PIC Technology Review

2013

PIC Staff

IRIS PASSCAL

New Technology Report
PASSCAL Standing Committee Summary

Over the past two years, the PASSCAL facility has conducted an extensive review of existing and emerging technologies to support the academic research community's seismic recording needs. This has been a significant undertaking because (1) IRIS PIs represent an incredibly broad range of science and field-recording needs, and (2) the seismic instrumentation market is currently undergoing very rapid evolution. Much of the recent technical evolution is focused on integrating and streamlining operations and reducing costs for features and data quality that the research community has come to expect.

This study attempted to address seismic recording holistically, including sensors, data recording, power systems and communications. The resultant report is *not* focused on recommendations for single-instrument packages for programs/initiatives such as Large N or RAMP. Rather, it reports on a wide range of seismic recording capabilities that has relevance across the entire scope of the PASSCAL program and all of IRIS.

The full report outlines the state of these technologies. Here, we outline a few overarching themes relevant to the PI community that ultimately drive and support the PASSCAL program.

1) Technical improvements exist today or are in active development that can improve the way we acquire data at virtually all scales.

The most obvious improvements are lower power, improved batteries, smaller instrument size and weight, larger data capacity, and improved data streaming. None of these are surprising, as they are driven by the rapidly evolving broader electronics and software markets. Modern systems have the potential to provide "dirt to desktop" solutions that streamline and improve quality of both field operations and post-field data preparation. Less obvious improvements lie in the robustness of some of these instruments under harsher conditions, such as in boreholes, wet environments, cold environments, erupting volcanoes, etc. The instruments described in the report range from incremental to significant improvements in data acquisition capability. Given that most of IRIS's existing technologies are decades old, *any* investment in new instrumentation will expand the types of experiments that can be performed using PASSCAL equipment as well as improve the user experience (fewer service runs, easier deployments, etc.).

2) Technical improvements do not increase the cost per station.

In almost all cases, costs are reduced relative to recent purchases. This is due both to improvements in manufacturing and to adopting developments from the broader electronics markets.

3) Existing and imminent technical developments can enable new science directions.

The most significant advance is the capacity to deploy a larger number of stations through a combination of reduced instrumentation costs and reduced field logistics. This advance is enabled by technical developments described in this report and exists at all scales. A second significant advance is the quality and cost of sensors in the intermediate-period band, which is currently served only by long-period instrumentation that is expensive and inefficient in the field. These two developments provide the potential for array recording of non-aliased wavefields at scales that are not possible today - the Large N philosophy. The largest potential for new science capacity is likely to be at intermediate periods, which include societally relevant topics such as earthquake hazards and nuclear verification.

4) Active technical development is occurring both at the traditional earthquake instrument manufacturers and in industry, and there is an increasing overlap between these systems.

First, industry has recently invested heavily in non-cabled nodal recording systems, which reduce field effort and environmental impact. This has been enabled by the same power, size, memory, and reliability improvements in electronics that are described above. Second, industry is becoming interested in recording at lower frequency ranges, at least to 1 Hz and perhaps to many seconds, as well as in passive, continuous recording. Both are being driven by characterization of hydrofracturing and by the need for longer wavelengths to enable full-waveform inversion at the basin-to-reservoir scale. This is a significant and recent change that may reduce costs and create improved synergies between IRIS and industry seismology.

5) The investigations detailed in this report directly inspired some of the new technologies outlined in the report.

Many of the systems described in this report did not exist two years ago. Most notably, in response to the inquiries of this investigation several traditional manufacturers have developed smaller, more efficient systems at lower cost, as was made apparent by visits to vendor booths at the 2013 AGU meeting. It can be argued with some conviction that IRIS inspired manufacturers to adopt modern technologies and solve some of our long-standing issues. Examples include borehole systems, intermediate-period sensors, and integrated all-in-one (sensor, DAS, power) systems. This rapid evolution delayed this report, but resulted in more exciting developments to report. At least within the traditional manufacturers, IRIS can (and should!) influence product development.

In addition, there are several significant technical themes in this report that we feel are important to highlight. These include:

1) All signs point toward the next generation of instrumentation being engineered specifically for vault-less deployment, either borehole or directly buried systems.

We cannot achieve a new era of science if we remain tied to vaults that are expensive and time-consuming and have a non-insignificant environmental footprint. A few vault-less systems have been tested by PASSCAL in the field and are available off-the-shelf today. While additional testing is required to prove this technology, it has the potential to significantly streamline operations.

2) Ongoing developments point towards the increased use of integrated systems, including sensor, DAS, and power, and incorporating dirt-to-desktop data streaming.

Effective use of such systems will require some standardization and perhaps fewer configuration options and more limited ability to mix and match hardware. The primary advantages are more robust systems and more efficient operations. Reduced, or at least not increased, maintenance may be achievable by purchasing fewer different systems and by lower replacement cost. A shift may be required from open-source to licensed software, but this may be an advantage by making data throughput a turnkey process. Standards set by IRIS are necessary to ensure quality and reduce maintenance.

3) No single technology exists that can meet the needs of the entire seismic community.

This is a natural consequence of the vast range of scientific scales and goals. Thus as decisions are made for future purchases, IRIS needs to carefully consider how to meet the needs of all communities, both existing applications and new applications that might be enabled by new technologies. That being said, the number of different systems supported by PASSCAL should be minimized to reduce support costs, perhaps through consideration of multi-scale embedded deployments. It goes without saying that acquisition of future instrumentation needs to be done with an eye towards ensuring continuity of existing capabilities. PASSCAL support for some of the existing systems will likely have to co-exist with support for new systems, at least for a period of time until all applications have been replaced by new technologies.

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Introduction

The New Initiatives effort at the PASSCAL Instrument Center (PIC) was undertaken to identify relevant commercial off-the-shelf (COTS) equipment, development efforts and industry opportunities that could be employed to improve the suite of instruments, field techniques and ancillary equipment the facility will need to support the PASSCAL Program mission now and in the future. This report is a snapshot of the state of the art equipment on offer by vendors and is contrasted with the legacy equipment currently in the PIC pool. The goal for a community pool should be for easily and successfully deployable instruments that produce high quality data that are easily archived and support the majority of experiments proposed for the least effort and cost. Simplified and purpose built instruments allow time and effort to be focused on research rather than data collection and archiving.

The aging and high percentage of un-repairable broadband (BB) and sensors in the pool is the most critical component to invest in to support the core mission of the PASSCAL Program. Several manufacturers are producing new posthole BB sensors engineered for temporary deployments appropriate for replacing the existing BB pool. PASSCAL has invested in a limited number of these posthole BB sensors, but discreet system components are not an optimal solution. The solution to simpler, cost effective and more reliable broadband or high frequency seismic station is an integrated system, including all the ancillary hardware, operational software and field archiving. An integrated system would encompass the majority of PIC experiment use-cases and engineering a system for rarely used scenarios increases the costs, complexity and chances for failure. The energy exploration sector used the approach of fully integrated systems with the cabled systems and the new cable-less autonomous nodes that are being built and currently deployed.

Most significant Technology developments for the IRIS PASSCAL Program

- Energy Industries increased utilization of lower frequency signals and continuous recording.*
- Adoption by the energy industry of autonomous node recording both blind and telemetered.*
- Emphasis on development of posthole type broadband seismic sensors by the traditional broadband vendors.
- Production of a very low-power and very small form-factor broadband with a higher noise floor, (exploration/research grade?).
- Digitizer and sensor integration efforts by all broadband vendors along with a simple deployment system.
- Development of new software and web access to statistical station analysis tools to easily characterize station performance and health.

*Investment in hardware, software and field techniques that will benefit the research community with new and most likely less expensive technology now and in the future.

Broadband Sensor and Integrated Systems: Portable Broadband Sensor

Summary

Two broadband sensor vendors are building new posthole type BB (broadband) sensors compatible with temporary station installations. Both Nanometrics and Streckeisen build next generation posthole/borehole instruments with performance comparable to the current pool of PASSCAL BB sensors. The significant difference between these new sensors and those requiring a vault are:

- Don't require leveling feet or precise leveling on installation
- Don't require vaults
- Are constructed of materials that don't corrode in groundwater and include robust cables
- Have tilt tolerances of greater than 4 degrees
- Environmentally rated for immersion to depths of 10 meters, some much greater for deep boreholes
- Deeper install will improve data quality
- Less loss of expensive data and sensors from environmental damage
- Alignment techniques that are simpler than vault type instruments

These new sensor designs address the needs of most portable type deployments that require quick installations on tight budgets and schedules. The environmentally robust design is a more appropriate install in shallow holes because it mitigates one of the worst causes of internal noise in a BB sensor, temperature fluctuations. In most places the solar loading at the surface can exceed 40˚C of temperature change. Installing the top of the sensor at least 0.5 meter below the surface mutes the diurnal temperature changes to less than 0.5˚C. Direct burying the sensor also eliminates most noise created from the circulation of air around the sensor and compacting around the sensor should reduce the time needed for settling of the disturbance the bore creates. Sensor installations can be completed in less than 20 minutes with little concern of flooding destroying the sensor. Further advantages of posthole sensors include: simplified siting; less material and cost for station construction; a more consistent install; less instrument loss; and a better data product.

There is a competitive market for more appropriately purposed BB sensors. Several vendors are interested in direct burial style deployments and are becoming more aware of the limitations on temporary seismic deployments. Furthermore, pressure from the energy industry with their interest in lower bandwidth energy, will provide a market to increase competition and lower the cost of equipment.

Broadband Sensor Requirements

The 1984 IRIS proposal notes the requirement for a portable broadband instrument to be developed for the PASSCAL program with a "usable" response from 100 seconds to 20Hz and a total pool of 400 three component BB instruments sets. The program was very successful in fulfilling and exceeding these loose specifications and requirements with the acquisition of the newly developed Streckeisen STS-2. The program today, including Earthscope, does not have a reviewed portable broadband sensor requirement; all new sensors are compared to the STS-2 that became the standard for portable BB seismometers. The GSN has a specification for both vault and borehole instruments. This specification could be used as a template to develop a new PASSCAL specification. What is generally accepted as broadband (BB) vs. very broadband (VBB) vs. short period(SP) sensors was described in an IRIS workshop on broadband seismology (Lake Tahoe, CA, 2004). A BB sensor specification can generally be defined as having a flat ground velocity proportional response from .01 -50Hz and a self-noise below the NLNM (new low noise model). Field and pier testing will be required for all new sensors. One test comparing vaults to directly buried sensors has been completed by PASSCAL and another is ongoing in Alaska. Both test have demonstrated equal or better performance of direct burial vs. shallow PIC temporary vaults.

Legacy Systems

The PIC BB pool uses sensors from three vendors: Streckeisen/Metrozet, Guralp, and Nanometrics. The queue for using these sensors can be up to two years depending on the number of stations requested. Sensor demand, experience in building sensors and cost were problems encountered when building up the inventory in the early years of IRIS. The vendors, Streckeisen and Guralp, had limited production and had no reason to create more production capability. The situation changed when Earthscope was funded and the vendors struggled to create production lines to produce 800 more sensors. The success of the US program encouraged others outside the US to create similar programs and initiatives creating further demand for instrumentation. Today there are two more vendors, Metrozet and Nanometrics, successfully building new models of BB sensors and a few that have faltered. All the vendors have unofficially "end of life" some components and models. The PIC has a range of model years that included some of these components and the list of models and parts not available is growing. There are over 1200 broadband sensors in the pool and approximately 150-200 in the repair queue. The PIC has a large number of broadband type sensors identified as intermediate and short-period, 200 Guralp 30 second corner 40Ts and 100 1-second corner Guralp 40Ts. Approximately 50% of the intermediate period sensors are in need of repair and because of the backlog of the higher priority 120 second corner instruments in need of repair and cost these sensors are being considered to be decommissioned as they fail.

Issues of Current Systems:

- Some parts for older units can't be purchased
- Sensor designed for pier installation in protected environment
- Sensor not waterproof
- Sensor corrodes when exposed to moisture
- Sensor electronics connected to case ground
- Very little centering range, limited tilt tolerance
- Sensor performance related to temperature stability
- Do not survive rough handling
- Parts are expensive and repairs require extensive testing
- Expertise to repair is limited
- Vendor support can be a problem and delayed
- Testing of older sensors takes more time than newer units and more iterations
- Maintaining performance specification harder with age and use
- Some response variance between sensors and models, hard to track

Benefits of Current Systems:

- Performance is well understood and not limiting in the majority of deployments
- Expertise in PIC to maintain most sensors
- Staff understand sensor issues and have developed training and techniques for "best practices" use
- Observatory quality recording where site noise floor is low and a high quality vault installed

Analysis of new COTS sensors and developments

Two performance groups are identified along with two overlapping deployment types.

1. Observatory grade, defined by lower self-noise at longer wavelengths, below NLNM from .001Hz to 10Hz. Cost $26,500.-$11,000.

- Use Pier:
    - Geotech KS-2000
    - Guralp 3T
    - Metrozet PBB-200S
    - Nanometrics T240 & T120PA & T120PHQ
    - Reftek 151
    - Streckeisen STS-2.5 & 5A
- Use simple bore to deploy in:
    - Guralp 3T
    - Streckeisen STS-5A
    - Nanometrics T120PHQ

2.Exploration, Research grade, defined by self noise below the NLNM at shorter periods, .04 - 20Hz. Cost $9,000.-$6,000.

- Use Pier:
    - Guralp 3ESP& 3ESPC
    - Metrozet MBS
    - Nanometrics T120Compact & T120PHC
- Use simple bore to deploy in:
    - Guralp 3ESP& 3ESPC
    - Nanometrics T120PHC

COTS Broadband Sensor Candidates as of 2013-10-1

Sensor Vendor/model	BB capable*	Low power ?	Directly buriable, tilt tolerance	Self Noise at 100 secs?	Cost (approx.)
Streckeisen STS-2.5	✔	.45W	No,	-190dB	$19,000.
Streckeisen STS-5A	✔	.45W	Yes, +/-5	-190dB	$26,500.
Guralp 3T	✔	.3-.75W	Yes, +/-2.5 ❄	-190dB	$16,000.
Guralp ESP	✔	.6W	Yes, +/-2.5❄	-180dB	$6,200.
Metrozet PBB-200S	✔	1W	No,	-180dB	$12,000.
Metrozet MBS	✯	.2W	No,	-170dB	$7,400.
Nanometrics T240	✔	.65W	No,+/-.2	-185dB	$19,000.
Nanometrics T120PA	✔	.65W	No, +/-.5	-180dB	$13,000.
Nanometrics T120PHQ	✔	.65W	Yes, +/-5	-182dB	$19,000.
Nanometrics T120PHC	✯	.17W	Yes, +/-2.5	-160dB	$9,000.
Reftek 151	✯	1.1W	No, , +/-.5?	-165dB	$11,200.
Geotech KS-2000	✔	1.5W	No, +/-.5	-180dB	$11,000.

*BB capable: ✔-Meets basic low noise specifications and bandwidth as set by PASSCAL Broadband Sensor Specification, ✯-Meets all but self noise requirement

Buriable: ❄-With modifications

New Posthole Sensor Features and benefits

The new post hole type broadband sensors

- Rugged, waterproof, appropriate build materials and connectors for a field deployment.
- Less cost, less time, less deployment engineering, less failure from exposure to environment
- Greater tilt tolerance.
- No adjustable feet!
- Small bore needed to deploy, not large hole to install vault.
- More siting options.
- Less material to be transported.
- Simpler concept of deployment.

The benefits of a vault-less seismic system

- Potential for better data, same instrument can be deployed deeper for less effort and cost.
- Less temperature swing when directly buried, less disturbance.at site
- More useful data with less sensor failure from tilt.

- Less time needed in field deployments.
- Uniform deployments.

Broadband Recording Systems: Portable Broadband DAS

Summary

The digital acquisition systems (DAS) required for recording broadband seismic data in portable deployments have a very diverse set of use cases. Portable deployments span most know environments on Earth from the ocean bottom to the high Polar Plateau in Antarctica. A wide-range of sensors connected to and a variety of sources recorded by these DAS further increase the unit complexity and cost by creating a need for many options and features not universally needed. The requisite flexibility of DAS function to serve the diverse set of use cases and the lack of IRIS purchasing power has discouraged the vendors from creating a product that is narrow in the mission it supports. The current offering of new, discreet DAS compatible with portable deployments of broadband sensors is not very different from the current pool of PASSCAL DAS. The average age of a PASSCAL DAS is 8 years and there has been little innovation to these systems over the last 10 years. For example minor and incremental improvements in cost, dynamic range, higher sample rates, size, greater media capacity along with a more comprehensive overview of reporting station status have been realized in the last few years. The miniaturization of a DAS for the realization of reduced volume, power, logistics, increased computing capability and cost savings is not likely for the size of the market the broadband vendors support. Most vendors have also moved to a web-browser for configuration, allowing for the use of many types of field servicing devices. The most significant change that is now being pursued by Nanometrics and Kinemetrics is integrating the DAS and sensor into a single unit which narrows the application, reduces costs and logistics, increases reliability and should simplify the data archiving process. However, an integrated system is not new. Guralp Systems has offered an integrated system for over ten years. Seismic Source is the one new vendor with a comparatively low cost digitizer utilizing the newest Texas Instrument 32 bit ADC (24 bit recorded) at approximately half the cost of the present PASSCAL systems and it can interface with the existing pool of BB sensors. If discreet components (DAS and sensor) is the method the community decides to pursue, then these types of inexpensive digitizer systems should be considered for specification testing and insuring compatibility.

DAS Broadband Recording Requirements

A general description of the broadband recording requirement as defined by Steim (1986) and Wielandt and Steim (1986) includes:

- Dynamic range: > 135dB
- Timing: GPS based with UTC time of at least 10 microsecond precision
- Sensitivity: Resolve small ground motion at the level of the lowest ambient Earth noise in a frequency band of .008 to 15Hz with great linearity
- Sample rates 1 to 40Hz
- Reportable filter coefficients

Some PASSCAL Program added requirements for new DASes:

- Data storage for at least 2 years at 40 samples per second
- Compatible with present BB sensors

Full performance requirements can be found in the Earthscope datalogger specification at http://www.iris.washington.edu/about/usarray/DAS6_RFQ.pdf. All the DAS considered for broadband systems will conform to the performance requirement. New DAS will require independent testing to be considered for purchase.

Legacy Systems

The two 3-channel DAS systems now in use at PASSCAL, Reftek 130 and Quanterra Q330, are mature and well understood by the PASSCAL Instrument Center (PIC) staff. Although mature, maintenance including firmware upgrades, repairs and testing are still a big part of the ownership costs. The majority of the broadband deployments use a very small range of the possible DAS configurations. Since these DAS are still similar to the newest flagship systems on offer from the respective vendors, a brief discussion of their common weaknesses and beneficial features is appropriate.

Benefits of Current Systems:

- **Digitizing performance**

The current systems have very good specifications for resolution, accuracy, sensitivity and timing and are only limiting when used with the most expensive and installation dependent broadband sensors that would not be deployed in a portable environment.

- **Power Efficiency**

Both of these systems require very low power, .8-1.5 watts in autonomous mode.

- **Portability**

Both of the systems can be deployed in a field environment and have relatively small footprints.

- **Familiarity**

After over ten years of experience PIC staff have a very thorough knowledge of these systems and a good relationship with the vendors. There is a large amount of documentation for deployment and training that has been developed and vetted along with specialized software and technical expertise in the operation and maintenance.

Issues of Current Systems:

- **Cost**

Current systems cost appears out of sync with the cost of similar technology with the same quality and features. The high cost is limiting the number of stations that can affordably be supported.

- **Size and Weight**

Size and weight govern logistics and impose limits what most researchers can field and support with the available resources.

- **Complexity**

The large amount of features and possible configurations that the current pool of DAS has make programming, cabling and servicing a nontrivial task. The added complexity contributes to data loss and other resource wasting. The meta-data problem created by this complexity increases resource requirements for data archiving.

- **Removable Media**

Both systems rely on solid-state, removable media for recording and quick servicing of a seismic station. Solid-state media is a continuing problem that will affect all vendors using this type of media. The main problem is that the media are mass-produced and that quality is inconstant, often dependent on the time of production. Media firmware also frequently changes making it hard for vendors to keep the DAS compatible with any new firmware requirements along with the demand by the users to make larger media cards available. The vendors have adapted by creating redundancy and fail-over type systems. Next to power issues, media is a significant cause of data loss and maintenance cost. A mitigation for future systems could entail a more robust disk-on-chip internally with a commercial grade removable media as a swappable copy that can be recreated from the internal disk on chip if corrupted.

- **Cables**

Cables are a multi-point of failure for both DAS systems. The DAS require multiple cables for deployment (e.g. power, GPS, sensor). Maintaining this large pool of cables is a growing and ongoing cost both in maintenance and staff time.

- **GPS**

GPS antennas in both DAS systems are weak points and need replacement. The Q330s external antenna is about half the cost of the external Reftek GPS that contains both antenna and GPS board.

- **DAS Enclosures**

Water damage and/or immersion are the primary cause of loss for of both systems. Both DAS are splash resistant, but often sustain irreparable damage with extended exposure and immersion in water.

- **Maintenance State**

These systems record various types of state-of-health (SOH) information to removable media, but not to non-volatile memory within the device. This prevents easily tracking problems over time or the development of a system capable of advanced and concise problem reporting. Subsequently, in-house testing and recording of maintenance information is time consuming and not scalable as the equipment pool increase.

- **Reliance on Specialized Handheld PCs For Field**

The PIC has already invested tens of thousands of dollars in new Apple iPod iOS handheld devices for field communications with Reftek DAS and the pressure is on to replace the Sony Clies Palm OS handhelds for the Q330s. If a common communication's protocol (e.g. http) were used for these DAS, the rapidly changing handheld device market would have minimal impact on PIC operations and budgets.

- **Factory Support**

Both Quanterra and Reftek provide good support, but there will be more component and end of life issues before too long which could lead to parts shortages and unsupportable boards/DAS. Any new purchase of equipment from these vendors should include negotiated extended support through the expected life of the new systems.

Analysis of New COTS DAS System Features

After meeting the recording requirements the most important feature of a PASSCAL portable system is reliable, autonomous operation along with telemetry capability. The most promising re-invented technology is a waterproof, integrated system. Internal telemetry is now an option for some of these systems including discreet DAS. Since the PIC supports experiments all over the world, internal telemetry is not recommended as it could complicate shipment due to import/export laws. Including telemetry inside the DAS also poses potential compatibility problems; the technology changes very rapidly and could become obsolete requiring more maintenance.

COTS DAS Systems

COTS Broadband DAS Candidates as of 2013-10-1

DAS	BB capable*	Low power	Field rugged	Telemetry optional	Cost (approx.)
Reftek, 130 based	✔	✔	✔	✔	$6,000
Quanterra, Q330 based	✔	✔	✔	✔	$10,500
Kinemtrics Basalt based	✔	✔	✔	✔	$8,500
Nanometrics Centaur+	✔	✔	✔	✔	$6,200
Geotech SMART	✔	✔	✔	✔	$8,000
PMD SD605	✔	✔	✔	✔	Quote Requested
Guralp SM24+	✔	✔	✔	✔	$5,250
EDS EDR-210	✔	✔	✔	✔	$8,100

*Meets basic performance specs as set by PASSCAL Broadband Datalogger Specification:
http://www.iris.washington.edu/about/usarray/DAS6_RFQ.pdf
+Available as an integrated system with sensor.

Discussion

The availability of the PASSCAL DAS, which is a measure of the robustness of these systems, is quite good. Both systems have slightly different complimentary strengths, weaknesses and features. The new discrete DAS systems available have no significant advantage over the present pool that would warrant having to replace them in the next five years. There is also a significant investment by IRIS in the present DAS pool beyond the DAS:

- Expertise - there is a knowledgeable, efficient and robust team for testing and maintenance in place along with deep field expertise and a training program for community.
- Cables - both digitizers have significant cable investments that will mate with the majority of sensors at the PIC
- Software - the PIC has developed the specialized applications needed for use in a support role. It could be argued the PIC has done a better job in many ways than the vendors in supporting their hardware with appropriate software.
- Parts - the PIC maintains approximately 1 year of most long lead-time parts for the Refteks.

Depending on the types of new missions to be supported by the PIC it would be advantageous to stay with the updated versions of the present systems and leverage the support the PIC has developed for these DAS. As we have significantly more DAS than broadband sensors, and that inequality is growing, it would take significant resources to have the staff spin up on a new system. If a substantially larger pool of these systems similar to the current pool were required for either a large N type initiative or an expansion of the current pools there would need to be more resources invested at PASSCAL to support that increase in volume, shipping, maintenance and user support.

PROPOSED INTEGRATED POSTHOLE SENSOR AND DIGITIZER BENEFITS

Integrating of sensor and digitizer will benefit the researchers using portable broadband sensors by lowering the cost of these systems when compared to discreet component seismic stations. The deployments will be much simpler and faster along with benefitting from the newest technology and software developments. The cost saving is expected to be 20% over an equivalent pier only broadband sensor and digitizer. Weight and volume should be reduced >50%.

A new integrated DAS and sensor system is a significant enough advancement to introduce yet anther system into the mix of PIC instruments and is the natural evolution of portable systems that are efficient and designed to perform in a portable deployment scenario. For portable deployments the engineered integration of a DAS with a sensor could achieve:

- Reductions in cost of systems and ancillary cables
- Logistical savings (shipping, storage, time in field, cost of vault components)
- Less complexity and failure points
- Increase data and hardware availability if designed correctly by insuring the system is waterproof and can be continuously immersed (#1 reason for total DAS loss)

An integrated system that can be directly buried will simplify the deployment by eliminating vault construction variability and will result in a simpler and uniform deployment strategy. Using these integrated system the reduction of meta-data issues will make it easier to archive data. One vendor has achieved some success with this integration approach and two more vendors are working on these types of integrated systems. Without the leverage of a large purchase to influence the features and requirements it's doubtful the results of these developments by the vendors will achieve the full potential of the systematic improvements that are sought. There is a parallel DAS and sensor integration process going on by the vendors for the energy exploration industry with substantially more resources available. The success of these energy exploration systems is measured in hundreds of thousands of integrated units fielded and reducing the logistical costs even more is driving further developments. The energy exploration and monitoring industry is the most likely driver of seismic system miniaturization and their investment to lower costs will eventually benefit the broadband seismology scientific community.

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Active Source Systems: Cableless Seismic Acquisition Systems

SUMMARY

The replacement for the Reftek RT-125A (Texan) and Reftek RT130 used for PASSCAL active source experiments ("legacy large "N") will be an environmentally rugged autonomous 3-channel (3C) node using GPS timing, recording for over 1 month at less than 50% of the cost of the current systems. These new systems are complete with download/charging stations, operational software (including programming, planning, data transfer and management system) and archiving software. There is a range of models from vendors to buy off the shelf that will fulfill the current role, adding much more capability and at a much lower cost. Recent 4D surveys completed by Nodal Science have demonstrated the technology in a concept of operation that had never been attempted in the energy industry or academia that demonstrated the potential. Further exploration of data handling and software capabilities, and the

extra shipping difficulties with the high capacity lithium ion batteries is needed. Some of these systems use Wi-Fi which can allow data downloads or SOH (state of health) monitoring but Wi-Fi increase the cost of the systems substantially and require more personnel to collect, analyze and monitor the data. All these systems are compact and made for deployers to be able to carry 4-8 in a deployment bag. Most of these systems can be leased for $2-$5/system/day (not including support) for a demonstration array without the commitment of purchasing.

System Requirements

The systems reviewed here are using the latest 32 bit or 24 bit ADCs and using GPS for time syncing to UTC. The recording systems are low noise, quieter than the noise floor of the geophones they normally record and are able to record autonomously for over a month. The IRIS PASSCAL community will set the final features and specifications.

Legacy Systems

Reftek RT125As and RT-130s have been used for the last 10 years and were the original autonomous 1-channel (1C) and 3C nodes. Well engineered for the types experiments that could be supported these units filled a requirement with the available technology, but required substantial support to make them operational through modifications to hardware, firmware changes, software development and mass replacement of parts including the data download systems. The DAS hardware and the ancillary hardware costs are probably close to $10,000 for the 2600 1C node system (not including FTE). To make a single channel system like the RT125A with all the improvements would probably cost about the same to design and build today, >$3,000, if there were only going to be 5000 custom made. This is the reason the energy industry can make a very specific tasked full system for as little as $1,500 with all the ancillary hardware/software needed. Some vendors produce over 100,000 DAS annually. All systems listed are likely to meet the primary performance and operational specifications of a future PASSCAL system.

System Evolution

Shift from cabled to autonomous nodes in energy industry.

Reasons:

- Geospace demonstrated a commercially acceptable design four years ago with GCR model
- Lower cost of operations
    - Less people, less time, less heavy equipment, less repair and maintenance issues
- Higher productivity/higher profits
- Confidence in equipment, seeing live channels not required though a percentage of stations are downloaded daily for quality checks, claims of up to 99% reliability
- HSE (Health, Safety, Environment)
    - Lighter nodes, no cables between nodes
    - Less impact on landowners and better security

Autonomous Seismic Nodes

COTS Cable Free Active and Passive Source Survey Systems

Vendor, node model	Self contained autonomy*	Weight (Kg)	Battery Weight (Kg)	Sensor
Fairfield Nodal Zland 1C	36 days	1.7	Internal	10 Hz + external
Fairfield Nodal Zland 3C	30 days	2.5	Internal	10Hz
AutoSeis	41 days	.3	3.2	external
Sercel RAU-EX3	12 days	1.6	Internal + optional	external
Geospace GCX	30 days	2.7	Internal	GS-ONE
Wireless Seismic	10 days	2.1	1.68	external
iNova Hawk	30 days	1.72	3.45	MEMS/Analog
Geospace GSX	30 days	.9	External	external
iSeismic Sigma	20 days + external	2.3	7.8	external
RT-125A (512MB)	6 days	1.1	Internal	external
RT-130	60 days	2.0	External	external
Sercel Unite RAU-EXD	12 days	1.95	Internal + optional	external

*2ms Sample rate continuous recording time

+Configuration settings 1-5 1-least

COTS Cable Free Active and Passive Source Survey Systems (Continued)

Vendor, node model	External Sensor Connector	WiFi Data transfer	SOH	Temp spec °C	Optional Settings+	Cost Based on ~5000
Fairfield Nodal Zland 1C	Yes	No	No	-40-60	1	$1000*+
Fairfield Nodal Zland 3C	No	No	No	-40-60	1	$1,400*+
AutoSeis	Yes	No	Yes	-50-85	1	$1,900
Sercel RAU-EX3	Yes	Yes	Yes	-40-60	3	$2,000
Geospace GCX	No	No	No	-40-70	1	$2,100
Wireless Seismic	No	Yes	Yes	-40-85	4	$2,300 *
iNova Hawk	Yes	Limited	Yes	-40-60	4	$2400*
Geospace GSX	Yes	No	No	-40-85	3	$2,600*+
iSeismic Sigma	Yes	Yes	Yes	-40-85	5	$2,700
RT-125A (512MB)	Yes	No	No	-40-60	1	$3,150 !
RT-130	Yes	Option, Limited to 200 sps	Yes	-20-70	5	$6,300
Sercel Unite RAU-EXD	Yes	Yes	Yes	-40-60	3	NA, Not sold in US

*batteries included

+sensor included

! does not include download stations

New Active Source System Features

- Very specialized systems = high production (everyone using these systems doing the same type of data collection).
- All 24 or 32 bit digitizing.
- Some models can be buried over 15cm and still get GPS clock locks.
- Very integrated software systems for programming, self-testing, performance recording, charging, survey planning and downloading.
- Very fast downloading, Example, Nodal claims 2GB/minute.
- Most report 98% error-free data recovery (includes all lost data for any reason)
- Fast battery charging for some, < 3hours for Nodal

After meeting the recording requirements the most important feature of a PASSCAL portable system is reliable autonomous operation along with the option of telemetry. Internal telemetry is now an option for some of these systems. Since the PIC supports experiments all over the world, integrated internal telemetry would not be recommend to avoid complicated international import/export laws. Additionally, given how rapidly communications technology changes, integrated internal telemetry is not recommended for the pool.

Caveats of New Cableless Seismic Acquistion Systems

- Most use lithium-ion batteries, UN3481 class 8 or class 9 hazardous material.
- Majority of vendors guarantee support for a 5-7 year operational life (not 15-20 years).
- Systems use large racks designed for mounting in truck trailers or milvans.
- Still no industry acknowledged solution for the problem of an inexpensive low frequency, low noise, low power and high gain sensor.
- Systems are highly integrated, requiring a commitment to a single vendor.
- Industry still growing and developing, expect some vendor, or specific models to be commercial failures.
- Free spectrum wireless standards and systems rarely are stable, expect phase out of wireless systems.
- The available 3C nodes are all discreet systems. At present fully integrated systems don't have optional external sensors.

Active Source Systems: New Sensor Technology

Summary

Broadband Sensor technology based on capacitance sensing negative force feedback transducers has not changed since the Streckeisen STS2 was created in 1984. Although the vendor's newer designs and models have been miniaturized. The newest re-casing of the latest models has resulted in sensors that can be direct buried or immersed resulting in a much more robust portable deployment and harsh environment tolerant design. For observing periods of energy in the seconds to 100's of seconds there is no other low noise technology that performs as well. There are a few new lower cost sensor developments that are being explored in the energy sector to expand the range of frequencies recorded to 10 seconds driven by the need for monitoring and passive recording.

Mettech. Makers of inertial sensors based on a technology called Molecular Electronic Transducers. Its liquid electrolyte based sensor being tested for active source systems, geophone in size and claimed to have a low noise floor and corner at 1Hz. The company is working with ASU scientists to develop a lunar seismometer. There is also a single component geophone that has been made and tested. There has been no update since 2011.

Silicon Audio. This group builds acoustic and vibration sensors based on force balance geophone with an interferometric transducer. Two vendors are investing in this development: Fairfield Nodal for the marine autonomous OBS (the Z3000) and Reftek for land applications. The sensor has been tested at ASL. The measured noise floor is still higher than proposed.

Symphony. This company based their sensor development on undamped ceramic disks and a interferometric transducer. No phone calls returned since initially tested at the PIC.

Shell/HP. HP and Shell have suspended development and are seeking new partners to continue the work on their custom high mass MEMs sensor and complete their integrated MEMs seismic data acquisition system.

Ancillary Systems: Telemetry

Summary

PIC is using modern telemetry that is commercially available. The obstacle to more systems and use is the greater costs coupled with a large increase in the time and personnel required to operate a network. Most experiments also archive data on locally recorded media since telemetry data always has data gaps, hence increasing the cost of data archiving compared to a stand-alone station. In areas where there is cell telephone coverage its simple to install telemetered seismic stations, cell cost is dependent on service contract based on usage. The cost of the old Earthscope's Flex Array (FA) program was ~$45/5GB/Month. Very reduced bandwidth can lower the cost to $5/1MB/month that is enough bandwidth for a state-of-health (SOH) message along with some data. This low cost and simple method to monitor a network hasn't been fully developed at this time except for Polar Regions where power and bandwidth cost much less than logistics. However, this development has not been tested scaled up to hundreds of stations.

Legacy

The PIC inventory contains cell modems, 2 types of spread spectrum radios that require an Internet access point, custom Iridium SBD and RUDICs based modems. The Transportable Array project uses VSATs and quite a bit of testing was conducted for TA at the PIC but no operational VSATs are left in the pool.

The modern cells and VSAT systems have the advantage that the gateway is supported by some other entity so it's less work overall. Spread spectrum type radios take more experience to plan the network topology, configure the radios and deploy, there can be conflicts between users of the free bandwidth that require reconfiguring the radios. This style of telemetry needs an access point to connect to the Internet. These free public bandwidth systems are time intensive for both the PI and the PIC.

Discussion

Most experimenters don't require real-time seismic networks to successfully complete their science objectives. The added cost and complexity along with the extra time required to maintain the servers, software and monitor the real-time information are significant costs when considering a new proposal. To fully realize real-time capabilities for the entire PASSCAL pool will require resource allocation, either by PIs or the facility, to build infrastructure and expertise.

LEO Satellite or VSAT Type: Costs for modems varies between $500-$3,500. Obstacle to more frequent deployment is cost, the extra power requirements, and with the time required for installation. For Polar Regions, SOH is needed for the long-term station monitoring and more efficient use of the limited and expensive logistics. When the polar researchers decide to return at least 20sps for all three channels it will more than double the stations power requiring a substantial investment in logistics, more energy storage, a new enclosure and personnel to manage and monitor the network.

Cell Type Modems: Certified units cost $300-$500. These systems work very well but require more power that can be an issue in colder climates and northern latitudes. What is lacking to really take advantage of these types of modems is software to duty cycle the power and to pull data with little management by personnel. At monthly rates as low as $5/month for a 1MB of data these modems could be a simple SOH device that can be turned on to send data of opportunity, such as a large seismic event.

COTS, EXAMPLES OF EACH RELEVANT SUITE

COTS Telemetry

Vendor/model	Up Speed	Power	Service cost $/data/time	Modem Cost
Xeos Iridium SBD Modem XI-202*	2,400bs	0.005-4W	$130./Unlimited/M	$1,500
Xeos Iridium SBD Modem XI-100B*	2,400bs	0.005-4W	$270./unlimited/M	$3,500
WiLan/AFAR SpreadSpectrum	1Mbs	1-5W	Need access point	$1,500
Cell Modem Raven X	60-100kbs	0.8-4W	$45./5GB/M	$500
Freewave 900MHz FGR	256kbs	0.1-1W	Need access point	$1,200
Wild Blue Exede	256kbs	20-60W	$60./5GB/M	included
Inmarsat BGAN Hughes 9502	448kbs	5-20W	$600./1GB/M	$1,500

*rates only available through DOD contract administered by NSF USAP program

Ancillary Systems: Power Systems/Battery

Summary

Lead acid AGM type batteries, simple solar charge controller and solar panels are the most robust and cost effective solution for longer endurance temporary deployments of over one month. Primary batteries are a good and simple solution for temporary deployments of over one month too if extreme cold or heat is a factor, security (bury most of station), low weight or robustness is required. Primary batteries can be an order of magnitude more expensive than lead acid rechargeable batteries. Wind generators, fuel cells and internal combustion generators are failure prone, expensive and hard to integrate in to the station in a simple temporary deployment. Wind and combustion generators create site noise in addition to their other drawbacks such as their need for maintenance. Li ion (lithium ion, different chemistries) batteries will eventually replace lead acid batteries, as the weight is 1/3 for five times the usable power. Li ion batteries are superior in almost every performance parameter except safety that can be addressed by packaging. As the push and progress for electric cars continues the lithium ion rechargeable batteries or some other battery will become affordable. Batteries are the crux for making lightweight, easy to install temporary deployments along with affordable logistics in extreme environments. Lithium style rechargeable batteries require a custom charge controller.

Discussion

Power system problems are the reason for most of the portable seismic system data loss. PASSCAL provides solar panels, solar panel mounts, and state of the art custom charge controllers but does not normally provide batteries for experiments. The PIC does provide recommendations and engineering support. Polar support is different in that the autonomous systems must be engineered as a complete station for the extreme environment. In the early days of the program, PASSCAL provided none of the components of the power systems but in the best interest of helping experiment success it makes sense that the integrator of the systems, the PIC, provide the solution for the use case the researcher is anticipating. All the requirements of the different components are considered to provide a solution that meets all the specifications of the equipment and the deployment scenario. The batteries, enclosures and siting are the part the PIC doesn't have much participation with except in Polar Regions.

COTS Batteries

Primary Batteries

Engineered Lithium Thionyl Chloride packs provide the highest energy density in a commercially available battery. However, they are relatively inexpensive compared to Antarctic logistics. Two good options primary battery options are:

- Lithium Thionyl Chloride
  - 190 AH at 18V = 3420WH
  - 5.4KG
  - Volume is .005m^3
  - $1,000/each
  - 3.42WH/$
  - Works in extreme temperatures, -55˚C to +85˚C
- Air-Alkaline (air cell)
  - 1200AH at 18V = 21,600WH
  - 34Kg
  - Volume is .04m^3
  - $1,000/pack
  - 21.6WH/$
  - Operating Temperature range, -20˚C - 38˚C

Secondary Battery Discussion

Summary of Li-Ion advantages compared to Lead Acid

- Higher voltage in lithium ion cells over lead acid 3.7v vs. 2.0v (almost 2x)
- Greater energy density per unit weight (3x), Volume (6x)
- Lighter / smaller providing more portability, less storage space, could even eliminate storage boxes
- Tolerates higher temp (140˚F vs. 80˚F)
- Faster recharge time, and more time between recharges (26 weeks vs. continuous or max 2 weeks)
- Higher turnaround charge efficiency (97% vs. 75%)
- More discharge cycles (2x)
- Deeper discharge tolerance (95% vs. 50%) – can offset cost due to shallow lead acid discharge performance
- State of Health and State of Charge can be readily and remotely monitored

- Longer time between service (24-36+ months vs. 6 months)
- Replacement timeframe Li-Ion 5-7 years

Battery chemistry comparison

- 40AH AGM, 13.8Kg, $100
- 40AH Li-Ion, 3.8Kg, $700
- 40AH $LiFePO_4$, 7.7Kg , $500 ($LiFePO_4$ less of a hazard)

COTS Charge Controller Candidates as of 2013-10-1

	Morningstar Prostar	**Trace/Xantrex C-12**	**GenaSun GV-15**
Self Consumption	23mA	5mA	2mA
Display	Yes	No	Yes
Max. Current	15A	12A	15A
Temp. Range	-40° to 60° C	0° to 40° C	-45° to 60° C
LVD	11.4V	11.5V	11.4V
MPPT	No	No	Yes
Regulated & controlled output	No	No	Yes
Temperature Compensation	-30mV/°C	-30mV/°C	-28mV/°C
Primary to Secondary battery switching	No	No	Yes
Cost	$230	$90	$250

Active Source Systems: Enclosures

Summary

Custom enclosures were first created for the polar program as an integrated solution to running portable seismic stations in the extreme polar environments. A custom enclosure can greatly reduce the time needed to construct a portable seismic station and also provide a convenient way to safely ship some of the major components such as the DAS and charge controller. Custom enclosures (not including enclosures for polar winters) are relatively inexpensive ($200-$500.) and greatly reduce the time required to install a portable station including the preparation time required to engineer, purchase and build unique systems. Some of the earliest polar summer only enclosures such as the MEVO boxes have been redeployed over 8 times proving the cost effectiveness.

Discussion

Enclosures are a relatively new addition to the PIC ancillary gear that is available. Besides protecting the batteries, telemetry, charge controller and seismic digitizer the enclosure made it easy to deploy a full broadband seismic station in under 1 hour in Polar Regions. For most deployments the station is running in the box before you reach the site. Custom bulkhead connectors, robust vault design and quickly deployable solar panel arrays as a part of a fully engineered and integrated system reduced to allow up to two full systems to be deployed from a Twin Otter aircraft. If an integrated system that includes an enclosure enables a 1-hour install in temperatures as low as -45C why shouldn't it be part of a fully integrated portable seismic station? During the FA part of Earthscope the PIC support for the FA deployments provided basic vaults and tough tote enclosures along with all the ancillary hardware to complete a station. This resulted in very uniform stations and less time spent at the station or scrambling to locate parts.

Example Enclosures Built at PIC

Enclosures	Solar panel?	Digitizer	Cost ($)
MEVO box	Yes	Q330/RT130	250
BIHO box	Yes	RT130	600
POLENET box	No	Q330	4,000
AGAP box	No	Q330	4,000

Large "N"

Any of the new COTS cable-less active source autonomous node systems could be purchase to create a large "N" system. All the energy companies use large "N" type systems, some with 100,000 nodes. These systems are well engineered and tested, complete, cost effective and commercially proven. However, there is not much choice in sensors for these systems. The majority of these nodes are only compatible with geophones and some with MEMs type sensors. The 10Hz ONE from Geospace is a common choice of geophone. A 5000-station 3C node system, including all the costs, is estimated to be $7,000,000. Breaking up the 5000 node pool into subgroups would cost more since one would have to duplicate software and download charging racks along with a data management computers. These active source seismic acquisition systems are very well documented and most include all the technical training required. It takes very little expertise and training to deploy, collect and successfully archive the data from thousands of nodes. The limitations of the legacy large "N" system (Texan RT125A) require expensive logistics if deployments are longer than 3-5 days. An experiment such as the Nodal Seismic's 5000 node Long Beach array work would be a monumental task. These new systems will enable new types of experiments to be supported from the PIC.

The energy exploration firms should be very interested in insuring future geophysicists are well trained and familiar with industry standard equipment. Since there is no comparable educational equipment pool at an industry or NSF sponsored facility it would be advantageous to approach the energy industry for a partnership through SEG and sponsorship that could build a research and teaching pool based on these types of instruments. A NSF MRI could be leveraged with the matching funds from a foundation or industry to purchase a system for the mutual benefit of both communities. SAGE (Summer of Applied Geophysical Experience) is supported by the SEG foundation and founding members of SAGE are members of the IRIS community. Lately SAGE has not been using the PASSCAL pool of instruments because of the age and applicability to their curriculum. This is a group to re-engage with the E&O of IRIS in any attempt to provide relevance to the SEG educational community and a connection to the industry too.

RAMP

RAMP (Rapid Array Mobilization Program) means different things to different researchers but the present system is composed of 10 Trillium T40s and 6-channel Reftek RT-130s. Most researchers would agree that this instrument pool is a high priority to replace with a modernized, easily transportable and quickly deployable system in greater numbers. The proposed bodywave specific integrated broadband digitizer and sensor systems from Guralp, Nanometrics and Kinemetrics are the recommended instruments for a RAMP if recording very small events is important though the cable-less autonomous nodes could be preprogrammed and deployed very quickly for an aftershock study to augment the broadband effort to create a mixed mode array. The newest instruments by Nanometrics are a likely COTS candidate for a new integrated BB RAMP instrument and the Fairfield Nodal Zland 3C a complimentary high frequency large N type system. Both of these systems offer capability lacking in older systems along with better performance than the PIC's present RAMP instruments.

An example proposal could include:

100 Nanometrics Meridian integrated Trillium T120PHC	$1,200,000.
200 Fairfield Nodal Zland 3C complete Mini Large"N" system	$505,000.
Ancillary gear needed for integrated broadband *	$100,000.
*(power, enclosures, telemetry)	
Total	$1,805,000.

An example telemetry system you could build for a quick deploy RAMP research grade broadband with modern ancillary equipment:

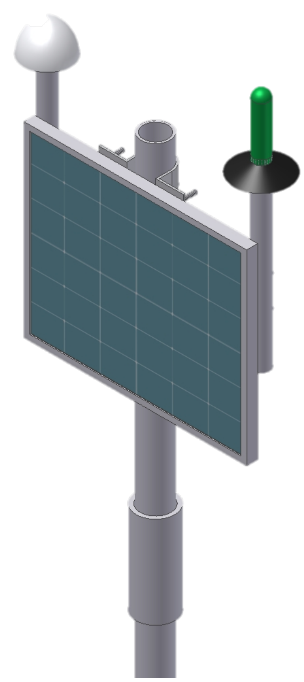
Nanometrics Trillium PHCompact with integrated sensor, lithium Ion Battery pack (40AH), 10W solar panel, lithium charge controller and enclosure attached to back of solar panel. A fence post is used to support solar panel, same auger used to install sensor is used to create solar panel posthole. Cost of system is estimated at $15,000 and total weight is 14Kg. Telemetry power usage is based on 100 sps 3ch digitizing and a duty cycle of 10 minutes twice a day with 60Kbs throughput. Data generation would be 1GB a month but most aftershock studies would need much higher sample rates. The cost of a commercial cell data service would be approximately $45/Month for 5Gb of data throughput.

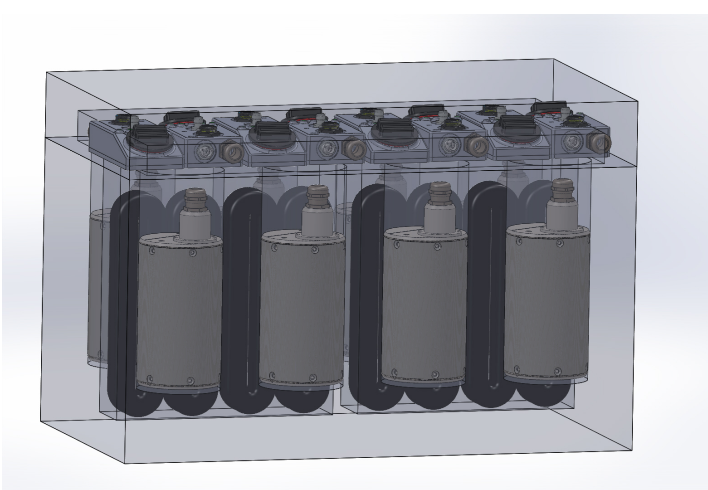
RAMP research grade broadband equipment matrix

Device	Pwr Input/output (Wh or total Wh)	Weight (Kg)	Cost ($)
Sensor/digitizer	1	1.5	12500
Lithium Ion 40Ah battery	560	3.8	$600
Enclosure	0	2	100
Solar panel	10	1.6	100
Charge controller	0.001	0.1	200
Pole, 5cm diameter, 2.4m		4.9	12
Cell Modem/controller	0-4W	.2	1,500
Total		14.1	15,000

Station autonomy in differing Telemetry modes

Autonomous with SOH	23 days
Realtime 0.5 day latency, duty cycle modem	22 days
Realtime, cell on	8 days





PIC New Initiatives Efforts, Meetings and Vendor Visits

New Technologies efforts at the PIC involve the IRIS PASSCAL Program manager and most of the staff at some level, from handling and importing new devices through the purchasing system to testing and evaluating a new sensor or emplacement technique. We use the experienced and professional staff to suggest, debate, purchase and evaluate any new equipment, ideas or new development that we think will benefit the PIC community and we have always partnered with the researchers and IRIS staff in these efforts. It's a group effort and the common goal is to provide the highest standard, appropriate, trouble free and robust equipment to the community on a very limited budget. Suggesting changes to the established "status quo" instrumentation and operations of the community and vendors has not been easy since both groups have a long history of successful experiments based on their own ideas of what is the best approach to equipment and to conduct temporary seismic array research. From our experience we see that many improvements can be made and new instrumentation development can be more appropriately proposed based on the PIC supported experiments in the past. It is the PIC's job to effectively convey these performance expectations and learned limitations to both groups and to successfully support experiments in every environment on the earth within the budget limitations of both the facility and researcher. We have had to develop the trust and relationships based on the performance of the PIC with both vendors and researchers to convey these new ideas and requests for improvements effectively. Success can be measured in response from the vendors in creating these new models of sensors and with limited prospect of orders. Investment in new instrumentation would insure the consortia has input on the details which could make a good new system great.

Vendor Meetings, Field site visits and workshops

Meetings and Workshops

- Polar Technology Conference Apr. 2012, Presentations
- IRIS Instrument Symposium June 2012, Presentation
- IRIS Annual Workshop Jun. 2012, Jun. 2013
- SEG, Nov. 2012 Las Vegas,
- SCAR Jul. 2012, GEOICE MRI proposal first discussed
- AGU annual meeting, Dec. 2012, poster presented
- Polar Technology Conference Apr. 2013 Presentation
- IRIS Instrument Symposium June 2013
- Large N Meeting, May 2013, Presentation
- SEG Nov. 2013 Houston

Vendor visits

- Guralp, @ Guralp, Jan. 2012
- Nanometrics @ Nanometrics Feb. 2012
- Xeos Technologies @Xeos Feb. 2012
- Quanterra @Quanterra Feb. 2012
- Genasun @ Genasun Feb. 2012
- Reftek @Reftek Mar. 2012

- INOVA Aug 2012 Visit to an active survey and meeting
- Geospace/Dawson @ Geospace Oct. 2012, Company tour, meeting and visit to an active survey
- Nodal Seismic @ Nodal Seismic May 2013, Meeting and visit to an active survey
- Kinemetrics/Metrozet @ Kinemetrics May 2013, Meeting
- Fairfield Nodal @ Fairfield Nodal Sept. 2013, Company tour and meeting

Vendor Visits to PIC

- INOVA Nov. 2012
- Genasun Jun. 2013

Science Facility Meetings

- Seis UK @ Seis UK Jan. 2012
- USGS CVO @CVO Jul. 2012
- USGS CVO @ PIC Aug. 2012
- USGS AVO @AVO Apr. 2013

Design Concept: IRIS Next Generation Broadband Portable Seismic Pool

PIC created a document used to help vendors understand the requirements for development of a quick deploy broadband sensor system applicable to a majority of the types of experiments the PIC has supported including RAMP. Presented to traditional PIC facility vendors: Quanterra/Kinemetrics, Guralp, Nanometrics, Reftek.

ISIS - Integrated Seismic Instrument System

This document is a desired feature and specification list for the design concept of a portable integrated datalogger and sensor package used for quick and robust deployment of seismic arrays or networks in a wide range of environmental conditions. This instrument will be compact, waterproof, corrosion resistant, and designed for the installation technique of direct burial or shallow borehole. The system will also be a low power, easy to install and service integrated system requiring minimal tools and time. The interface will be user-friendly and intuitive to configure with relevant and simple feedback on instrument state of health and operational status with the data ready to be directly archived with minimal handling to the IRIS DMC. The instrument must be capable of telemetry over conventional methods and internally store at least 64GB of data including a lifetime (10 years) of SOH and self-calibration data that can be offloaded and archived for review.

Instrument, Required Features

Package

+ Waterproof to 10m of prolonged submersion
+ Corrosion resistant, ESD proof
+ Designed to be direct-buried in 1m deep hole
- Minimal diameter, <15cm
- Less than 4Kg in weight
+ Waterproof, keyed connectors to provide GPS, communications, power and removable media dongle
- 0.5W average power consumption when running in stand-alone mode and minimal SOH telemetry
+ 9v to 36v input range
- -55° to 70° C operational temperature
+ Shock resistant (for rough transit)
+ Some self test and reporting capability

Seismic Sensor

- 120s to 150Hz Response
+ Tilt Tolerant to ±5°
- Noise floor below NLNM from 30s to 100Hz
- 30 mm/s Clip Level
- Easy to orient within ±1° of north when required

User Interface

+ Web browser based
+ Allows control of device

Datalogger

+ 64GB (or greater) on-board data memory
+ Lifetime SOH information
+ Ethernet Telemetry
+ IPv6 compliant
+ Internal GPS with external antenna for timing and self-location
+ Internal clock disciplined to GPS with <200µS error
+ Metadata automatically generated
+ Time series data and metadata encapsulated in a common file in an open format
+ Web browser interface for command and control
+ 24bit or better ADC
+ Multiple concurrent sample rates for multiple recording destinations
+ Ability to offload data at 1GB/min(could be removable media)
+ Telemetry and on-board data recording should be independent, a failure in one should have no effect on the other
+ Supports concurrent downloads over Ethernet

Telemetry

+ Supports multiple modes of transmission, for example:
+ SOH Mode, sends SOH data on a user-configured

+ Allows configuration and configuration cloning
+ Displays SOH information statically or graphically with a user selected date range
+ Displays interpretation of the SOH information
+ Easy to use for unskilled/inexperienced users
+ Ability to run a sensor calibration, store the result, interpret and report on the result
+ Data downloading should have no effect on the ability to command/control the device
+ Ability to view data metrics of recording (gaps, overlaps, % data available per day, etc.)

Items marked with a + (requirements), -(desirable features)

schedule with user selected SOH channels
+ Real-time Mode, sends continuous real time data and SOH
+ Low Power Mode, sends data and SOH on a user-configured schedule
+ Pushed alerts for errors and warnings