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How the unique exploration challenges of operating in the Indian land environment can be met with the latest cableless technology.

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Summary

Any reasonable and detailed comparison of the various countries in which significant amounts of land seismic activity are undertaken will fairly conclude that India has some of the most awkward conditions anywhere in the world. Despite this, the country has achieved significant exploration success and is increasingly recognised as being at the forefront of a variety of geophysical approaches.

It is of course true that various seismic crews in the deserts of the Middle East, in the vast open lands of Russia as well as some surveys in North America employ far more channels than is practical for typical Indian operations. However, this may be seen primarily as a reflection of the relative simplicity of operating in those geographical areas compared to the multiple challenges which the Sub-Continent has to throw at land exploration.

The essential differences between India and many other geographical regions are further exemplified by issues which include the logistical difficulties in some Indian states such as transport and security as well as the huge variations there may be in weather between locations and from season to season. Thus, while India is rapidly improving its infrastructure, it still must routinely confront a huge variety of challenges which are not typical in many other areas of the world.

As a result of facing up to these problems and recognising that new technologies are now available to ameliorate the operational situation, after some initial caution, both large and small Indian companies have begun seriously to investigate potential benefits for their particular situations of cableless seismic acquisition technology.

As one who may have been the very first to discuss cableless acquisition technology in India, through the media of previous SPG Conventions and industry magazines, this author believes that India has more to gain than most from use of appropriate cableless hardware, and especially that which has only recently become available. However, the country's exploration plans may also have a lot at risk by using technology which may not be up to its special challenge. Bearing in mind the costly mistakes made in some other countries when using inappropriate or less-capable cableless hardware in taxing environments, it appears that India's reticence to date in using this technology may have been wise.

This paper picks on just two ostensibly simple issues in cableless technology and operations to demonstrate that there may be much more to system choice than may at first seem obvious, especially for challenging locations. By analog with how cable based land acquisition system developments helped solve geophysical problems a few decades ago, this paper also investigates the special requirements of the Indian exploration environment by reference to recent use of cableless systems in similarly awkward locations around the world. It suggests how local operators may benefit from the changing landscape that there has been in geophysical innovations as regards cableless seismic acquisition technology while attempting to point out pitfalls which have affected others who perhaps made too many assumptions about how hardware could work, or who underestimated the potential problems when using some types of cableless operation.

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Introduction

In most areas of scientific endeavour, the investigative tools available to undertake experiments, to record data and to further our knowledge tend to be fairly well suited to purpose. They allow relevant research to be conducted without significantly forcing the experimenter to bend to the limitations of the hardware.

However, for most of the history of land seismic exploration, this has not been true. Geophysicists have long understood the need for high fold data containing a large range of offsets and azimuths, and which properly samples both noise and data in time and frequency. But in most cases the only one of these criteria which has been met with any ease is that of adequate frequency domain sampling. Compromises, some of them significant, have had to be made in all other areas and results have occasionally been less than ideal.

The reason for not being able to undertake “ideal surveys” has been related to a variety of issues. These include the technological limitations of instrumentation, to the cost of a “unit” of hardware restricting how much of it can be purchased, its on-going costs and the ease with which varying types of equipment can be used in the tougher locations of the world.

A historical example of equipment limiting experiments which the geophysics community had wanted to undertake is that of recording systems dependent on analog cable. Here, each seismic channel required a separate pair of wires running from sensor to recording cabin where digitising electronics were housed. Such cables were expensive, heavy and fragile, and in general they limited practical and economic operations to little more than a few hundred channels at most.

If one is to assume that adequate data and noise sampling requires a separate channel every five or ten metres at least in one dimension, and that good offset and azimuth sampling benefits perhaps from a couple of dozen lines each up to ten or fifteen kilometres in length, simple arithmetic quickly demonstrates the significant compromises which had to be made with analog transmission cabled instruments. Despite such equipment limitations, the industry was still able successfully to locate hydrocarbon reservoirs although one may suggest that these were the easy-to-find ones.

In the 1980's much of the industry started to move from analog cable transmission to equipment where digitizing electronics were on the seismic line allowing digital data from large numbers of channels to be directly sent on a few data pairs inside telemetry spread cables to a central system. Even early versions of such recorders instantly enabled many hundreds of channels to be handled with ease. A little further development and channel counts went into four figures thus allowing highly sampled 2D lines which finally met most or all theoretical sampling criteria, as well as permitting coarsely sampled 3D surveys to be undertaken. The change in technology and increasing knowledge of how to use it to advantage, enabled significant leaps in exploration geophysics.

By the 1990's channel counts were commonly at the level of several thousand and 3D techniques continued to be perfected. Geophysicists, with affordable and reliable large channel capacities based on digital cable telemetry hardware devised experiments (seismic surveys) which gathered ever more detail of the subsurface. We began to understand more about reservoir complexity, and even about the science of exploration geophysics itself. It was a huge difference between the technology available just a few decades earlier but noone could claim that it did not present its own problems as channel counts grew.

By the end of the century, such hardware was asymptotically approaching power consumption and weight per channel limits beyond which it was difficult to move. The costs to use such equipment also budged little. The geophysical needs of the industry continued to grow whereas the capabilities of then commonly used hardware had almost nowhere space to move.

The environments most hit by these limitations were not those where cable laying was simple but those where working with heavy cabling was the most difficult. These includes areas of thick rain forest and jungle, of high population density, of large and difficult water bodies, and of rapid elevation change. Few countries in the world have more locations combining some or all of these logistical difficulties than India.

Thus, it will also be such countries as India which stand to benefit most from technologies which are not dependent on telemetry cables and which can be configured to work around these geographical challenges. Appropriate cableless systems will allow the exploration geophysicist to make the fewest compromises in terms of running his ideal data gathering experiments, be they active or passive. The requisite technology is at last available but its characteristics must be understood.

To make the most of this hardware, some essential questions to consider are: given that there is much more variety in cableless technology than there ever was in cabled systems, which cableless features and functionality are the most beneficial to allow optimal results in the local environment? What can India learn from the mistakes made by the early adopters of different cableless hardware in other countries?

Answers to these questions have been covered in part by this author elsewhere. However, two of the less obvious but related issues, which on the face of it have seemed rather simple, but which have lead to unexpected problems internationally and caused the most concern, are herein covered.

Theory and technical considerations

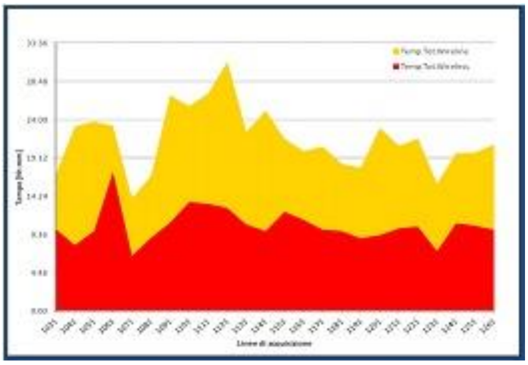
The Indian geophysicist is confronted with a range of practical pressures which many of his international colleagues do not face. Reservoirs are rarely without complexity, locations are not often simple while security of hardware and data are high on the agenda. Equipment available until recently was easily configurable to cope simultaneously with many of these problems and so inevitably compromises have had to be made, perhaps exchanging lower cost or safer operations for less fold and poorer data in some areas.

The ideal cableless system would not only improve the way geophysical data is acquired to provide better data quality but impose no new operating challenges. Most cableless systems boast these sorts of advantages in general terms but unfortunately, after seeing the experience of some other parts of the world, cableless technology inappropriate to tough environments could well create wholly new problems of a data quality and operational logistics nature. While there has been a number of comparisons in the literature between cabled and cableless systems (perhaps the most recent and insightful being a paper given by the Italian oil company giant ENI at 2012 SEG Convention) there is little written to compare different cableless technologies, and until recently there was nothing in terms of cableless use in areas as difficult as Indian faces. This changed on the publication of a piece by the seismic contractor CellSeis about their experiences of cableless operations in the jungles, villages, steep hills and water bodies of the Far East.

In the first of two examples to demonstrate how apparently simple choices in cableless recording can have significant and often unexpected consequences, we look at power for digitizing channels. Power was taken for granted with cabled systems; few people had to pay it much attention as it was usually not warranted, and in any case there was little in terms of choice (or even a necessity of choice) when it came to energising the seismic line. Although cabled recorders tend to take significantly more battery energy than one may have ascertained from system specifications, as can be demonstrated by simple applications of Ohm’s and Watt’s laws, a cable system still managed to use a small truck type battery, based on a stable and low cost lead acid chemistry, to provide power to around 50 seismic channels for a convenient period of time.

In contrast, a drawback of cableless systems is that each ground unit needs it own battery. This disadvantage is often made worse when a single ground unit may “encourage” use of more than one battery and/or of expensive battery chemistries. If the ground unit contains only the digitizing circuitry for a single seismic channel, then to operate such a cableless crew could require one hundred times more batteries than a cabled crew. Even the best cableless system still require at least ten times as many batteries as a cabled recorder of the same channel count, thus this “battery issue” can become one of considerable complexity and risk. This may include battery chemistry choices, handling logistics and costs (both initial and on-going) any of which can seriously affect the geophysics in some cases, and often not in obvious ways.

Whatever battery chemistry is chosen, the sheer quantity of batteries can in some cases make the cableless system heavier than many cabled systems, though the weight differential obviously depends on trace interval, battery chemistry, number of channels per ground unit, remote control capability of cableless systems and so on. This issue has been investigated in the literature by this author and others, and more recently is included in the paper by ENI which makes the point about needing choice in batteries on cableless operations.



ENI comparison of effort needed for cabled (yellow) and cableless (red) operations. SEG 2012 paper.

Depending on the communication functionality provided, some cableless technology cannot easily make use of simple low cost, locally available and safe SLA-based batteries and their chargers but need those based on some very expensive lithium chemistry. There are various options available including lithium ion, lithium polymer, and lithium ferrite all of which have different weights, energy densities, safety levels, battery lifetimes (charge/recharge cycles), cost and ease of charging characteristics - all of which are heavily dependent on temperature. Operating in environments where systems left out in the sun will achieve temperatures higher than 50^{O} C reduces battery voltage, capacity and life time (Bloom *et al*, 2001; Zhang *et al* 2003). However, the single advantage lithium chemistry brings to seismic is that it will generally be lower in weight for the same energy compared to the already established seismic battery technologies such as SLA and NiCad. If weight is the only criterion for choosing cableless technology, then although weight is governed by many other issues, the lithium option is more worth considering. In most other cases, it comes with many serious disadvantages for the tough land environment.

For example, some lithium batteries are ten times more expensive than SLA, as used widely with cabled systems and available as an option with only a few cableless systems. This simpler and cheaper battery technology may also be much better suited to the typical Indian environments given their advantages in terms of battery life times, local availability, charging temperature range, security issues and difficulties in shipping of hazardous cargos etc.

The next issue with ground unit power of some relevance to how operations are carried out in India is whether batteries should be internal to the ground unit or external. While the advantages of installing a battery inside a ground unit are obvious, the problems associated with this configuration have been less often pointed out but are essential to consider. These include making the equipment more likely to be stolen just to extract the valuable battery, increasing the box weight, restricting battery chemistry choice, need to open the unit simply to change battery at the end of its life, and risking the electronics of the ground system if some forms of lithium are used which can erupt or even catch fire. Each of these could have a profound effect in some locations.

Putting this all together, not having “battery choices” often exchanges what was usually seen as “the cable problem” on earlier recording technology with an equally unrelenting “battery problem” with cableless exploration. Therefore, so as not to be caught by surprise it is essential for users to understand that choice of box power almost certainly has the greatest logistical influence of all on the cableless operation in difficult areas.

The fact that even simple issues of box power can have such significant affects on a crew has occasionally surprised some who are considering this approach. Given that relatively large numbers of batteries are needed for any cableless crew, and that Indian operations face more difficulties than most, potential users should question any battery technology “forced” on their operation given the knock on effects. As referenced by ENI operators are recommended to seek choice allowing them then to make their own judgment in terms of weight, cost and any other issues relevant to their own particular circumstances. The battery issue is one which many users, including those working in far easier locations than is common in India, have ignored to their regret.

It has been shown that something as basic as powering the system can make very large differences to how cableless crews may operate. However, this is not the only issue.

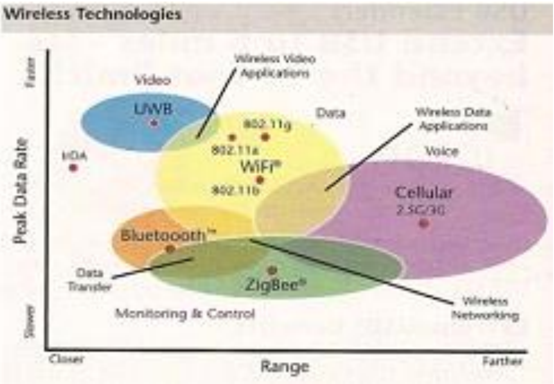
The other essential question here considered which often strongly affects the geophysics is in respect to the choice of cableless systems with or without some assured communication capability between all deployed ground units and the operator. There are two major choices: technology which is not able to communicate (including those systems which are designed without such capability as well as those which include a communication facility but which will not work in tough locations) and those technologies which can ensure some level of communication, at some acceptable level of deployment effort even in difficult environments. The former group is usually referred to as shootblind.

Some cableless technologies may require operating with many more channels due to the need to take them off the line for data harvesting.

Shootblind systems generally may need up to 33% more channels due to the necessity in most cases of halting acquisition into those units, collecting them up and taken to some central download/harvesting area. Therefore weight, cost and battery usage are not necessarily better with this technology, which has its greatest following in the United States where the security and logistical situation is very different to that in India. However, even in the USA, there is a move with some users of shootblind technology to “add sight” to their operations by use side by side of a cableless systems which can ensure come level of communication. This may be for reasons of excessive shootblind equipment loss or poor data quality due to having no ability to monitor noise, perform sensor/instrument tests, monitor GPS timing signal reception etc.

Shootblind systems, as defined above to include those with some form of inbuilt but non-universal communications technology, often do not function well in difficult terrain, risk data quality and security issues. This is well reported in the literature, for example (Lansley, M. 2012) refers to “very large” numbers of Unite channels being stolen and “only 300 recovered” apparently on a single operation. New Technology magazine, Oct 2011 reports a crew losing $100,000 of equipment through theft and vandalism. Conversely, CellSeis (Fleming, C. 2013), the operator of cableless technology which does provide some communications even in the toughest environments reports that despite working in areas where illegal surface mining activity went on, it suffered no equipment loss or data noise problems at all, thanks to the ability to remotely and cablelessly monitor the line under virtually all conditions.

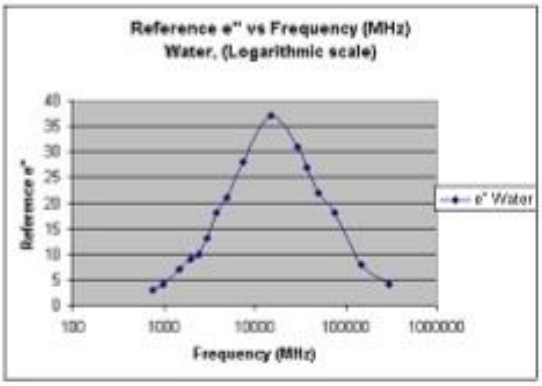
It seems that the response from the industry to the problems of stealing, instead of insisting on reliable line monitoring, is the suggestion that ground units should be buried. The idea is that hiding line equipment underground will reduce theft. This approach has worked well in some places to minimise equipment loss but has failed miserably in others. This is apparently because those inclined to dishonesty are often locally based and notice the effort going into burying equipment, which can be considerable.



Several transmission protocols already exist for use in cableless seismic recording.

Burying also may bring new problems. Most ground units rely on regular receipt of GPS signals to time stamp data. This only requires acquisition of a single satellite but, according to information available variously online, even this may be impossible in some locations over long periods. For example where GPS signals are already attenuated by forest canopy, various weather conditions which turn out not to be so rare in hot climate conditions, and where soil conditions may not be conducive to GPS signal propagation to buried units. A simple calculation reveals that burying, while suited to simple locations, is probably not an easy option in tougher terrain and, depending on hardware, for every thousand channels may require moving up thirty or forty tonnes of earth by hand. If this could ensure that the system functioned perfectly and without data or equipment loss, it may be a price worth paying. However, reports from the industry show that burying of systems may often not guarantee prevention of equipment loss.

There are various frequencies and well known communication protocols which could be used in geophysics for wireless operations. However, all cableless systems which offer communication rely on use of the licence-free 2.4 GHz ISM band. In most countries this includes the range of frequencies from 2.4000 to 2.4835 GHz, which itself is split into a number of sub-bands. In a few countries, other frequencies may be available for use in exploration geophysics, including 5.6 and 5.8 GHz and in the 900 MHz region but in many countries, including India, these are not available. Further, most countries restrict use of the 2.4 GHz band to level of 10-100 mW EIRP. The difficulties of using this band and such low powers are not alway understood by the geophysics industry. For excellent independent consideration of available technologies to use in land exploration a wide range of references is provided and all interested in understanding the problems of 2.4 GHz-based transmission in tough location are strongly recommended to read these.



Dielectric loss ”e” relevant to transmissions using 2.4 GHz, 5.6 GHz and 5.8 GHz bands.

This major issue for land exploration, especially in India, is that radio waves of 2.4 to 5.8 GHz are very readily absorbed by water molecules, be they in the atmosphere or in foliage. The method of energy loss is through dielectric heating. This is the process where polar molecules, such as water which is negative at the oxygen end and positive at the hydrogen end (giving it an electrical dipole moment) align themselves in an electromagnetic field. As the field oscillates, which is does 2.4 billion times per second in the case of this 2.4 GHz ISM band signal, molecules continuously line up and in the process lose a little energy on each rotation through electrical forces coupling. This energy loss appears as heat and is the reason why most microwave ovens operate at 2.45 GHz - right in the middle of the only band which is available to this industry internationally to transmit geophysical data. This rapid reduction in 2.4 GHz strength as distance increases from transmitter means that generally such communication suffers far more rapidly than the inverse square law would imply.

Even the water contained in bushes and tall grasses can attenuate signal by 10-15 dB which reduces real range significantly compared to the free space range. Other types of static and moving obstacle, such as may be found in populated areas, will also have an effect. This can be calculated or at least estimated and any cableless system should make available some indication of what this will be in any set up, just as cabled system manufacturers inform users of the maximum number of channels/sample rate that can be used in each receiver line.

In addition to the above, a general rule of thumb for radio technology should be understood by all planning to use cableless systems and who require some level of full time communications. This is that for any defined radio installation (transmitter power, antenna type and height, receiver sensitivity etc) one may transmit either high bandwidth or long range, not both. If more effort is put into the transmitter/receiver set up, e.g using directional and/or raised antenna, then either greater bandwidth or greater range can be accomplished. Thus, in cableless land seismic we can only trade between bandwidth, range and ease of deployment. Indeed, the ideal cableless system is one which allows this trade off so that hardware can be be suited to each environment.

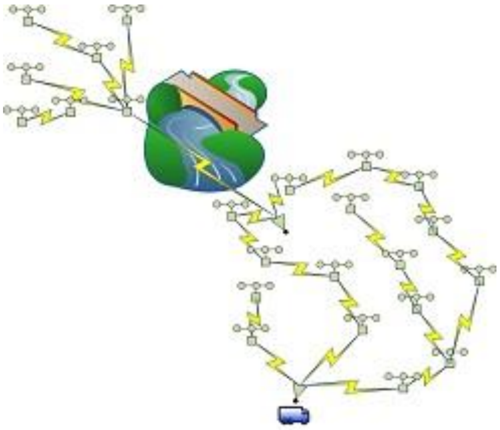
Most people’s experience of 2.4 GHz away from microwave ovens is with WiFi. However, WiFi was never intended for geophysical acquisition purposes in which it has many potential problems. If connection is not virtually instant or with sufficient power, WiFi quickly changes modulation scheme and so reduces data rate. WiFi allows few simultaneous users none of whom expect uninterrupted access whereas land seismic needs many channels operating continuously. WiFi is “asymmetric” in that it expects high download and low upload bandwidth, whereas land seismic is the opposite.

These characteristics rapidly lead to intermittency which is not usually an issue when a few domestic users go on line via an access point but it is usually a serious problem for geophysics. They also mean it can be difficult to plan how to use some 2.4 GHz-based cableless systems in differing but challenging locations, primarily those trying to send high bandwidth with small ground unit antenna deployed close to the ground.

One way WiFi has been used in geophysical data acquisition is the cellular approach. Set ups such as this may be ideal for GSM mobile telephony but the above-mentioned problems of 2.4 GHz mean that a cellular WiFi approach tends to result in only seismic channels very close to the access point tower being able to connect continually, making it more likely to result in shootblind. Further, as one attempts to increase range to include more seismic channels, then data collisions are much more likely to happen causing further intermittency and for most (if not all channels) no connectivity at all. This may explain why this method cannot ensure communication at most usual levels of land seismic (active crew) deployment. However, by increasing deployment effort, for example using directional raised antenna with ground digitizers and relays/towers, as one can afford to provide and deploy on permanent/passive installations, cellular WiFi can work reliably.

Point-to-point use of 2.4 GHz transmissions is another option and may be less unsuccessful for geophysics than cellular use of 2.4 GHz. However, this is also constrained by the laws of physics and if high bandwidth is required, then range may quickly reduce below desired seismic trace interval, especially as terrain becomes more challenging, unless additional effort (for example, taller/better antenna) can be employed. Further, required bandwidth may be related to the location of each digitiser on the point to point transmission chain and thus range (and attenuation) may change rather unpredictably and very inconveniently according to position along the seismic line.

The solution to these problems in general terms has proved to be use of short range transmissions with a mesh topology. In a mesh each unit transmits/receives to/from all its nearby neighbours, any/all of which can be involved in further transmitting signals. Meshes usually form their own best pathways. Therefore, range required is only to be as far as the “next” ground unit. This may not always be the nearest one as a tree in the path between two boxes will attenuate much more than mere free space distance between two others farther apart. In land seismic, to a 2.4 GHz transmission, space can be very anisotropic due to differences in foliage density in each direction, and this is why a mesh approach tends to be preferential to a point to point approach.



Mesh acquisition of full bandwidth realtime data using multiple sub-meshes topologies and aggregator relays in difficult terrain. Courtesy SRD Innovation, Sigma-hyMesh system.

Sub-meshes in seismic acquisition can also be defined and inter- connected, meaning groups of seismic receivers in a specific area can be configured all to use one mesh, (Spagnolini *et al*, 2013) and connected using a mesh relay or aggregator to further sets of seismic receivers using another mesh perhaps across a river.

As range, data rate, ease of deployment and topography are all related, in non-shootblind cableless operations geophysicists are able to decide what is important for their survey in each case. What is the bandwidth they must have and in each environment, how much effort can be used, is it enough to have only health/QC/noise information from all channels or all is data required in real time from some or all channels?

In this respect, it should be noted that seismic cabled systems send two types of data: the field data from digitisers usually representing seismic reflections, and all other data such as instrument tests, noise, QC and health status. Cables provided sufficient bandwidth for both. The latter type of data requires far lower bandwidth than the former and this difference can be exploited by some cableless technology with minimal deployment effort, because such noise/health data may be enough in most cases to provide data quality control, and system/data security. If “full” seismic bandwidth is required then more deployment effort is almost certainly required too, as long as the hardware also supports this functionality.

So for the first time, the geophysicist aware of how this technology works, can decide how much field effort he wants to apply for how much data. This was never possible with cabled but, used correctly, can make significant changes to how geophysical recording may be undertaken in difficult terrain.

Summary

Experience dictates that users must consider five characteristics of any cableless technology fit for the geophysics industry:

- Capacity: the ability of the transmission technology to actually transmit the amount of data being generated by the seismic survey in real time. For a 1,000 channel survey this is around 12 Mbps, though less if only noise/QC is required and data to be harvested later.
- Coverage: the ability of the network to reach every active node as required by geophysical model.
- Range: the distance at which two deployed units of geophysical equipment can be placed and still make connection at the required bandwidth.
- Ease of Installation: how easy is it to deploy in the terrain in question, given all local and national issues regarding seismic work. He should not be forced to consider burying of any equipment merely or security reasons.
- Ease of use: how easy is it to configure and actually operate the system.

In order to cover the points above, the geophysicist must understand how/if the technology can provide what he needs. Generally, he did not have to worry about this when using cabled systems, though he of course had to put up with all the disadvantages of working with cables. Some understanding of cableless technology is now recommended for any company wishing to make the most of what cableless has to offer.

Conclusions

There is no doubt that cableless recorders/nodes can provide lower cost surveys than cabled systems in difficult areas, or that the cost reduction may be used to provide higher quality data for the same crew effort. However, there is great choice in cableless technology and the user must decide which is suited to his range of environments and operational necessities.

By reference to only two ostensibly simple issues, this paper has attempted to show how much there is to comprehend about cableless technology when applied to acquisition geophysics.

Other important areas this paper could have covered include: GPS reception, data harvesting, use of cableless technology side by side legacy cabled systems.

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