

Use of 2.4 GHz Communication Technologies in Land Seismic and its Impact on "Real Time" Recording, System/Data Security (v2).

INTRODUCTION

In terms of technology used and variety of operations that can be undertaken, the low number of competing cabled telemetry seismic recording systems have little to differentiate them. Such hardware is comparatively easy to understand and generally it is not difficult to foresee under which conditions their use might cause problems.

For example, it is well known that laying such telemetry cables across a major road will not only be hazardous to traffic but also that it will degrade the capability of the cable to carry high bandwidth data so that sooner or later transmission errors will occur. Thus, users make sure that cables are protected in such situations.

In contrast, there are many types of cableless/cablefree* seismic recording systems available (*these terms are used synonymously here, even though strictly speaking they imply different types of instrument) each using different technologies and sometimes with vastly differing capabilities. This means there are various ways to use them correctly each with advantages for any situation, and many ways to use them incorrectly or unsafely.

Given this variety of instrumentation and some lack of knowledge in a few parts of the industry about how they work it is not uncommon for some instruments to be misunderstood and inadvertently used inappropriately. Therefore, when a potential user of cableless systems is choosing equipment, it is imperative to understand what can be expected from using such hardware in the environment specific to that operator.

For example, some cableless systems may work satisfactorily in flat areas with little vegetation but will not work in rain forest and may even be affected by humid weather. Some may work when deployed on the ground, others when raised above the ground, others may need to be buried, and some systems, once buried, may have their performance severely degraded under certain circumstances.

The purpose of this paper is primarily to explain issues associated with cableless systems which claim some ability to communicate between deployed ground units and the central system, i.e. non-shootblind systems. All such systems are obliged to use the 2.4 GHz ISM band and the issues which affect how much data can be successfully transmitted wirelessly using this band must be understood, and under what circumstances data transmission becomes unreliable or impossible. It goes on to cover knock-on effects of limited and restricted communications which all users should familiarise themselves with.

Given the aims of this paper, we group cableless systems into three broad categories.

SYSTEM GROUPINGS

The first is that group of recorders which are designed to make no attempt to send any data back at any time. These are called shootblind systems. Except in special circumstances, **Group 1** instruments should be avoided due to the data and hardware theft risk. (See iSeis paper "Data and Hardware Security Issues".)

Whereas they appear superficially to offer some level of convenience, a growing number of reports (e.g. New Technology Magazine, Oct 2011, which talks about the loss of \$100,000 of equipment) mention significant amounts of data and hardware loss from crews. Such loss may not be discovered for some while after it had taken place, due to lack of any communication capability. It is increasingly common now to visit operations using shootblind equipment and hear some level of regret in regard to having made that choice. This indicates that alternatives to shootblind hardware should be seriously considered.

Further, despite shootblind systems forcing acceptance of a far higher risk profile, they are often neither lower in cost to buy nor cheaper to operate than systems with some communication capability due to the

additional equipment and personnel which is usually needed.

The second class of system (**Group 2**) is those with technology to send back **some** amount of data under **all** conditions. As will be explained, **Group 2** units differ significantly from the third group of cableless systems: those with technology designed to send back **all** the data within a certain time frame in certain operating environments.

The term "real time" should be used with caution. This is because in control theory or with cabled seismic systems this term has very specific meanings which cannot easily be applied to cableless operations. For example, there are a number of recorders which can get all seismic data back under certain operating circumstances, though there may be some tens of seconds or minutes delay in all the data being available. However, all such hardware can suffer transmission problems in some common seismic environments which may delay some or all records for indeterminate periods. If the data is delayed from some or all channels for a period which is inconvenient to the operational parameters of the crew, for example generation of SEG D files (which is generally not an ideal format for most cableless or mixed-mode operations), such recorders may have to be considered in the same light as **Group 1** systems. This means that significant local memory is required, that the operator may be shooting blind and have to make special arrangements for gathering the data despite having invested in a "real time" (**Group 3**) system.

For the sake of clarification, **Group 3** systems comprise those recorders which have at their disposal some in-built or add-on optional technology which can send all the data back within an acceptable time frame under specific sets of circumstances. These tend to be called "reasonable time" systems rather than real time systems. It is worth stating: No cableless system is available (as this would mean breaking some laws of physics) which can guarantee real time data in all seismic environments through simple deployment effort.

In summary, at the timing of writing, there are four **Group 3** systems on the market which can send back data without significant time delay with relatively small deployment effort in very simple environments, but in areas of high signal absorption or interference, such systems may either stop working or only operate at some level of reduced efficiency. It is then the case that some of these systems allow the user to choose to use more deployment effort to guarantee real time communication even in the most difficult environments but this choice is not realistically available to most **Group 3** systems.

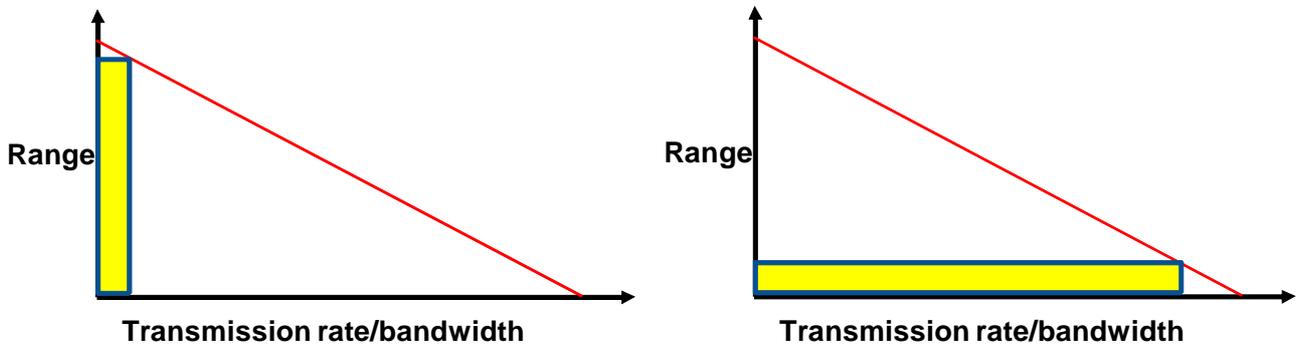
So why is this issue of data transmission so complicated?

BASIC RADIO THEORY

Put simply, for a certain communication set up, it is possible either to send a low amount of data over a longer range, or a larger amount of data over a shorter distance. This may be obvious from basic physics.

Assuming a fixed transmission power and antenna arrangement, in order to receive a bit of data enough power has to be generated inside the receiving circuitry to be seen above its noise level. This power can come from a high amplitude at the receiving antenna and/or a long duration used to represent that bit. As radio power usually decreases according to the inverse square law, high reception power comes only with shorter range from the transmitter whereas a long on-duration for a single bit implies low data rate.

The situation can be ameliorated to some extent by improving the transmission and/or reception conditions. For example, raising the transmit and/or the receive antennae by some distance, especially above any obstacle, source of interference or absorption, will increase useable range or data rate. Directional antenna can also be used at either or both ends of improve the situation. Indeed, permanent radio installations, whether one's home terrestrial TV or mobile phone transmitter, all make use of high



For fixed transmission-reception set up, it is possible to achieve longer range with lower data rate or vice versa, not both.

levels of such "deployment effort".

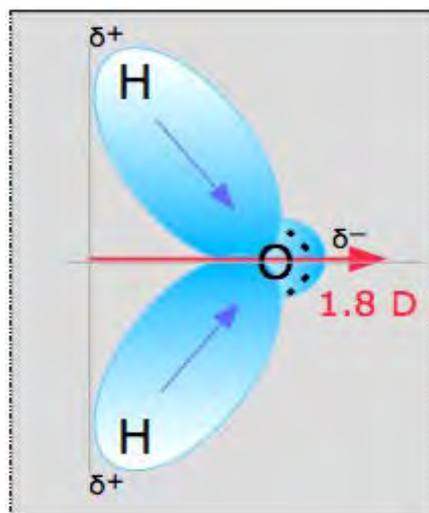
So, it is easy to see that range, data rate and deployment effort are all intimately related and that generally one can only be improved at the cost of one or both the others. In geophysical operations specifically, high deployment effort is generally more expensive or time-consuming.

2.4 GHZ BASED TRANSMISSION

Seismic recorders are generally designed by manufacturers to be used in as many countries as legally possible. There are no known restrictions legally to using cable systems anywhere but all **Group 2** and **Group 3** cableless systems have to limit themselves to reliance only on internationally permitted radio frequencies and transmission powers or their operation will be illegal.

The only radio band which can be used (almost) everywhere is the "2.4 GHz ISM" band. Strictly speaking, this is the band from 2.4000 - 2.4835 GHz in most countries, and consists of a number of sub-bands within the 83.5 MHz bandwidth. However, even here, there are various restrictions in different territories in how it can be used. For example, in the USA far greater radio power can be used than is legal in the European Union or in most of the third world; different groupings of sub-bands are not allowed in some countries whereas they are permitted in others. So what may be legal in the USA is often not legal outside of North America.

Additionally, some countries restrict how high any antenna can be placed, and what gain they have. Some countries permit use of other bands, e.g. in the 5.n GHz region but there are many more restrictions in the 5.n GHz bands than in the 2.4 GHz band. It should be repeated - the only band which is permitted virtually everywhere is the 2.4 GHz band with effective isotropic radiated power restricted to 100mW or less. This places significant limits on what can be realistically expected from seismic hardware.



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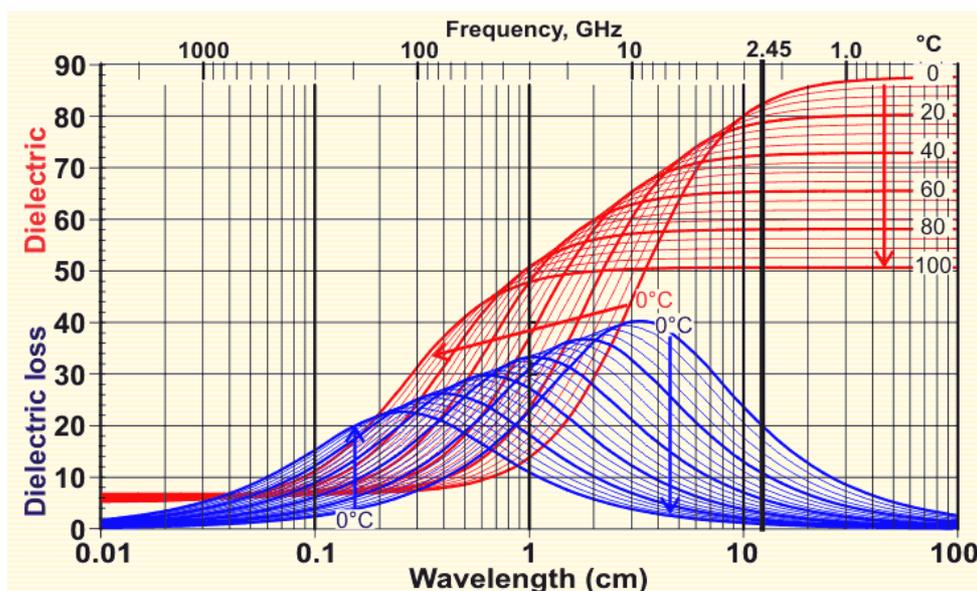
iSeis strongly recommends readers perform their own tests and investigations to make sure that they understand the limitations of any technology for their desired application.

It is strongly recommended that operators in each country considering a cableless system find out the legal restrictions of its use in their territory prior to purchasing any recorder. It is not unknown for purchasers in certain countries to import hardware only to find later it contravenes local RF rules. Sometimes, system manufacturers are not even aware of local regulations.

However, whereas the 2.4 GHz band has far fewer legal restrictions than other radio frequencies, in addition to the laws of physics affecting general radio transmission explained earlier explained, the 2.4 GHz band has further issues which affect its performance in the seismic environment.

Its main problem is how quickly it is absorbed especially by water molecules - yet water molecules exist in most environments either in vegetation or in most weather conditions. 2.4 GHz signals are so effective at being absorbed by water that 2.45 GHz (i.e. right in the middle of the band under discussion for seismic use) was the frequency chosen for most microwave ovens where, of course, the idea is for high level of absorption to heat up food.

The method of energy absorption, whether of 2.45 GHz in a microwave oven with 100's watts power or a 2.40-2.48 GHz data signal with tens of milliwatts, is the same. It is called dielectric heating and the physics is simple. Water molecules are composed of two hydrogen atoms and one oxygen atom. This molecule is polarised as the hydrogen ends of the molecule are positive whereas the oxygen end is negative. In the presence of an electromagnetic field, the polarised molecule aligns with the field direction. When the field direction changes, as it does 2.4 billion times per second, the molecules flip direction. In doing so, this creates friction. Simply put, the 2.4n GHz radio energy ends up as heat. Nothing can change this "dielectric loss".



In the seismic situation the amount of absorption thus varies according to the density of water molecules in the transmission path, as well as the temperature of the working environment. These both vary considerably from location to location, (and may well be anisotropic on the seismic spread), season to season, day to day and even minute by minute. As the amount of absorption directly affects range of transmission and reliable/sustainable data rate, it is not possible to guarantee that most such hardware works well all the time unless significant fade margin is allowed.

As an example of this, in some of the earlier field tests of 2.4 GHz systems in forested areas (not jungle type vegetation which is worse) hardware could be made to work during the day with a range of around 200-300m but dew on the leaves in the morning could reduce range significantly and the system stop working effectively. This is not a failing of the equipment necessarily, it is the

laws of physics applied to a design with small fade margin for that environment.

Even though generally RF output power is severely limited by regulation or system design, as has been alluded to already, the reliability of data transfer can be improved, where regulations allow, by using directional antenna rather than omnidirectional, by raising transmission/reception antenna higher, by attempting to transmit shorter distances, by acting to transmit lower data bandwidths. The first two of these operational solutions make deployment more time consuming, the fourth may rule out real time capability.

Where environmental absorption is significant, i.e. dielectric losses are high, major increases in transmit power, even beyond what is legal, may produce little or no benefit. This is rather like realising that no matter how bright the light beam from a torch, it simply will never shine through e.g. thick cardboard.

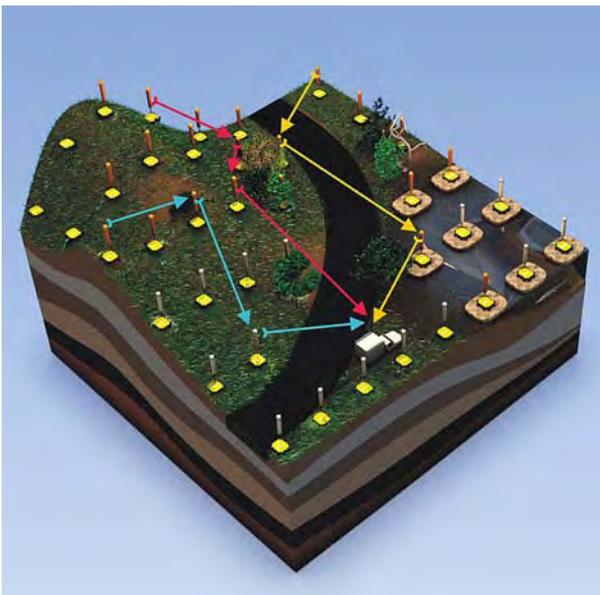
HOW TO OPERATE SUCCESSFULLY WITH 2.4 GHZ.

However, even though physics works strongly against us at 2.4 GHz, there are some strategies which can be successful in seismic recorders if we work within physics' boundaries.

It has been demonstrated that absorption of 2.4 GHz signals is variable according to water molecule density along the transmission path. Therefore, if we never try to go too far in range or transmit too high bandwidth, in the seismic environment we should be able to guarantee transmission without having to entertain unrealistic levels of deployment effort.

By deliberately restricting bandwidth while using legal levels of 2.4 GHz power, the range that can be traversed even with omnidirectional antenna placed on or close to the ground when there is little to no absorption can be as much as a few kilometres. This bandwidth is not enough to send back all data in real time but it is high enough usually for everything else the observer needs, including line noise, QC checks, equipment security information, all-important GPS reception status, ground unit/sensor/and battery health, albeit with some small time delay as channel counts rise to high levels.

However, more importantly in tough environments for 2.4 GHz such as dense jungle/wet climatic conditions, this volume of data can be successfully transmitted with minimal deployment effort with the only downside of reduced range. This range is still greater than the distance between adjacent field units in orthogonal directions. So if we incorporate technology which enables each field box to



receive data from nearby units and retransmit it, as well as adding its own limited data set (as

described in the previous paragraph) to the stream, then we have a reliable wireless transmission system which overcomes the usual 2.4 GHz problems by communicating in a mesh (like a spider's web or a net) topology.

This method of operating is called mesh radio networking - MRN, and it allows all field units to communicate with a central system almost no matter what the environment. It also allows virtually unlimited number of boxes/channels to be used, as each box is only aware of its nearby neighbours.

A unique licence-free MRN subsystem is included as standard in the Sigma cableless system. It has been used very successfully even in dense jungles and areas of large elevation change where no other system has been able to demonstrate reliable operation.



Note that if we were attempting to send over longer range or to use much higher data rate - equivalent to the that of a full real time system - then absorption losses would almost certainly mean serious operational problems in most environments. It is because MRN is always working within the laws of physics (shorter range, lower data rate) that its communication success is assured almost everywhere with the minimum of deployment effort. It also provides multiple communication routes which enable greater levels of data transfer security. When Sigma is used this way, it is a very successful and the most flexible **Group 2** system.

One excellent example of Sigma operations using 2.4 GHz over long ranges and high data rates is in microseismic monitoring. The system has been operating in various permanent and passive monitoring sites for around three years 24/7. One such operation is on-going in one of the hilliest states of the USA, with significant temperature and humidity swings, sending data back in real-time from around a thousand stations over an area of about 750 sq.km. and all powered by solar arrays. Just in case there are transmission issues (these are mostly caused by animals) data is also locally stored and can be transmitted when comms links are fixed.

Not only would any of this be impossible with a cable system, it is probably impossible with every

other cableless technology. Cables left deployed for so long in such a rugged area would quickly have been destroyed and using 2.4 GHz in any other configuration does not provide the range/data transfer rate combination necessary. This type of set up can also be adapted to jungle conditions with reduced range. It must be stressed that such directional Wi-Fi is an option in addition to Sigma's MRN. Most users find Sigma's simple-to-deploy MRN more than sufficient for their QC and security needs, as long as flexible methods of data download are also provided (see later).

For users who wish to achieve full seismic data rate real time transmission, consideration must be given to the relationship between range, data rate and ease of deployment. Proprietary mesh-WiFi technology exists, called hyMesh, which connects ground units in a similar way to that found in mesh radio networking. However, by use of different transmission technology and using raised antenna in areas of greatest absorption, data rates exceeding 10 mbps can be achieved along with multiple paths being available rather than a single point to point.



Use of proprietary 2.4 GHz hyMesh, achieving >10mbps, more than enough for full data rate real time seismic transmission . Deployment effort effectively increases to cope with tougher environments.

TESTING 2.4 GHZ

Many potential cableless system users are surprised about the problems with 2.4 GHz signals in the seismic environment. However, they can demonstrate for themselves the difficulties. Simply set up a standard Wi-Fi access point, perhaps a few metres above ground level. Take a Wi-Fi enabled PC and walk away from the access point, stopping every so often to see what connectivity is possible at different ranges. Do this also with different heights for the AP to see how connectivity changes. Try this also in different weather conditions and then, if possible, do the same in different densities of foliage. Now relate this to range and data rates in your exploration environment. Even with only one PC trying to make connection, you may be surprised as to how unsuited to high data rate seismic some 2.4 GHz protocols can sometimes be. It must also be remembered that connecting to the internet across an AP, unlike seismic field acquisition, is not a situation where real time communications are critical.

And it is not just the physics of 2.4 GHz signal absorption. In the majority of telecommunications networks, such as mobile phones and computers going on-line, the data flow tends to be from base station to field unit and small volumes in the opposite direction. In geophysical applications, the data flow requirements are reversed. Typical telecomms networks also rely on "traffic theory" whereby relatively limited numbers of users are expected to be using the system at any one time, and the design incorporates "over-subscription" routines, whereby if too many users try to gain access they will receive (what is effectively) a busy signal for some period of time. In the case of

seismic recording, data from many users is all generated at the same time and a "busy signal" would be unacceptable.

In addition, Wi-Fi protocols generally start by trying to establish communication at the highest possible data rate, e.g 11 mpbs for 80211.b (note: the maximum data rate achievable is much less than this under ideal conditions due to overheads etc). If connection is not successful, the AP switches to a lower data rate and tries again. If this does not work, it tries even lower rates and changes modulation to attempt successful linkage. If that is not successful, then no data transfer happens or is so slow as to be useless. None of this is acceptable in land exploration.

If real time rates cannot be sustained from all connected channels all the time, then at best the user is left with a **Group 2** system despite perhaps the system being designed as **Group 3**. At the point where communication is so poor that it is effectively unusable, then the **Group 3** system has become **Group 1** for some or all of the spread. Indeed it is not at all uncommon to see some seismic instruments described as **Group 3** having to be used in a completely shoot blind mode.

DATA HARVESTING AND 2.4 GHZ

It has been shown that the absorption characteristics of 2.4 GHz radio signals imply that most systems cannot establish real time communications in all environments. Therefore, such systems **must** have a fallback position in which data can be collected from ground units in some other way. This phase is known as harvesting.

Shootblind systems generally require ground units to be collected up and taken to a central point where they are all connected to a "harvesting rack" in order to access data. Clearly this is not only requires the significant expense of such a rack but also means the ground units are not on the ground acquiring any more data.

Some other systems offer other means of data harvesting where the harvesting device comes to the deployed ground unit rather than the other way round which generally has obvious and significant advantages. This brings into question the method by which ground units can reliably and simply connect to the harvesting device in the field to allow collection of data.

The standard method used for this type of data collection is that of "pass-by harvesting", in which the ground unit's Wi-Fi connects to a roving (drive-by, walk-by, fly-by etc) computer also with Wi-Fi enabled. However, given that pass-by harvesting may have been necessitated simply because real time transmission was made impossible by 2.4 GHz absorption, then pass-by harvesting Wi-Fi which also must use 2.4 GHz may similarly not work well in all circumstances either. The matter may be made even worse where such boxes are buried in order to avoid theft, depending on the 2.4 GHz absorption characteristics of the ground in which the box is buried. (See iSeis paper "Data and Hardware Security Issues".)

This potentially ubiquitous problem of 2.4 GHz means that cableless systems, even **Group 3**, and especially those which are expected to gather large amounts of data should have multiple means of harvesting, some of which do not depend on 2.4 GHz.

One example is the Sigma system which offers 2.4 GHz Wi-Fi for drive-by harvesting but also allows use of external USB-based memory devices (actually far faster than any pass-by radio method) and direct cable from ground unit to data collecting PC for when 2.4 GHz is problematic.

SYSTEM AND HARDWARE SECURITY

As it is impossible to assume that 2.4 GHz will always permit reliable communications, then any data/hardware security plan based on the assumption of full time/real time communication is also in jeopardy.

Sigma provides multiple levels of security, none of which rely on high bandwidth 2.4 GHz. The

important issue of system and data security is covered in a separate paper available from iSeis.

CONCLUSIONS

- "Real time" data communication in cableless seismic operations should be defined by each manufacturer and system users should insist on obtaining such definitions. In most cases, users will be disappointed if they do not understand the technology involved in making reliable communication possible.
- All users should familiarise themselves with the simple physics of radio transmission in the 2.4 GHz band and understand how this will affect their desired seismic programme.
- No licence-free wireless technology exists which can guarantee real time data transmission in all seismic environments without extra deployment effort.
- Users should separate the need of seeing some of the data all of the time from the need to see all the data some or all of the time, and the acceptable delay in receipt of the data, as the technologies used are very different.
- 2.4 GHz communication is the only frequency band useable around all the world. Yet is it significantly absorbed by water molecules. Therefore, being able to operate systems within the limits of physics helps operations considerably. Cableless systems must be configurable to the problem being encountered, understanding the amount of data, range and deployment effort that can be expected and may be required for any operation.
- Any operator looking for a non-shootblind cableless system should arrange for a demonstration of the system in its typical environment.
- Not all manufacturers know the limits of their own technology. Some may even be rather optimistic in their estimates of what can be expected having not made field tests to find the limits of their system. Experience shows that most 2.4 GHz-based high data rate systems may work rather less well than end-users expect. This is why Sigma has so many options.

SUGGESTED FURTHER READING

1) Effects of rainfall on link quality in an outdoor forest deployment.

www.cs.ox.ac.uk/files/3204/WinSys.pdf

2) Outdoor links for 2.4 GHz frequencies. www.adv-radio-sci.net/1/301/2003/ars-1-301-2003.pdf

3) Seismic of tomorrow, configurable land systems. R G Heath, First Break June 2012.

4) Cableless seismic recording, a new problem for geophysicists. R G Heath, DEW Feb 2012.

5) SEG 2012, Las Vegas. "Wireless vs. Wireline Land 3D in N. Italy". ENI Italy.

6) Video at www.findingpetroleum.com/video/Wireless_Seismic/John_Flavell_Smith/642.aspx

7) S.Savazzi, U. Spagnolini, L. Goratti, D. Molteni, M. Latva-aho, M. Nicoli, "Ultra-Wide Band sensor networks in oil and gas explorations", IEEE Communications Magazine, vol.51, n.4, pp. 142-153, April 2013").

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