System 2000 revisited

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In October 1996, *TLE* published a "discussion document" which, in my opinion, was to initiate the most important change in the modern seismic instrumentation era. That document, Ian Jack's "System 2000," more than any other article, paper, or event that I can think of, can be credited with the start of a whole new movement in land hardware. I will henceforth somewhat irreverently refer to this document as S2K.

Now, 13 years later, the industry enjoys a range of choice in recorders unknown during more than 70 years of instrumentation development. The S2K paper is available through SEG's Web site, and I strongly recommend it as it is a piece of hardware history.

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Seismic without cables

Jack was working for BP at the time and his two-page document was intended to motivate the industry into thinking about a new type of recording system in time for the Land Seismic Instrumentation workshop to be held at SEG's 1996 Annual Meeting. As Jack put it, the objective was "for customers of such a new system to make their requirements known to manufacturers" (Jack's quotation marks).

My memory of that workshop was that it was fairly well attended, but few participants were demonstrating much lateral thinking in terms of new directions in which land hardware could venture. I did not get the impression that many then-existing manufacturers were paying too much attention to what the "customers" wanted, instead insisting that what they already had or already planned was perfect for the job. Some were even slightly hostile to the notion that existing technology was not already perfectly suited to the task at hand.

Cable and cableless systems in use on the same operation.

In some ways, perhaps the discussion document and the workshop were a little naive. One of S2K's primary requirements was that new systems should be much lower in cost. However, hardware developers and manufacturers, just like oil companies, are not charitable institutions. I saw little evidence of any incentive from the "customers" at that time which could encourage or entice the manufacturers to develop lower-cost products or to sell them more cheaply if they did not have to.

Manufacturers exist to make profits for their share holders and, contrary to what some may think, the most efficient route to this end may not always be developing what customers say they want. In the second half of the last decade, in an exploration industry where there was little choice and system development costs were enormous, it was usually easier to persuade end-users that what was available was already the best solution.

But there's no doubt that a growing chorus of "customers" wanted a less expensive way to do land seismic. A paper prepared by the A paper prepared by the Italian major Agip (now ENI) for the workshop more precisely suggested that the methods then used for land acquisition were "inadequate" (to solve the severe logistical constraints usually encountered in land operations), and Agip was not unique in this specific view. One solution suggested to achieve the "cheaper seismic" ideal was a sort of quality driven acquisition approach: in other words, adjust field effort according to the quality of

The sun has not yet set on cable systems.

data being recorded. Other oil companies at the time also had ideas along a similar path.

However, my opinion is that this approach may have been slightly at odds with S2K's central message, which could be summed up as *sismique sans cables* (seismic without cables). "Cables" in this case did not necessarily include anything with an analog signal in it but referred to digital-spread telemetry cables on the basis that they and their associated line connectors were the heaviest and generally least reliable component of a land system. They were thus likely to be the most expensive part to deploy and maintain.

The S2K document went on to add some flesh to the bones of the cableless ideal. There were hints that the perfect product might be a sort of modern SGR (see "Suggested reading"), i.e. an autonomous recorder but updated to offer more sophisticated operational features over and above the basic "shoot blind" one. The first suggested extra mode would be a variant where QC/status data could be sent back to the central system using some form of RF communication. Next would be the option, again without cable, to send back all seismic data, and finally, (in acknowledgment that copper wire can have its uses) a cabled option to cope with the situation where radio communication had problems.

The ideal S2K system would incorporate means of returning the QC/status data, and perhaps also of the entire seismic record.

I should pause here for a moment for those who may be fairly new to this industry. Before anyone jumps to the conclusion that meeting these requirements should have been a technological piece of cake, remember that this was 13 years ago. Oversampling convertors with the specifications we enjoy nowadays were then very expensive, as were electronic subsystems associated with memory, communications, and high-capacity batteries. The wealth of clever hardware we are spoiled with today was not even dreamed of then. Such things were only to emerge after 1996 and from a number of directions, including the cell phone industry, broadband and wireless internet/ethernet requirements, mobile computing, and so on. (After leaving BP, Jack paid homage to the contribution these industries have made in his 2003 article "Land seismic technology, where do we go from here?" in *First Break*.)

S2K had a brief section referring to sensors. MEMS technology was not so widely known at that time, but it was clear that there was little point in striving to reduce seismic system weight by some pounds per channel, since at the time the geophones attached might weigh so much more. Only the availability of larger numbers of channels would allow shorter group intervals as long as geophones were being used.

UniQ FOX unit—a fiber-optic data hub—which facilitates the real-time transfer of 150,000 channels on a cable system.

So now in hindsight can we see that cable free has given new life to such velocity sensors, perhaps even taking some spotlight away from MEMS, which it may otherwise have enjoyed. This may have been what helped effort to be diverted back into developing even better geophones.

As S2K referred to precise system specifications, it is pointless to repeat all the detail of that document here. Jack took the sensible approach that all that's really needed in seismic are specifications and features good enough to find oil (safely), hinting that anything more was just expensive overkill. I remember one comment from the floor during the workshop that this was a dangerous route to take. It was said that we

S2K cableless systems must work in more environments to be accepted as universal acquisition solutions.

should strive for the highest system specifications all the time as we "never know what we throw away."

This was my view too at the time, but I came to see that there was a fallacy in believing this. To require all land recording technology to be "the best it could be," irrespective of price, would be like insisting all cars be the most luxurious and highest performance they could possibly be, as you might never be sure when you'd want one of those features or specifications. Making land exploration more expensive than it needs to be, like restricting driving only to those who can afford to buy and operate Rolls Royces, just reduces the market for both product and services. In seismic acquisition, as in any other field, what manufacturers should offer needs to be fit for purpose and no more. Part of the S2K paper and the follow-up meetings were to discuss what exactly fit this description.

I remember no major conclusions being drawn at the first workshop, but Jack made it clear that his S2K quest was not going to go away. Other meetings followed on both sides of the pond, and, after some years, eventually the movement attained a greater following. Unsurprisingly, it does not seem that the established manufacturers were the first to produce innovative S2K-like hardware. A few brand new companies sprang into life specifically to face the challenge. Very possibly, such development had only become possible for smaller outfits because of the rapid advances in technology referred to above. Unlike a few decades earlier, it no longer required armies of development engineers and budgets of US$50 million to come up with a new piece of seismic kit. What did take serious money then, as now, is bringing the product to market and getting it accepted.

Some of these new companies stealthily stayed under the radar, and at least one fell by the wayside due to funding difficulties caused by the 9/11 disaster. Nevertheless, in the first five years of the 21st century, almost half a dozen new systems emerged which, even if they did not know it, could trace their heritage back to the 1996 event. Today, the number of S2K-inspired products is just about in double figures, so if success is measured by how many such systems are on offer, then Ian Jack deserves some recognition—or blame.

Nevertheless, it would be unfair to think that cable technology stood still for the last dozen years.

Telemetry systems relying on cables are obviously better than they have ever been, even compared to their immediate predecessor products of the mid 1990s. They can handle more channels, come with more bells and whistles, and have even managed to lose a little weight. Cable-based hardware is actually still responsible for the largest land operations to have taken place so far, though some older style RF systems, especially in the United States, are regularly around the 10,000-channel range too. At SEG's 2008 Annual Meeting, WesternGeco announced its UniQ land system, claiming an ability to handle up to 150,000 channels. So cable technology may be aging, but so far it has proved itself capable of setting the bar a little higher each year, and this is the act that cableless kits now has to follow. Already, a definite area of success for some cable-free products is in their ability to work side-by-side with cabled systems to give users the best of both worlds. To me, this is an admission that some advantages of life without cables are already recognized.

S2K success

It would have been a miracle if, in 1996, someone had foreseen all the exploration circumstances we would now be facing and made precise recommendations about what a future system would need in order to cope. But S2K also heralded the idea that new equipment needed to be more adaptable to cope with the widest range of environments. So how well do all these new offerings meet today's growing variety of requirements?

Whereas cable free has yet to enjoy too many starring roles, there is no doubt that cable free is already being offered more than just bit parts. It has proved itself flexible enough to take on different surveys that cable could not do so easily. However, it appears that this flexibility has arrived in packets with almost no single technology able to tick all the right boxes. It seems one approach may have been needed to deal well with one acquisition problem, while it may take another cable-free tack to handle a different problem. Due to this compartmentalization, and because the industry now knows more of what to demand from developers, we are just beginning to see new-generation cableless approaches emerging, the sum of much previous experience. So have we at last reached the tipping point that allows cableless to take on the Oscar-winning performances through their increased versatility?

To answer this question we must review how modern technology has had to be adapted, and is continuing to be adapted, to cope with as many environments as possible. Perhaps the most difficult challenge has been in regard to system timing. Cable systems obviously can distribute accurate timing along conductor pairs to each box attached. But remove the cables and you remove this type of timing too, so cableless ground units have had to get the information some other way. This has been seen potentially as an Achilles' heel of the hardware.

In the cable-free world, every ground unit has to contain an electronic clock both to drive precise analog-to-digital conversion, and to allow recorded data to be accurately time-stamped at regular intervals so that they can later be synchronized with source-timing information. This has a few problems; one is that all electronic clocks drift, especially with temperature and especially the cheaper ones. This is traditionally helped by use of GPS PPS signals, but this is not a universal solution.

Mesh radio network on iSeis's Sigma system. "Cableless no longer means QC-less."

Ground units may each have their own GPS receiver and use this to adjust the internal clock and to provide the time stamp. (In some cases, it also gives box location.) There is a question as to whether it's better to have a more accurate clock that needs help less often from GPS satellites (thus overcoming problems of when GPS reception is marginal) or a less accurate, and probably lower cost, clock that needs GPS lock more often and could potentially end up taking more power.

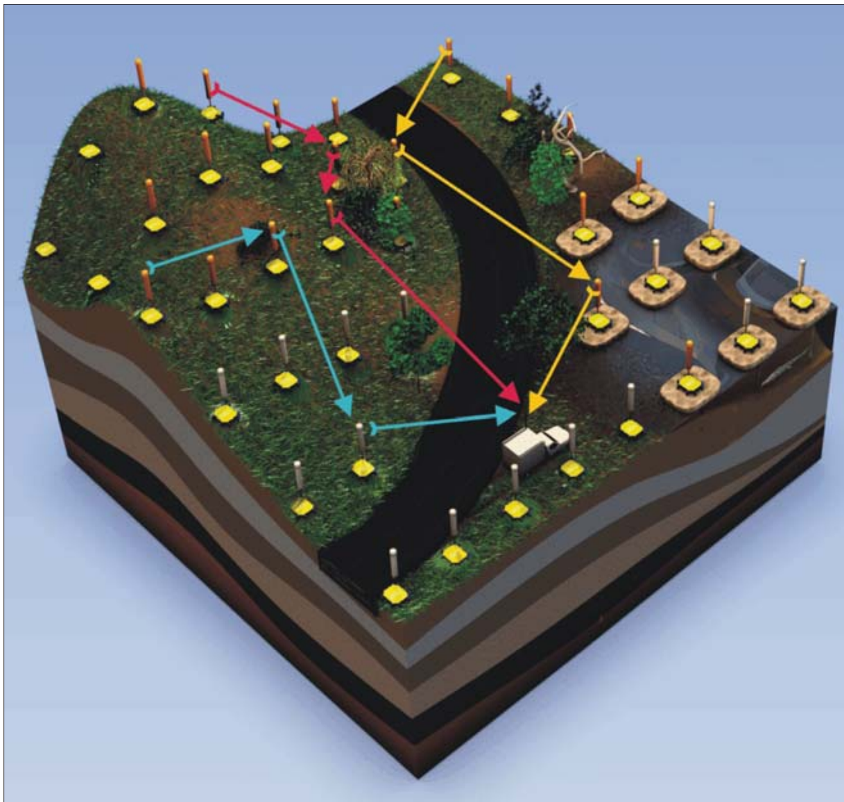
The decision to use an accurate/expensive internal oscillator probably affects how universal the cableless product can become. The issue is exacerbated when cable-free systems are in a shoot-blind mode in marginal GPS reception areas—perhaps they get GPS lock at the time of deployment but lose it a little while later. As no information is being sent back to the central system, then data could be lost, or the system just not function (both problems which could go unnoticed until it is too late). Relying wholly on GPS for systems which are entirely shoot-blind may be problematic for some "customers." I suspect that S2K did not entirely foresee this.

A solution for when GPS reception is marginal (e.g, when station units are deployed under heavy foliage) is to synchronize the recorded data or the ground unit internal clock by some other method. One way would be to distribute timing information over a VHF radio channel, which penetrates foliage better than the high frequencies emitted by positioning satellites. Each box then needs a suitable radio receiver, but various RF-based methods of redistributing timing have already been successfully demonstrated.

However, some have pointed out that even this is still not good enough to make cableless as universal as it must be. There still may be problems of radio licensing or RF absorption. What is needed, if there is to be a brave new cable-free world, is a way to get timing that does not rely on GPS at all. This would be especially important for shoot-blind operations, all marginal GPS-lock environments, and essential to allow cableless equipment to be used while submerged. (Transition zone and shallow-water markets used to be the natural homes of radio systems. S2K needs to keep them happy too.)

The way around GPS timing deficiencies is to have ground/TZ units (or seabed units) synchronize using repeated seismic shots. The technology already exists to do this. If we can know the precise initiation times of some original and repeated but identical shots, then any apparent difference in traveltimes to the same receiver location are measurable and are attributable to clock drift which may thereby be corrected in processing. This sort of approach makes cableless equipment much more universal than relying on US Department of Defense orbiting equipment alone.

An area where S2K did prophesy requirements well was in terms of the need to provide an option for getting some information back to the central system reassuring that "all's well with the line equipment." There are many operational advantages to shooting blind, and I suspect that the larger the seismic crew, the more likely it is that operators will chance deploying equipment that does not report back whether it's still there and working. But in some parts of the world, acceptance of cable free is stalled because of the lack of any low-cost or reliable ability to return any of this "reassurance data" (QC and status are sufficient for most purposes.) After



Routing of signals in mesh radio network. Communication is two-way and allows remote control, QC, status return, etc.

can be remotely controlled—a big bonus when it comes to battery energy saving. I forecast that MRNs will be one of the main research areas of seismic instrumentation in the coming decade.

One problem with cable systems that S2K equipment has very nicely addressed is improving receiver roll rate. This new equipment is far easier to move, and to then get up and running than anything that needs long lengths of heavy cabling to make it work. But this high maneuverability can present problems. The benefit of cable hardware is that, once the cable network is complete, data conveniently pour out of the twisted pairs and quickly end up as SEG D or SEG Y files in the recording truck, ripe for processing. This happy state of affairs clearly cannot exist in the cableless domain. So even though the S2K paper did not realize it, significant innovation has had to go into rapid data harvesting.

Some S2K-type technologies have the option to add on hardware, which permits long-range, high-data rate, wireless data retrieval. Some can perform short-range connectivity for "pass-by download" and permit harvesting even without interrupting acquisition, but these are the exception. Most cableless systems require the user to go collect the ground units, bring them back to some centrally located staging area, and pull out the seismic files. Data retrieval is an area on which the original S2K document did not dwell, but efficient file retrieval may turn out to be one of the essential keys to the technology's success. It might also well be an area, like mesh radio and alternative forms of system timing, where the industry will be putting more development effort.

all, if you know the box itself is functioning, is still where you deployed it, that the sensors all test well, and sends you rms noise figures, and the battery is good, then you have pretty much tested everything that can go wrong.

Most understand that returning such information packets from thousands of channels is a technologically far more doable proposition than sending all the data back wirelessly, which may require hundreds of times the bandwidth. Nevertheless, only recent technological breakthroughs are making the possible transmission of QC/status data from thousands of scattered channels in reasonable time periods, and without tying up large sections of some unlicensable part of the radio spectrum. The way that this transmission problem is being solved is with the use of mesh radio networks (MRN) installed in each seismic ground unit.

MRNs are not like any other form of radio communication. Seismic MRN-enabled ground stations within a mesh system rely only on being able to communicate with one or a few of their closest neighbors, which in turn only have to communicate with a few other near neighbors, and so on until there is a complete path from each unit back to the central unit, and vice versa. Mesh networks thus provide redundancy so that when one node no longer operates, the rest of the nodes can still communicate with each other directly or through one or more intermediate nodes. Two-way mesh networks using license-free radio frequencies have recently been successfully demonstrated in the cable-free arena showing that "cableless no longer means QC-less." It also means that cableless boxes

The S2K paper and subsequent workshops, as far as I remember, paid relatively scant attention to source control, saying little more than that new hardware should "interface with existing equipment" or that consideration be given to new source initiators that would fully integrate with the recorder. It did not foresee the huge source productivity improvements that would arrive or the knock-on effects this may have for instrumentation. And indeed, some cableless products, in order to push productivity boundaries even further, have devoted as much effort to the high-level, source-controller integration as they have to perfecting the line equipment.

Most especially, quite a number of new vibroseis techniques have been perfected since 1996, including HFVS, slip sweep, ISS, DSSS (the latter two advancements are both thanks to Jack's former employer) and their variants. Some of these multisource operations can produce over 10,000 VPs per day and place severe strains on older acquisition systems, not just because of the number of channels, but because of the quantity of cable on the ground. So cableless equipment looks ideal to take on this sort of operation and do well.

But no matter how many independent fleets of vibrators are being used (and some vibroseis control systems can now handle up to 255), we must know where all fleets are for every sweep and which shots are recorded. For each group of vibs, we need to know the center of gravity for each array of vibrators, and for single-sweep operations this is just the average of the vibrators that actually shook for that sweep. For multisweeps with move ups, each sweep on the VP must also be averaged. (Some GPS-view programs can even monitor all vehicles on the crew and interface with Google Earth.)

This huge volume of source-position information must be recorded and documented as the survey is performed, and merged correctly with the vast amount of seismic data being recorded and harvested by various methods from cableless equipment.

Trying to do all this after the fact is almost impossible. And it is a situation that will only become more complicated as new systems allow ever higher production rates, or new methods of S2K-related exploration (e.g., multitarget simultaneous acquisition) put further strain on source-receiver integration. From my recall of the S2K meetings I attended, I do not remember anyone realizing how much effort would have to go into this area.

Conclusion

Viable cableless seismic has taken longer than most hoped or expected back in 1996, and I suspect the reason is that it wasn't proving flexible enough. New generation recorders are changing this, though "System 2000" has ended up more as "System 2009." New applications, apparently just perfect for what seismic without cables has to offer, are also emerging, including passive monitoring and permanent installations for the "E-field."

This is all just the beginning of a new era. The experience of the last 13 years should make us all optimistically curious as to where it will take us. All we can be sure of is that only the most adaptable instrumentation will be along for the ride.

Suggested reading. "An update on string theory, or the grand unified approach to land acquisition" by Heath (*TLE*, 2005). "Rapid acquisition of small 3D seismic surveys: Urban areas within the Fort Worth Basin" by Bowman (SEG 2006 *Expanded Abstracts*). "Channel-count requirements for 3D land seismic acquisition in Kuwait" by Rached (EAGE 2007 *Extended Abstracts*). "Cable-free freedom" by Heath (*GeoExpro*, 2007)."Wireless geophone networks for high density land acquisition" by Savazzi and Spagnolini (*TLE*, 2008). TLE

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Postscript

Courtesy of Bob Heath and *TLE,* I am invited to add a few words to Bob's paper, apart from saying that he has been very generous to me with his credits.

So, would I like to add anything to my *TLE* article of 1996 (or indeed to my *First Break* paper of 2003)? Bob's article has already said much of what I would have added, so I only have a few comments.

If I may, I will make the observation that we are a very conservative industry, and so it takes a long time to bring new technology into production—a complaint which I have heard many times from drillers and engineers as well as from our seismic community. It doesn't have to be this way, but change usually entails a bit of risk-taking, and we do seem to be excessively risk-averse. Luckily there are some exceptions, and I am pleased to cite the ISS methodology which moved from an idea of Dave Howe's in 2004 through some feasibility tests in 2005, to an at-scale field test in 2006, into production in 2008, and broke vibroseis production records on WesternGeco's field crew for BP in Libya in early 2009.

These high production rates (in excess of 13,000 VP/day) will of course put pressure on the sensor and recording technologies in terms of reliability and ease of moving the equipment around!

Likewise, the continuing move towards higher channel counts has tended to increase the overall weight of the gear and also the overall power requirements (and maybe stretched the data transmission capabilities on systems which transmit all the data back to a central location). But there is no doubt that the improved ground sampling which is allowed by these high channel counts has greatly improved the seismic quality, so congratulations are due to those who have enabled us to achieve this.

Fast production rates? High-quality seismic? These surely form an irresistible combination. Recall the huge improvements in the marine seismic systems which took place over the last 15 years. We tow more and more streamers (and longer ones) closer together and surveys are generally quick and efficient. The improved equipment has given us better-sampled data which in turn have triggered the development of improved processing algorithms. So do we spend less on marine seismic as a result? No! We spend ever-increasing amounts on it because it represents better and better value for money.

The same will happen on land. In the short term, the extra costs of the extra channels will be more than offset by the faster speed of the crew. As the recording equipment continues to progress, we will be able to continue to increase the channel count. The channels will become lighter, cheaper, smarter, and will use less and less power. They will be mass produced.

In my 1996 article, I mentioned US$1000/channel as a suitable target. Actually, I had wanted to write a figure such as $50/channel, but even I realized that the time was not right —because every time I mentioned this figure verbally, I was ridiculed by half of the listeners and hated by the other half. And if I was to push that figure now, I would lose that credit which Bob has so kindly given me. TLE

—*Ian Jack*