomes very convenient to mix cableless systems and offer a different type of hybrid approach. Recently there have been some interesting developments in this regard.

The initial main beneficiaries of the growth of cableless have arguably been those systems which never designed in any method of communication. These have come to be known as shootblind systems – some refer to this as 'operating in the dark'. The proposed advantages of such systems over those with a reliable communications capability were lower weight, cost and power consumption. However, with experience, each of the three claims has been disputed, and some problems appeared which were not so obvious a few years ago. It is not impossible to make the case in some operations that shooting blind can require expensive and heavy peripherals not needed by the cableless alternative, and that shootblind hardware cannot be remotely controlled so may end up using more energy and thus need extra batteries. Both of these mean more weight and cost, and greater energy usage.

But these are not the only issues causing some to rethink their cableless operations strategy and the use of more than one type of cableless system in a single hybrid operation. A major concern is that shootblind systems, as well as those designed with communications which tend not to work well in all environments, risk coming back with substandard data, which, it is claimed, is much more difficult to process and makes it awkward for end users to know if contractors have complied with acquisition contract terms until too late. This was highlighted at the 2012 SEG where ENI gave an interesting and revealing paper, where they did not look at different types of cableless kit but compared cabled and cableless systems with the same crew. They were operating in a typical European environment (difficult compared to the Middle East but probably far easier than much of South America, India or the Far East) but nevertheless seemed to

Sigma cableless recorder with high bandwidth hyMesh antenna side by side a shootblind cableless system in a hybrid operation.

have difficulty in making the communications work on the cableless system they were employing. What was needed was to add sight to cableless systems which, by design or otherwise, can be shot blind.

TESTING COMPROMISES

The problem they had discovered is one that radio engineers already knew; that in wireless systems there are always trade-offs. When working in the exploration environment the three main issues to be weighed up are data rate, range and ease of deployment. If one does not transmit too far, then the receiver finds itself able successfully to 'see' more bits of data, i.e. high bandwidth. As the range increases, the strength of the radio transmission picked up by the receiver diminishes and it becomes more difficult to see high bandwidth data. This can be mitigated by increasing transmit power, using directional antenna, raising antenna further off the ground and so on, but all those involve extra deployment effort. So we see how compromises can be made if the hardware lets them, but never at zero cost. Possibly the hardware referred to by ENI did not support much communication unless a level of deployment effort was used which would have been impractical for that particular seismic operation. So how do we know with cableless systems – those with inbuilt comms capability – what will work and when, and how useful they will be on a hybrid crew?

Cable system manufacturers traditionally always reported in their specifications such things as the maximum number of channels that can be deployed in a simple receiver line and how many batteries are needed to make this work for a certain period. Everyone knew that these values could not be ignored or the system would tend to fail. Cableless systems do not need to talk about such figures but this does not get them off the hook of describing where their chosen wireless technology may run out of steam in any particular exploration environment. It is of course the case that it is much more difficult with cableless to specify actual numbers because they vary quite wildly, but this should not excuse them from making some sort of effort to do so. And if the industry wants to know what systems can be matched with others to create an ideal hybrid instrument, then some knowledge of this 3-way compromise is essential for each system.

However, the problem is that most such systems rely on transmissions using the 2.4 GHz licence-free band, and that this particular frequency is very readily absorbed by water molecules, interfered with by various other man-made transmissions, and blocked or reflected annoyingly by a wide variety of moving or stationary objects. For example, a medium-size tree branch can interfere with the passage of the signal simply because its dimension is inconveniently similar to that of the wavelength of the 2.4 GHz signal.

So if a seismic crew is working in flat desert with predictably dry weather, then it will get the maximum performance from a cableless system. But if the same crew goes to a rain forest, then things will be very different. Not all end users know this and it seems some have already suffered bad surprises. In fact, with today's technology, it seems that if you want high bandwidth data in tough environments, especially with longer trace internals (the range part of the three-way equation) then you may have to be prepared to put a great deal of effort into making

SRD-Sigma Mesh WIFI option: high bandwidth cableless communication unit.

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Hilly forested areas present special challenges to all instruments. Flexibility is the key such that a recorder can succeed in any environment with or without another recorder. Sigma with directional WiFi plug-in option.

the system work in the feld. It may then be that users fnd such effort not much less than it would have been to use cables in the same area. One solution is to compromise on bandwidth – fortunately the seismic acquisition process makes it easy for us.

In the feld, seismic data coming from deployed ground units to the central recorder comes in two types which helps the hybrid approach. There is the seismic data itself, comprising the vibrations being refected from the earth's strata, and there is the ancillary data which represents the health of the equipment such as battery voltage, the condition of the planted sensors, the status of the ground electronics and test results of the same electronics, levels of ambient noise and so on. The former type of data represents a very much larger volume of information than the latter, but the latter is what we need in order to know that the hardware is all working correctly and that the noise level is acceptable. So if we use wireless comms systems which only need to handle the data rate of the latter, then we have solved part of the problem.

Much of the rest may be helped by the topology of how the data is transmitted. As we have already seen, trying to send data over long distances is not an easy thing to do as ranges can be too great to maintain data throughput. So a better approach is to transmit from box to box in the feld, being careful not to have too much data, then funnel through one point as we would then be back possibly to the issue of data rate. Therefore, the use of mesh radio networking sending back everything (except the actual seismic data fle) across a network of possible communication routes provides a solution to the great majority of what users need, especially those looking for a hybrid solution.

TESTING COMPROMISES

If the ideal hybrid system could beneft from short-range multipath wireless communications, we must still be sure that the links work fawlessly in tough seismic environments, so we must run a large variety of relevant trials. Some examples of this were recently carried out by iSeis company in their test area in Ponca City, Oklahoma. A number of seismic channels were set up on different locations within a large trials area, including fat felds, rolling elevations, various cereal and other plantations, locations with rapid elevation change and areas of forest of varying thickness. The climate in this part of the world, ignoring tornados, varies from very hot and dry to very wet, with sudden changes, making it easy to test set-ups simulating a wide variety of feld environments.

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Gulrap and Sigma systems working together

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In the fgure on the frst page we see a directional antenna transmitting through a dry hay bale. As there are few water molecules to impede the path of the 2.4 GHz radio signal, communication was successful. After a heavy rain storm, the hay bale is soaked and it is very much more diffcult for the radio to penetrate, which would mean a much reduced range to the next ground unit and/or much reduced bandwidth. Similarly, problems can occur with deployments in forests where the green leaves on dry trees can also only be penetrated by directional antenna if high bandwidth is required. To be successful in coping with such a range of terrains and climatic conditions, we may need a variety of antennas or communication options, all with the ability to easily connect to ground units. So in terms of hybrid equipment, i.e. the type where everything can ideally work with everything else, what does this tell us?

Many seismic survey areas of the world are not uniform. One part may have population centres such as villages, transport routes and so on, which are within a kilometre or two of scrub, or paddy feld, cereal plantations or forested valleys. In some of these places cables would be our best solution, in others we can settle for cableless systems with little or no communications, and in others we could only use cableless systems which are able to monitor what is going on perhaps for security reasons as well as data quality. The ideal would be for one system to offer such confgurability, and the alternative is to be able to mix equipment which can provide what is needed for each part of the survey.

But the issue of hybrid surveys is not just about recording equipment. We also want to be able to use multiple sources: larger vibrators where possible, smaller where the larger vibs cannot go, perhaps dynamite and/or accelerated weight drop in others. So we need multiple source types controlled by appropriate source control and monitoring attached to a central system which can handle all the different types of recording system. This would be a true hybrid approach. It is exactly what benefts oil companies and other data end users as they would then get the right tool for the job, not just on a contract by contract basis, but also on a channel by channel, hour by hour basis. The Sigma system appears to have come the closest to offering such extreme levels of fexibility. Some initial hybrid uses of this recorder were in operations with a cable system, which was deployed where it was easy to put cables and the Sigma system was used elsewhere along with another cableless system. Four different sources were used. The data sets could then be flter matched and merged.

But more exciting in terms of the hybridisation of exploration instrumentation is the use of the same system, with its assured communication capability, side by side with shootblind cableless systems. Here Sigma's ability to transmit noise, system health and QC data back to the central system in real time, coupled with an ability to be deployed at the channel density necessary on an otherwise shootblind spread, provides insurance to the operator that data recorded in the dark is not all going to be contaminated by high levels of noise. Where the end user wanted more bandwidth, it was just a simple matter to add industry-standard communication systems to provide enough bandwidth to send the full seismic record back as well.

BENEFITING THE INDUSTRY

So we see that hybrid systems may mean different things to different people but the most important issue is to have hardware with the fexibility such that its 'hybridness' can be used to maximum advantage. Sigma is undoubtedly the frst such instrument helping both cabled systems, and cableless systems with no or limited communication ability. If it continues with the trend it started, it will force other manufacturers to be less closed in their approach to technology and, in the end, that is what will beneft the majority of this industry.

ADDITIONAL INFORMATION

REFERENCES

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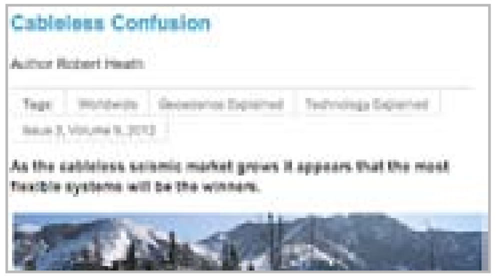

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REFERENCES

Cuinas A. et al. A comparison of radioelectric propagation in mature forests at wireless network frequency bands. Dept. Teoria do Sinal e Communicacions, Vigo University, Spain.

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

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

Heath, R. Cableless seismic recording and new problems for geophysicists. Drilling and Exploration World, Vol 21,

CLOSE

ABOUT THE AUTHOR