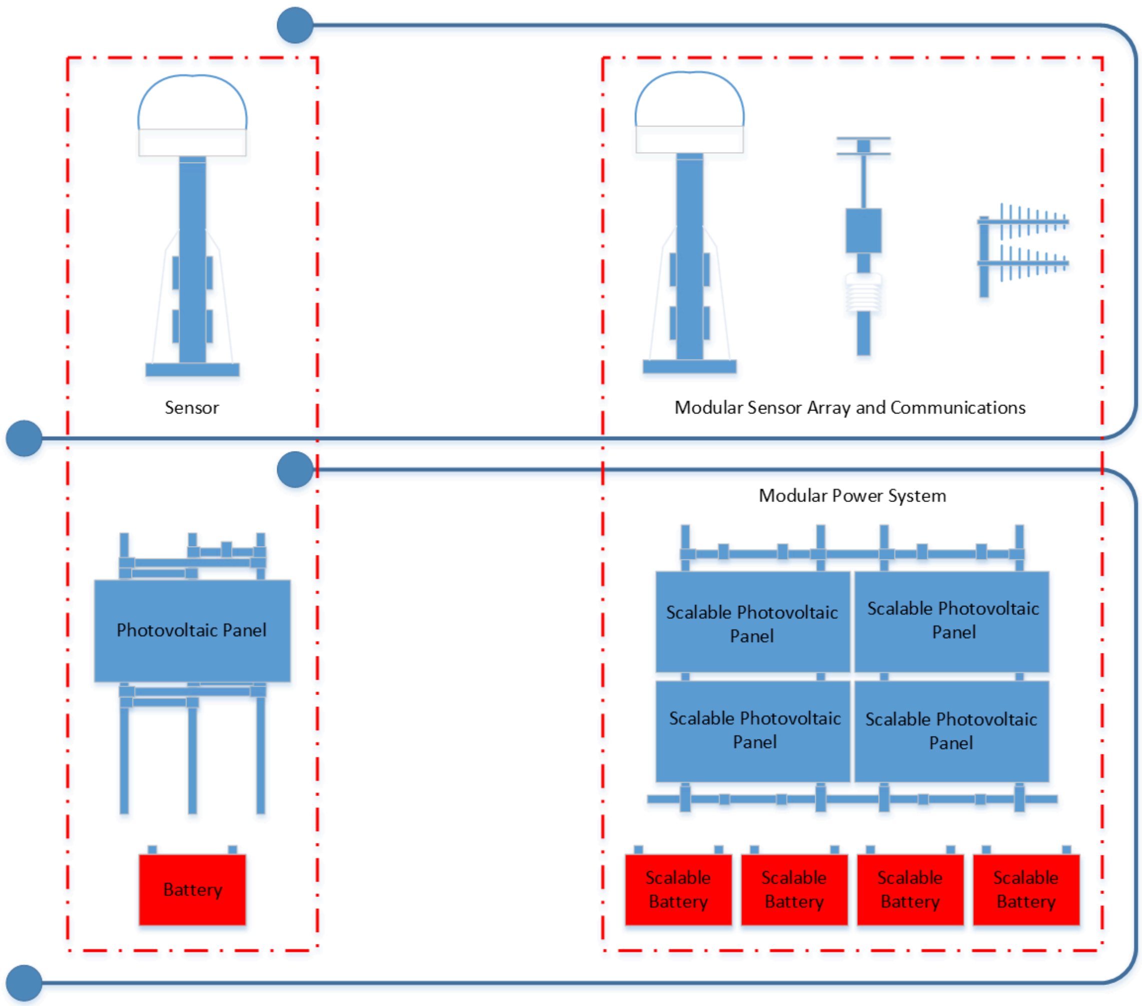

Common Sensor Platform Technical Design Document

Prepared by the Core CSP Team, Instrumentation Services, EarthScope Consortium
September 2024

EarthScope Consortium

Revision History

Date	Version	Author(s)	Change
9/30/2024	1.0	MO, KA, NB, GE, WG, WJ, DM, JS, MS, KW, EW, CP, EM	Creation

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Overview

For nearly four decades, versions of the National Science Foundation's (NSF) Geodetic Facility for the Advancement of Geoscience (GAGE) and the Seismic Facility for the Advancement of Geoscience (SAGE), now operated by the EarthScope Consortium (formerly UNAVCO and IRIS), have successfully managed and supported a multitude of geophysical instruments, experiments, and networks around the world. GAGE and SAGE have continuously optimized station design in support of Earth Science research and scientific goals. In April 2022, a team of engineers formed to undertake an effort to develop a Common Sensor Platform (CSP), standardizing station design into a scalable and modular framework to be used across multiple sensor types. Since the beginning of its efforts, the major objectives of this initiative have been to:

- Identify commonalities and differences in historic station designs.
- Develop a core sensor platform drawing from commonalities.
- Specify scalable and modular components for diverse environments and usage cases.
- Leverage Earthscope's broad engineering expertise to enhance design commonalities and optimize engineering operations.
- Foster a collaborative engineering culture for ongoing station/platform design and optimization.

These goals are in direct alignment with EarthScope's core organizational values and specifically strive to maximize scientific objectives and data return and quality through improved station reliability and reporting of in-situ conditions.

This Technical Design Document (TDD) is a direct deliverable of the CSP project and describes the most common core station framework and its scalable and modular features. The vast majority of EarthScope's funding is in support of permanent networks, thus this TDD directly applies to stations intended for long-term operation. However, the basic elements of this design can be translated to portable stations as well. Complementary deliverables to the TDD include:

- Existing Station Summary Report.
- CSP Requirements Document.
- Interactive "EarthScope-CSP Station Builder" Webtool.

Design Objectives and Benefits to Science Community

The CSP is designed to serve as a versatile and scalable platform for geodetic, seismic, and other geophysical instruments and networks in support of NSF-sponsored Earth Science research. Its primary design objectives are to streamline station design, installation, and maintenance processes while optimizing data quality and reliability based on a project's main requirements. The major design goals and benefits to the science community include:

Station Design Standardization: The main design goal of the CSP is the development of a standardized, scalable, and modular instrument platform that accommodates various sensor types and can be easily adapted to a wide range of scientific objectives and environmental conditions. In other words, the CSP streamlines and facilitates interoperability between the varying science support requirements that exist across the GAGE and SAGE facilities.

Common Componentry: While a site's geographic location will dictate material and component requirements, the CSP aims to standardize componentry where feasible. This will allow a stock of common components to be maintained and replenished on a wholesale basis, reducing inefficiencies surrounding minimum number orders, lags in manufacturing, and other third-party constraints. By prioritizing common components, this will allow EarthScope to work more closely with vendors and may encourage increased collaboration on custom pieces. This would be translated within the Earth Science community to more consistent and familiar components from project to project.

Enhanced PI and Science Community Support: By consolidating the efforts of Instrumentation station engineering, the CSP allows for externally-facing information to be better organized and distributed cohesively and efficiently to all stakeholders. Current versions of design materials will be made publicly available. These engineering products and tools will allow technical and operational information to be easily disseminated to researchers who may not have experience with field operations and station design, or who are looking to improve upon their station design.

Risk Mitigation and Data Integrity: The implementation of thorough testing and evaluation protocols for common components, which are being developed in tandem with the CSP station design, enhance system resilience, minimize errors, and reduce risk of data loss. By identifying and addressing potential points of failure proactively, the CSP will decrease station downtime, thus increasing data integrity across permanent networks and portable stations.

These design goals will continue to guide the development of the Common Sensor Platform through its future iterations, ensuring that it meets the evolving needs of Earth Science research and maximizes the value provided to the scientific community.

Increase Operational Efficiency: One of the major design goals is to increase operational efficiency by reducing the need for cross-training through the adoption of common elements and tools. The CSP design also helps standardize activities such as station installation, maintenance, monitoring, upgrades, and decommissions. The Earth Science community will benefit by adopting station designs and standardized operational procedures through CSP resources and by receiving a more uniform experience when requesting and receiving EarthScope project support across a broad range of projects.

Collaborative Engineering Culture: The CSP has set the foundation for a collaborative and unified engineering culture that fosters open communication, knowledge sharing, best practices dissemination, and continuous improvement. By leveraging the expertise of engineers across EarthScope, the CSP initiative creates a dynamic environment for innovation, interactive peer and science community review and feedback, and optimization in scientific instrumentation and infrastructure.

Exceptions to Design/Use: While the CSP is intended to provide a standardized framework for the most commonly deployed instrumentation and station designs, it is not intended to capture fringe cases that may depend on unique scientific requirements, environmental constraints, or other technological requirements. In such cases, deviations from the standard CSP design will be necessary to optimize performance or accommodate novel research needs or sensor technologies. Any such deviations should be carefully evaluated to ensure component and whole-system compatibility and interoperability.

How to Use this Document

This document describes the most common core station framework for geophysical instrumentation intended for semi-permanent and long-term operation. Many elements of this design can be translated to portable stations as well. While this Technical Design Document delves into minute station design and componentry, the Science Community may find the following aspects specifically useful when using this document:

- As a resource for selecting station componentry which have been field tested and selected for their functionality and reliability.
- As a guide on componentry scalability and/or modularity so station designs can be adjusted, if necessary, to meet science objectives and utilize available resources (Table 1).
- A comprehensive repository (Appendix A) and a list of materials with vendor specifications and links (Appendix B).

CSP Station Description

While utilizing the information in this document, it must be emphasized that "station" is an overarching term that covers an array of possibilities. Permanent stations, with indefinite timelines, may have different requirements compared to portable stations which may last from a few weeks to a short number of years. While this document allows for streamlining of components and flexibility of installation, there is no universal design that would account for all possible environments, deployment length, and science objectives.

The CSP station (Figure 1) consists of a Core Station design based on the most common elements, as well as modular and scalable components in order to meet the multitude of project requirements. This section provides an overview of the station design. A summary of the core, modular, and scalable components is provided in Table 1, while a comprehensive list of components is located in Appendix B.

Core Station Subsystems

The CSP station design is categorized into 4 major subsystems:

- Site Infrastructure and Mechanical Design.
- Sensors and Data Acquisition.
- Power System.
- Communications Systems.

Each of these subsystems and their core components are discussed in greater detail in their respective sections.

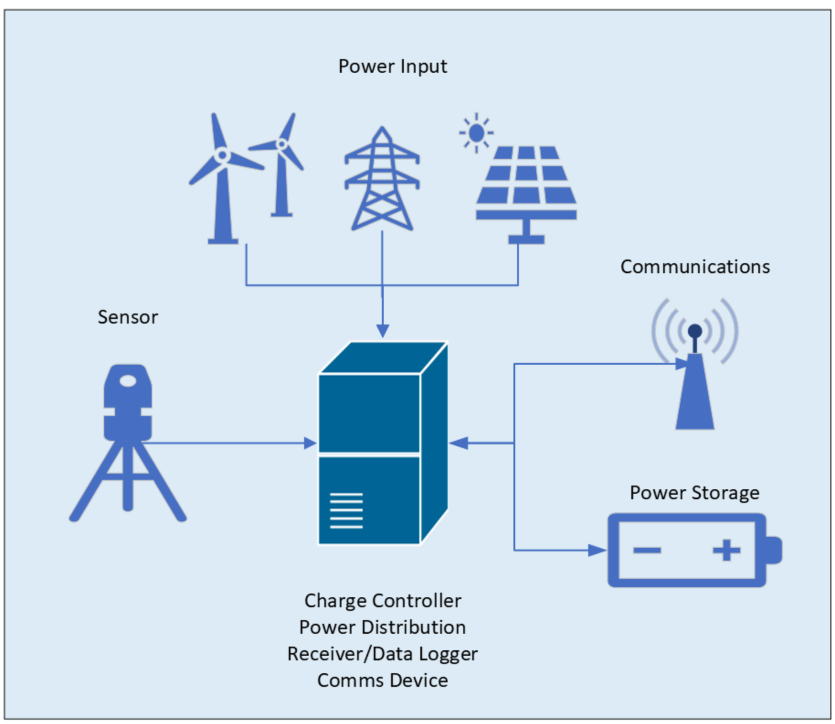


Figure 1: The main components of the CSP station design are shown above.

Core Elements

The Core CSP Station consists of:

- One or more sensors.
- A receiver or datalogger.
- A DC power system consisting of photovoltaic (PV) power generation, rechargeable battery power storage, a solar charge controller that regulates and distributes power, and a grounding rod.
- An optional telemetry device.
- An enclosure and additional infrastructure to house and secure the equipment.

Modular Elements

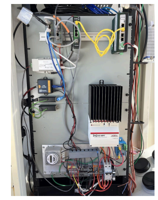
The core station design consists of modular devices and hardware capable of being re-used or expanded as project needs dictate, per Table 1. These devices are suitable for temporary or permanent station installations.

Scalable Elements

Some elements of the core station are scalable for different project requirements. Specifically, the power system, enclosures, or other infrastructure elements can be scaled as project needs dictate.

Core System Element Matrix

Element	**Modular**	**Scalable**	**Typical Example**
Station Infrastructure			
Enclosure (Rotomolded shipping cases, stainless steel, fiberglass, etc). Scaffolding (swingset, enclosure pole). Sensor Monumentation. External or ancillary power or communications enclosures can be added to the station design.	yes	yes	

Power System			
Power distribution back panel and terminal block: ● Charge controller - capacity can be increased based on need. ● High- and low-voltage disconnect. ● Power conversion including AC-DC and DC-DC power converters. ● Grounding system and surge protection. ● System voltage can be stepped up to 24V, 48V.	yes	yes	 
PV Panels can be added as needed.	yes	yes	 
Batteries - single use, lead acid, lithium ion. ● Battery size, type, and count can be increased based on anticipated or unanticipated external power outages.	yes	yes	 
Wind turbines, Thermo Electric Generators, or Fuel Cells can be added as needed.	yes	yes	

			
Communications Systems			
Communications devices.	yes	no	
Sensors, Data Acquisition, and Edge Computers			
Sensors and Data Acquisition Units.	yes	no	
Edge Computers.	yes	no	

Table 1: The Core Station elements are presented above.

Site Infrastructure and Mechanical Design

Station infrastructure varies on a site-by-site basis and is influenced by a wide array of factors, including the location, project scope, and environmental conditions. The selection of components for the site prioritizes utilizing parts that are readily available and cross-compatible with other systems.

Enclosures

EarthScope's recommended enclosure options are determined by a combination of environmental, sensor-specific, power, ventilation, and security requirements.

The following factors contribute to the overall enclosure selection and design:

Environmental	Temperature Moisture Corrosion Access considerations
Sensor Needs	Sensor mounting RF shielding
Power Needs	Sizing
Security	Enclosure armor Bear-proofing Cattle-proofing Repairability
Ventilation	Air exchange mechanism

Table 2: Factors affecting enclosure selection.

Our most commonly deployed enclosures are depicted below along with a brief description of their main characteristics and usage cases.

Rotomolded Shipping Cases (Hardigg and Pelican Style Cases):

Many geoscience field deployments use hard plastic cases to securely store and protect critical equipment, including batteries, power distribution systems, and data loggers or receivers. These cases are proven to withstand harsh field conditions over a number of years and are considered standard equipment.

Small Rotomolded Cases (Pelican) SAGE and GAGE Portable PI projects:

Small to medium sized cases for temporary to semi-permanent projects requiring a robust and easily modified case. Pelican Protector 1550 and 1600 cases and Pelican Storm iM2750 cases are recommended for small systems. For longer-term temporary deployments requiring slightly larger cases, the Pelican Protector 1660 case and Cube Protector cases are recommended.

Figure 2: The Pelican iM2750 Storm Travel Case modified for a temporary seismic deployment.

Dimensions / Weight: Varies by make and model.
Environment: Ideal for nearly all terrestrial environments not requiring significant thermal insulation.
Sensor**:** GNSS, seismic, and nearly any other type.
Power: Depends on size of case.
Security**:** Low. Case can be locked and secured to the ground.

Ventilation: Cases feature a pressure-relief valve to regulate the air pressure inside the case.

Large Rotomolded Cases: Hardigg MM36 and MM24 cases
GAGE Polar Permanent Station Networks:
Long-term projects requiring a large number of batteries such as the ANET and GNET permanent station networks which use ruggedized, insulated polyethylene cases to enclose batteries, power systems, and GNSS receivers.

The Hardigg MM36 and MM24 cases have been proven to work reliably in various environments for decades and to withstand the harshest polar conditions. These cases are commercially available (COTS).

Figure 3: MM36 (left) and MM24 (right) cases for Polar deployment.

Dimensions / Weight:

MM36: 34.4” x 27.4” x 23.4” / 45 lbs.

MM24: 48.6″ x 24.6″ x 19.7″ / 62 lbs.

Environment: Ideal for polar, alpine, and other cold environments, but can be used in nearly all terrestrial environments.

Sensor: GNSS, seismic, and nearly any other type.

Power: The enclosure can support up to six (MM36) or ten (MM24) 100Ah batteries.

Security: Very low. A small cable connects to a locking pin. In polar environments, stations are located in remote locations that are only accessible by small chartered aircraft. In other environments, additional security, such as a chain, are recommended.

Ventilation: Cases feature a pressure-relief valve to regulate the air pressure inside the case.

Figure 4: The Hardigg enclosures used in polar environments can hold up to ten large batteries. These cases weigh down the aluminum structure.

AL3434-2807 cases: GAGE Polar Permanent & SAGE Polar Semi-Permanent Station Networks:

The AL3434-2807 is one of the standard enclosures used for ANET GAGE Polar Permanent & SAGE Polar semi-permanent stations located in Antarctica.

Dimensions / Weight:

External Dimensions: 37.38” x 37.38” x 38.43”.

Approx. Internal Dimensions (Depends on insulation thickness): 26.75” x 26.75” x 25.5”

Uninsulated Weight: 66.8lbs.

Approx. Insulated Weight (Depends on insulation materials/method): 160-220lbs.

Environment: Polar (extreme cold, high winds, potentially coastal, snow loads, etc.).

Insulation: Custom insulation, including froth foam liner, polystyrene foam board, and/or vacuum insulated panels with acrylic/HDPE lining to protect the insulation.

Sensor: GNSS, Seismometer, accelerometer, and/or infrasound.
Power: The enclosure can support up to eight 129 Ah AGM batteries, with up to four additional supplementary Lithium Thionyl Chloride Tadiran 190 Ah batteries (as needed).
Security: None. Most Polar stations are located in remote locations that are only accessible by small aircraft.
Ventilation: Split gasket at parting line allows for pressure equalization.
Other Features: Sealed bulkhead with MIL SPEC connectors, stainless steel hardware, injection molded handles, hinged lid, stainless steel lift/tie-down rings.

Figure 5: A SAGE semi-permanent enclosure. This enclosure is insulated with double-layered vacuum insulated panels with a sealed acrylic lining encasing them for protection.

Custom NOTA Enclosure:

The standard enclosure used for the NOTA stations was designed in the early 2000s and is widely used across the network.

Figure 6: The standard NOTA enclosure.

Dimensions / Weight: 32″H × 16″W × 14.4″D / 40-70 lbs (aluminum vs. stainless steel).
Environment: These enclosures are suitable for temperate, tropical and sub-Arctic climates. They are not suitable for heavy-snow load environments.
Sensor: GNSS Receiver.
Power: The enclosure can support up to four 100Ah batteries, per the configuration shown in Figure 6.
Security: Lock.
Ventilation: Top and bottom passive vents.

Figure 7: This type of enclosure is typically mounted to a 2.5”-3”x 10’ galvanized steel pole.

Specialized Enclosures- Various projects:
Depicted below are a set of enclosures that are used in specialized environments.

Grizzly Cooler Rotomolded Case: Bear-Proof Alaska NOTA enclosure.

Figure 8: The Grizzly Cooler is a ruggedized case used in bear habitats.

AL3627-1505 Rotomolded Case Cases: Lithium-Primary SAGE Polar:
These enclosures are froth-foam lined for insulation and have structural internal foam compartments to provide protection and organization for internal components. Their current design can house up to twelve Tadiran 190Ah Lithium Thionyl Chloride (LiTC) non-rechargeable batteries, one 34Ah AGM rechargeable battery from SunXtender, and station electronics. If installed on the polar plateau, they must be buried in the snow for additional insulation.

Figure 9: The SAGE semi-permanent power system enclosure used in Polar applications.

Alaska Hut: This enclosure design is used primarily in remote Alaska locations.

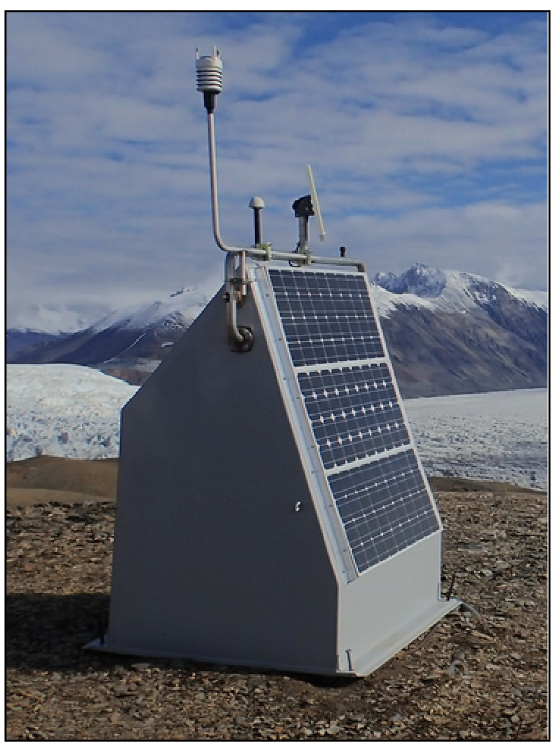


Figure 10: An Alaska style hut used by the NOTA network.

Power Design cat ME2-48-2127-L2-WG: Borehole Strainmeter and Seismometer Networks:

This is the standard enclosure used for the BSM stations located in the contiguous United States and Canada. Enclosure is placed on a concrete pad and covers the borehole.

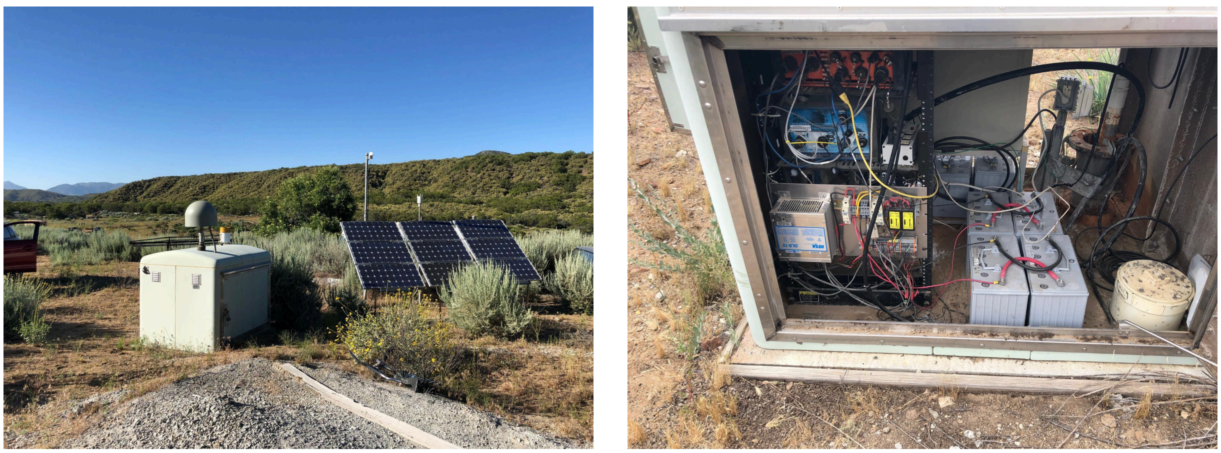


Figure 11: Typical BSM enclosures are shown above. The external view (left) shows station B946 with a mounted GNSS option. The internal view (right) depicts a typical layout at station B093 (right). Note primary and shallow boreholes.

Dimensions / Weight: 48 x 60 x 48 in (121.9 x 152.2 x 121.9 cm)/150lbs(68Kg).
Environment: All environments other than those with an extreme snow load or other extreme weather.
Sensor: Borehole Strainmeter data logger, seismometers, environmental sensors, strong motion.
Power: The enclosure can support up to twelve 100Ah batteries.
Security: Lock.
Ventilation: Side vents with option for fan on thermal switch (not used by EarthScope).

Heavy Snow-load: Reinforced, heavy-duty enclosures or structures are recommended in heavy snow environments to prevent structural damage due to excessive loading.

Figure 12: These types of ruggedized enclosures prevent buckling in heavy snow accumulation zones.

Stainless Steel NOTA Enclosure: This is the same as the NOTA enclosure with the exception of the enclosure material. These are used in corrosive environments such as coastal areas.

Grounding & Surge Protection

Stations should incorporate both a safety ground system and surge suppression for equipment. The standards for each are described below. It should be noted that it may be impossible to achieve adequate ground in certain environments such as ice sheets and glaciers. However, surge protection systems should still be put in place to help divert electro-static discharge (ESD) away from station components.

Standard Grounding Rod:

The CSP core station calls for a standard home grounding rod. This is the 5/8" diameter x 8' copper-clad steel rod that is available at most hardware stores.

AC Power Systems:

AC powered systems will comply with the controlling jurisdiction and property owner requirements. Field staff will prioritize working with a local professional authority or electrician as needed. If the controlling jurisdiction does not require grounding, field staff will add it as an additional safety measure.

Surge Protection:
Lightning surge protectors are used on enclosures and tied to the power system. Inline surge protectors are also used on antenna cables and station networking cables. Only certified gas-cap surge protectors will be used for GNSS antenna cables.

Cabling

Color coding:
In order to avoid cross-wiring and facilitate field operations and troubleshooting, the color coding conventions shown in Table 3 have been recommended for the different elements of a power system. If color-coding material is not available during site visits, cables and terminations should be clearly labeled.

	Subsystem	Comments
(black)	Ground	Common Ground or Negative
(red)	Battery	Battery Bank Positive
(orange)	Solar Power	Solar Panel Positive
(blue)	Wind Power	Wind Turbine Positive
(purple)	Wind Discharge	Typ. Heat Pad
(yellow)	Load	When protected by a Low Voltage Disconnect circuit

Table 3: Color conventions for power subsystems.

Cable Management and Routing:
Cables should be tied and routed for wire protection and ease of tracing. Use of ties to hold wire bundles in place or use of braided wire looms are a few possibilities.

Cable Length, Size and Type:
Cable length and gauge should be sized based on the anticipated maximum voltage and current of the power system. A number of online tools exist that allow users to appropriately size cables

and estimate losses. Cable length and routing should allow for adequate strain relief; excess cable should be trimmed to keep systems tidy. Cable temperature ratings should be considered based on environmental conditions. Solid core or stranded copper should be used for all other power systems needs. Solid core copper wire shall be used for grounding.

External Mounting

The main components for mounting station equipment externally are saddle clamps and U-bolts, piping of various diameters, strut channels, and aluminum angles, which allow for a variety of options in achieving an optimized and adaptable station design. Stainless steel is the recommended material to support functionality and longevity of all external mounting parts, and some environments may require a coating or treatment to mitigate specific corrosion types.
A list of approved common elements are shown in Appendix B.

Photovoltaic mounting:
PV Panels are securely fastened to a custom stainless steel frame, however, there are many different requirements and constraints for how the solar array can be installed. The final recommendation has not been finalized at this time, but will be updated with subsequent phases of the CSP project.

Figure 13: PV Panel stainless steel frame

Communications equipment mounting:
The external mounting of communication antennas depends on the type of equipment used. Many systems (Cell, Starlink, BGAN antennas) come with mounting hardware provided or recommended by the manufacturer, and third party providers frequently offer improved solutions. Additionally, the above-mentioned external mounting componentry (ie u-bolts, saddle clamps, pipes, etc.) are utilized in the assembly of mounting kits.

Accessory equipment mounting:
External mounting of accessory equipment (e.g. weather stations, infrasound, GPS timing antennas) will depend on type and required location with respect to other equipment, but is usually attached to the standard enclosure or to a separate mounting system.

Internal Mounting

If using the CSP power distribution panel, then the mounting bolts in an enclosure should match the mounting-hole pattern of the standard CSP power distribution panel to securely fasten it. Note: the HDPE back panel material allows for easy modification of the mount holes. The panel includes a DIN rail for mounting other equipment such as cell modems, switches and routers. We recommend mounting peripheral devices on a DIN rail to keep a tidy and easily maintained site (see Figure 15.1 and 17 for examples) .

All items in an enclosure should be secured to prevent movement in the case of an earthquake or other environmental disturbance. To ensure security and stability, enclosures must be capable of securing internal batteries and other equipment that cannot be mounted to a DIN rail. Standard solutions include foam inserts, velcro straps, and cut-outs. Batteries can be secured to themselves when placed on the ground.

Sensors and Data Acquisition

A sensor is a device or component that detects changes in its environment and converts them into signals and/or data that can be interpreted or used by other systems. A sensing system includes not only the sensor, but data acquisition, data storage, and potentially data processing. The sensing system may consist of a single device or multiple devices. Sensor system selection will vary greatly based on science objectives, thus detailed guidance on selection is not included in this document. There are a wide array of modular sensors and data acquisition units available and EarthScope is capable of assisting with the planning and loaning of specific sensor systems based on need. The EarthScope Station Builder webtool includes the most common sensors and data acquisition systems available in the EarthScope pool.

Edge Computing

One application of data acquisition and processing currently being explored by the CSP working group is Edge Computing. EarthScope has developed low-power edge computers to support these applications. They are based on an ARM processor (Nitrogen8M_Mini) with a total power draw of about 1.4 W. Each computer has 4 ethernet ports, two serial ports, and a console port for set up. They utilize Docker images for easy configuration and flexibility.

Figure 14: The Nitrogen8M_Mini, a 4 port switch and a power supply in a custom EarthScope enclosure.

Power/Electrical Design

The CSP power design consists of four major elements: a power source, regulation, storage and distribution, and surge protection and grounding systems. AC or DC input is stored in batteries which are used to power the other components of the station. A list of currently used power system components is provided in Appendix B.

Core Power System Specifications

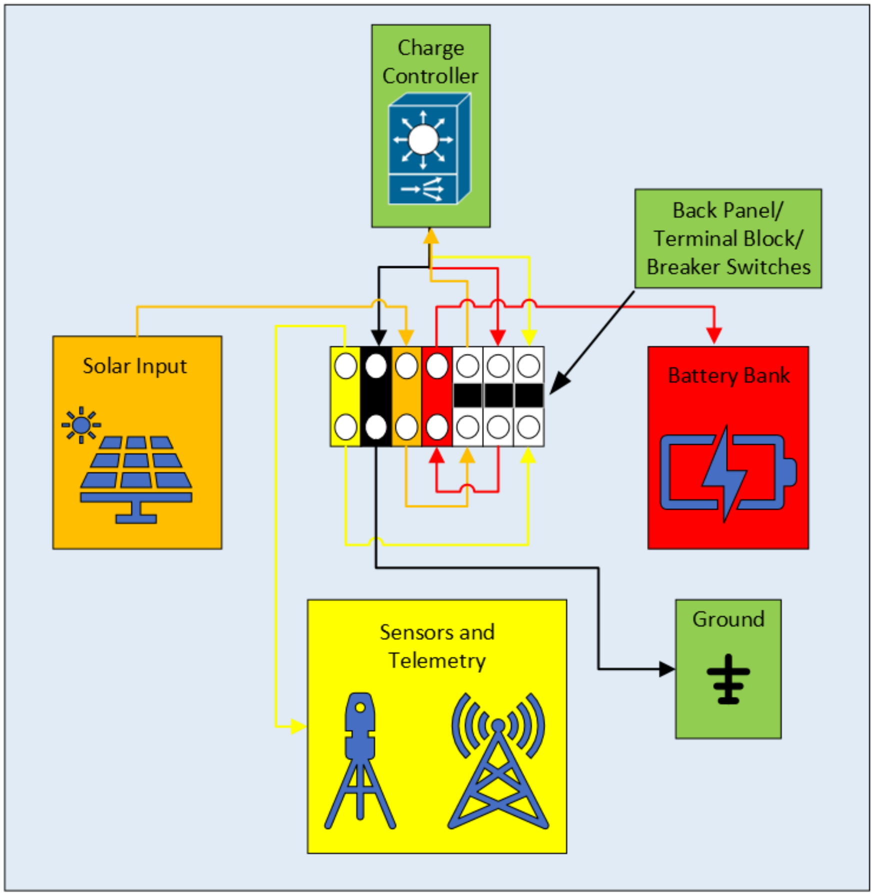


Figure 15: Core Station power system block diagram.

The Core Station DC system, represented in Figure 15, consists of a photovoltaic system, represented by any number of panels wired in parallel, a solar charge controller with a Low Voltage Disconnect (LVD), an High Density Polyethylene (HDPE) power distribution panel, batteries wired in parallel, a grounding system, and lightning and surge protection.

The Core Station AC system is nearly identical, but utilizes AC input and an AC-to-DC converter rather than a solar charging system. An inline surge protector and disconnect is used between the AC input and the AC-to-DC converter. The power distribution panel is similar and the system is typically deployed with fewer batteries (Figure 15.1 - Typical AC system). Local electrical codes must be observed or work performed by a certified electrician.

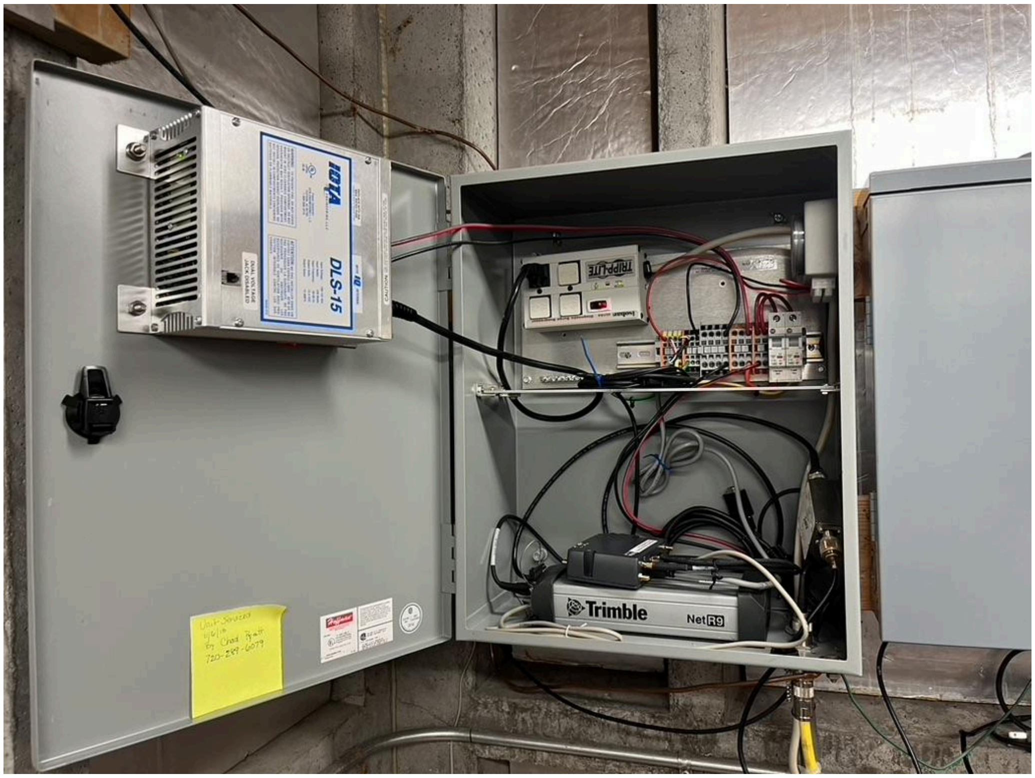


Figure 15.1: Typical AC System

The core power system is designed to operate stations requiring 1-20W of power with minimal modification. Medium (21-50W) and larger (51-100W) sized systems are easily implemented by adding solar panels with a higher capacity charge controller and by increasing battery count. Additional power sources may be used to augment solar power (e.g. wind generation, fuel cells, or thermo-electric generators).

Each station implementation will need to determine power requirements prior to deployment. Some typical power consumption estimates for common sensors are found in Appendix C.

Core Power System Diagrams

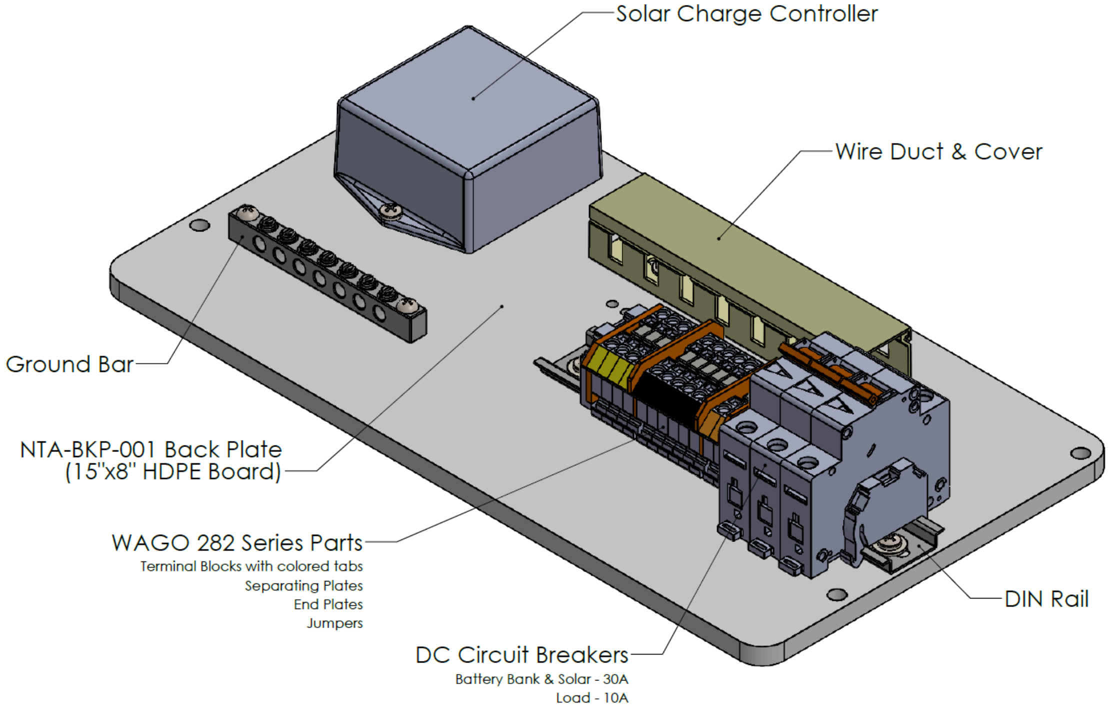


Figure 16: The Core Station power distribution back panel.

The Core Station power system is shown in Figures 16 and 17. The 15” x 8” HDPE back panel holds a set of terminal blocks and power breakers, a solar charge controller, a grounding block, and a wire duct. Note that WAGO, the terminal block manufacturer of choice, has not updated their product CAD drawing database to include the LeverLock wiring terminals. This diagram will be updated when the CAD drawings are available.

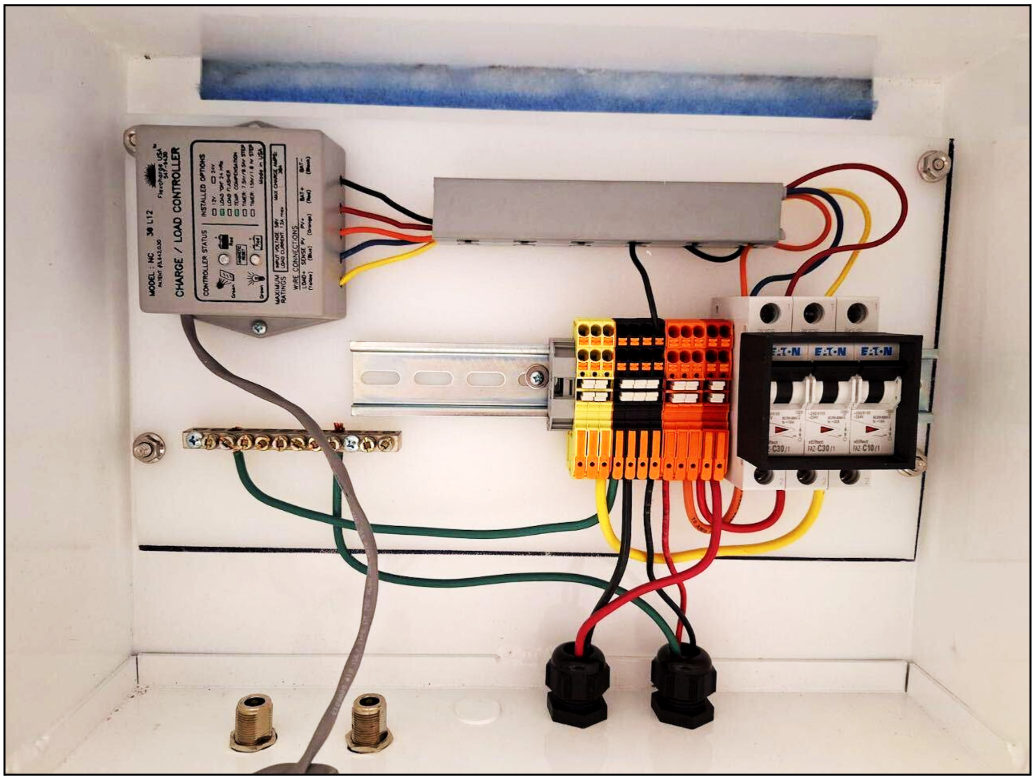


Figure 17: Core Station DC power distribution back panel.

Power Storage

Power storage is usually achieved by battery technology, however, certain sites and project requirements may require additional or different solutions. Factors that may affect power storage choices include: ease of site accessibility, backup time when no input source is available, maintenance schedules, the availability of resources at location, logistics or shipping constraints regarding different types of hazardous materials, and power efficiency/density.

Different types of power storage may be selected or combined depending on project requirements; these options are described below.

Rechargeable Batteries:
The Core Station power storage element is defined as a sealed- lead acid (SLA), rechargeable battery that has been engineered and tested for renewable solar energy applications where deep cycles are required. Currently, the standard component is the Deka Solar 8G31-HST-DEKA, 12 V, 100 Ah battery. This battery model has been in use for geodetic and seismic operations for nearly

twenty years, with excellent reliability and longevity performance. Additional approved CSP rechargeable battery models are listed in Appendix B.

Single-Use Battery Technologies:
Lithium thionyl chloride (LiTC) batteries are primary (non-rechargeable) cell batteries that are known for their high energy density, more than that of AGM batteries, and their stable voltage output across a wide range of temperatures. These lightweight batteries may provide significant savings in remote areas where logistics and transportation are cost prohibitive. However, there are three major limiting factors that may impact the use of LiTC batteries in station power system designs: Once depleted they must be replaced, their unit cost is approximately twice that of an equivalent AGM battery, and they have highly regulated transportation and shipping requirements.

Scalability:
Battery power is easily scalable by adding additional units, but care should be taken not to mix batteries of different ages since this can easily damage newer batteries and more generally reduce the power system's performance.

Additional technologies:
Additional power storage technologies, such as zinc-air batteries, are under consideration. As they undergo testing and evaluation, and should they reach design acceptance, this document will be updated to reflect those changes.

Power Regulation

Overview:
The power system is designed to perform as an Uninterruptible Power Supply (UPS) for the station. Power is regulated by a charge controller which takes power input (DC/Solar or AC/outlet) and distributes it to the battery bank for storage. Power is then drawn from the batteries by station equipment (e.g. sensor(s), data loggers, and communications). Refer to Appendix B - Power Input for Regulator examples.

DC Charge Controllers

DC/Solar charge controllers are DC-DC converters which convert the higher voltage of the solar array to the lower voltage of the battery bank (typically 12V). DC charge controllers use two charging algorithms: Pulsed Width Modulation (PWM) and Maximum Power Point Tracking (MPPT). PWM charge controllers use variably timed on-off charging dependent on the sensed battery voltage. MPPT charging algorithms regulate the solar panel operating point, ensuring that they consistently operate at their maximum power output.

AC Charge Controllers:
AC/outlet charge controllers are AC-DC converters which perform similarly to PWM DC charge controllers. Input AC power (eg. 120VAC) is converted to 12VDC and distributed to the battery bank.

Low Voltage Disconnect (LVD):
An LVD is an inline protective device that disconnects the batteries from the system load at a preselected shutdown setpoint and re-connects the batteries once a power-on setpoint has been reached. These devices are critical to preventing battery damage during extreme discharge conditions.

Charge Controller Selection:
A charge controller should be chosen based on three principal criteria:

- Battery voltage.
- Input open circuit voltage.
- Output current or rating.

The charge controller must match the battery voltage (12V, 24V, 48V - some modern charge controllers are configurable for different battery voltages). The charge controller must be sized for the maximum open circuit solar panel voltage or the charge controller will be damaged. Finally, the charge controller must be able to output the proper amount of power to charge the battery bank.

Charge Controller Size Calculation Example:
Battery Voltage: 12V.
Input Open Circuit Voltage: 22.85V (in parallel configuration).
Input Power: 225W (3x75W solar panels).

Charge Controller Rating = Input Power / Battery voltage = 225W/12V = 18.75A.
A charge controller with a rating of 50V/25A or 75V/25A would be selected in this example, which would provide a safety buffer over the nominal 22.85V/18.75A minimums shown above.

Induced Noise and Sensor Interference:

PWM and MPPT charge controllers can induce electrical noise into the power system during normal switching operation. This noise can create spurious data in quiet seismic system deployments. The existing preferred charge controller for those conditions is the GenaSun GV-5 which was specifically designed to minimize noise. Testing is underway to determine the impact of this noise and how to mitigate it when using other charge controllers. Once completed, this section will be updated with those findings.

Communications and Station Networking

Many existing EarthScope instrumentation networks require, or choose, to incorporate communications systems in order to transmit data, including State-of-Health information, from a sensor or data logging device to an external server for dissemination and archiving. Communication options for any given station depend on many factors, including existing station power budgets, infrastructure, such as cellular and satellite networks, data file size(s), bandwidth requirements, compatibility with instrumentation, and anticipated technology future-state. As seen in Figure 18, there is a tradeoff between device power and transmit bandwidth. This should be considered when designing a station.

Depending on the number of networked components in your system, additional networking equipment, like routers and switches, may be needed. Additionally, media converters (i.e. devices that convert data to different data protocols) may need to be utilized. Examples of media converters are USB-to-Serial, Serial-to-Ethernet, Serial-to-fiber, and RF-to-fiber..

Device Power-Bandwidth Envelope

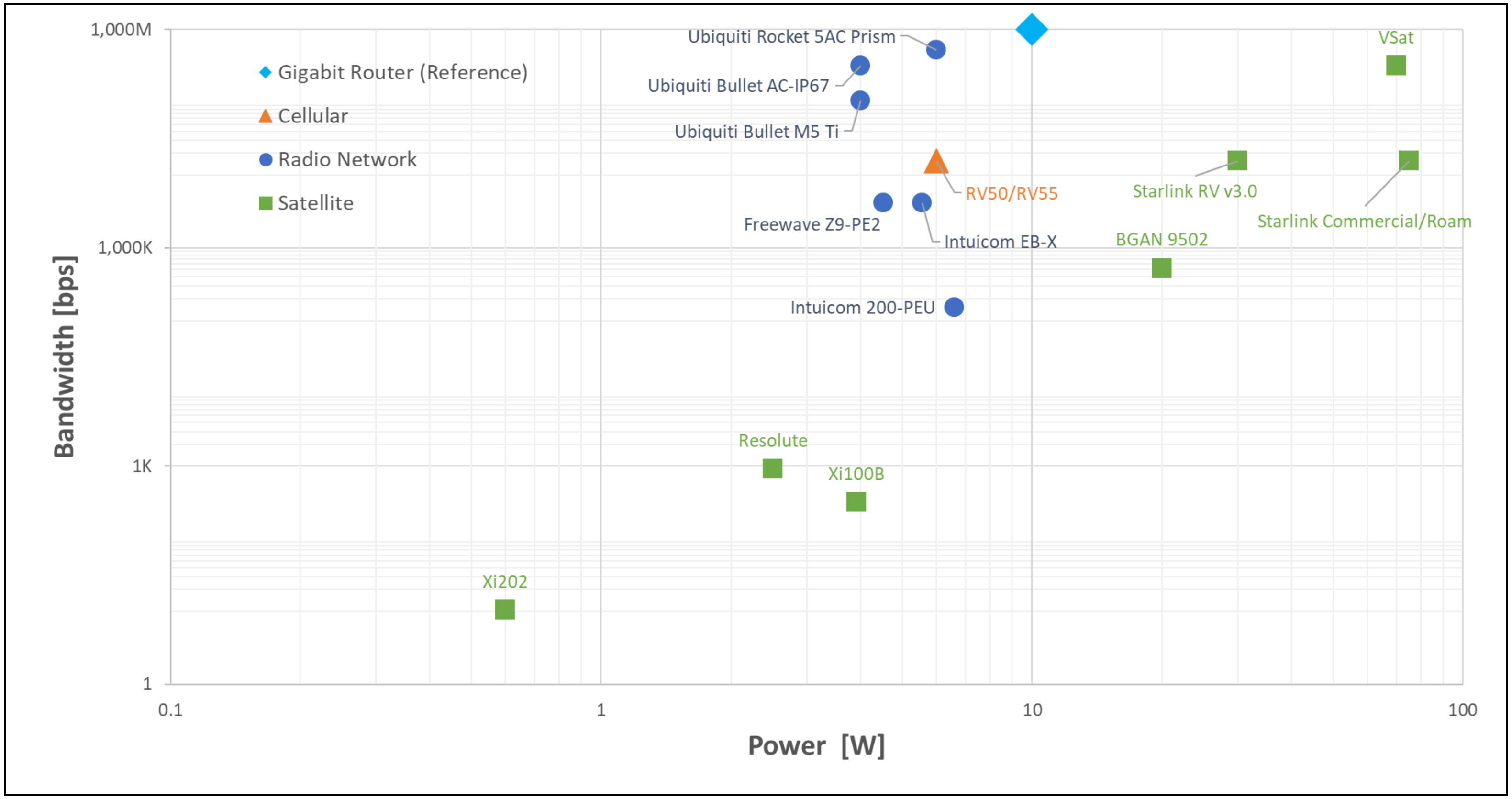


Figure 18: Communication Devices - relationship between the advertised maximum upload bandwidth and power for the different types of CSP communication devices. A home gigabit router is shown for reference.

Existing Communications Systems

Cellular: In many areas, cellular networks are available for (high, medium) rate data transmission. These are generally favored for their wide coverage areas, ease of connection and scalability, reliability, and security. Note, when available, cellular communication generally is the most accessible and affordable option for the science community.
Frequency: Varies by location.
Bandwidth: Up to about 10 - 15Mbps upload speed.
Hardware cost: ~$650-$700.
Data Transmission Approximate cost: Varies, but domestic rates average 100MB/USD.
Power Draw: 5.5W.

Radio: In the most basic sense, radio communications provide wireless bridged network connectivity between the connected sensor and another radio connected to an internet connection. Radio networks can expand out to multiple repeaters and endpoints to bring multiple sensors into a single communications hub.
Frequency: 902-928MHz, 2.4GHz, 5.8GHz.
Bandwidth: Up to 300Mbps upload speed.
Hardware cost: $200-$1200 per radio depending on manufacturer and model.
Data Transmission Approximate cost: $0 for the radio network itself. The transfer from the collecting hub to the archive center may involve a data plan.
Power Draw: 1-4W. daily power draw for GNSS file transmission 1W.

Cellular and radio antennas:

Antenna are designed to operate at one frequency, however, several antennas can be built into the same package. Cell antennas are an example of several different antenna elements combined in a single package to operate on multiple frequencies. This works well for some types of antenna, such as Yagi or Omni, but because of physical constraints does not work so well with Parabolic or Patch.

Antenna	Type	Characteristics	Gain	Beamwidth
Yagi	High gain directional antenna.	Power loss to the side and back of the antenna.	Up to ~20 dBi.	~15 degrees to 80 degrees; more elements result in a narrower beamwidth.
Parabolic	High gain directional antenna.	Very little power transmitted to the side or back and very low interference from the back or side.	Typically ranges from 15 dBi for small dishes to over 60 dBi for larger dishes.	Generally very narrow, depending on the dish size and frequency.
Flat Panel	High gain directional or broad beamwidth antenna.	Can provide up to +/-90 degrees beamwidth. Larger panels offer higher gain.	Varies based on panel size and design, typically ranging from 10 to 20 dBi.	Can range from narrow to broad, depending on the design.
Omni	Non-directional antenna.	Signal radiates power evenly in all directions. Gain can be increased by using a longer antenna element.	Typically ranges from 0 to 12 dBi.	360 degrees in the horizontal plane, with a narrow vertical beamwidth as the gain increases.

Table 4: Types of Cellular Antennas.

StarLink: Starlink communications utilize the satellite internet constellation that is owned and operated by SpaceX.
<u>Frequency:</u> KU- and KA-bands, 12-18 GHz and 26-40 GHz, respectively (LEO).
<u>Bandwidth:</u> Up to 25Mbps upload speed.
<u>Hardware costs:</u> $600 - $2500 depending on model.
<u>Data Transmission Approximate cost:</u> costs are changing rapidly. $50-150/mo. depending on the plan.
<u>Power Draw:</u> 20-80W.

Iridium Satellite: This communication system utilizes the Iridium constellation of satellites that are useful in remote places across the globe. Iridium is used as the primary communication type in our polar applications.
Note: Iridium operates in the L-band frequency range, resulting in interference with GNSS signals. Many modern instrumentation has built-in filtering and shielding to address this issue, but it is important to test equipment before fielding it. See Best Practices.
Frequency: 1616-1626.5 MHz (LEO).
Bandwidth: ~1 kb/s upload speed.
Hardware cost: from $1500 to $2500.
Data Transmission Approximate cost: $500 per month, unlimited data. As of 2024, Antarctica projects are directly funded by the NSF Program Manager.
Power Draw: 1W.

VSAT: VSAT (Very Small Aperture Terminal) is an existing technology that is operated by Hughes Satellite Systems. However, this communications technology is being phased out by EarthScope due to the increasing power consumption of modern units, which are in excess of 100W. This system is noted here for historic reasons.

A set of spider charts depicting the differences across the major communications device types are provided in Figure 19.

Figure 19: Bandwidth, Power Consumption, Frequency and Costs across the five types of communication devices are shown above. Note that for radio systems, costs shown are per radio. If a receiving radio is needed, costs will double.

Network Security

Security measures are necessary to maintain the station dataflow, remote access, and continual operation. The following security measures are recommended for all station communications systems as applicable:

Unique Station passwords: Required for devices at stations (radios/sensors). Ideally, these are stored in a password management system.

Virtual Private Networks (VPN): It is best practice to use Virtual Private Networks (VPNs) to ensure secure remote access and data transfers. VPNs also allow easy access to field equipment through static private IP space.

Firewalls: For sites not on a VPN, IP filtering should be enabled on devices to limit the access to select IP ranges.

Best Practices

Any communications device may interfere with sensors, both in terms of the measured signal as well as the instrument's electronics, and create additional system noise which may impact the data or the instrument's operation. For this reason, it is important to test and document all communication and sensor devices for interference before field deployment.

Operations and Maintenance

Operations and Maintenance involves the ongoing activities and processes necessary to ensure that a geophysical station functions efficiently and effectively throughout its lifecycle. Station and network operations and maintenance vary based upon a variety of parameters, in particular sensor type, operations budgets, and geographic region.
Best practices related to all Operations and Maintenance activities are summarized below:

- Any operation and maintenance activities should align with station requirements.

- Ensure that any needed permits are in place, in good standing, and easily retrievable to ensure compliance with environmental, land use, and regulatory requirements.
- A method is in place for tracking information related to inventory, equipment, shipping, and logistics.
- A method is in place for tracking information related to station visit activities and changes (i.e. firmware changes, equipment swaps, etc), as well as site access/contacts.
- Documentation requirements (templates, checklists, photo archives, etc) should be standardized across stations and projects as much as possible and the information should be archived and maintained in a documentation management system.
- Ensure that field personnel are trained in on-site maintenance activities and have all required safety training and/or certifications (e.g. Wilderness First Aid/CPR, Tower Climbing).
- Ensure all data is archived at the EarthScope Data Management Center.

Conclusion

This document captures the current state and design principles of the CSP Core Station. Due to the diverse portfolio of geophysical research projects represented by the CSP effort, this design must remain flexible and incorporate the project's principles of modularity and scalability. It is important to note that the CSP is a living engineering design and that it will be updated regularly as changes and improvements occur. The CSP, therefore, remains at its core a *design process* that continues to function both in the scope of this project as well as an organizational practice.

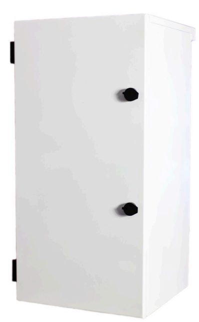
Appendix A - Glossary

Term	Definition
AC	Alternating Current.
ANET	The POLENET Antarctic Network (ANET) is an NSF-funded and EarthScope-supported GNSS and seismic network spanning West Antarctica and the Transantarctic Mountains.
BSM	Borehole Strainmeter.
COTS	Commercial-Off-The-Shelf: commercially available off-the-shelf products are packaged or ready-made hardware or software.
DC	Direct Current.
DIN	Deutsches Institut für Normung: a metal rail of a standard type widely used for mounting circuit breakers and industrial control equipment inside equipment racks.
Docker	Docker is a set of platform as a service products that use OS-level virtualization to deliver software in packages called containers.
EPIC	EarthScope Primary Instrument Center: located at New Mexico Institute of Technology in Socorro, NM, this state-of-the-art facility houses EarthScope’s geodetic and seismic instrumentation pool.
GAGE	Geodetic Facility for the Advancement of Geoscience.
GNET	The POLENET Greenland Network (GNET) is a network of 46 continuous GPS stations spread across Greenland.
GNSS	Global Navigation Satellite Systems: Global geopositioning satellite constellations, spread between several orbital planes, that are used for determining position, navigation, and time relative to objects on the earth's surface. This currently includes: Chinese BeiDou Navigation Satellite System, European Union Galileo, Russian Global

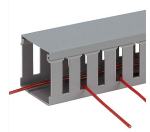
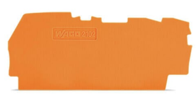
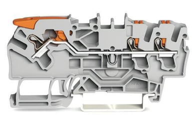
	Navigation Satellite System (GLONASS), and U.S. Global Positioning System (GPS).
LVD	Low-Voltage Disconnect.
NOTA	Network of the Americas: an international geophysics sensor network operated by the GAGE facility. NOTA spans more than 20 countries and is composed of more than 1,200 continuously operating instruments, including high-precision GPS (and multi-constellation GNSS) stations and borehole strain, seismic, and tilt instruments.
Permanent Station	A station installed and maintained with the intended operational time of years to decades or with no initial intent of being decommissioned with real-time or near real-time access to data.
POLENET	POLENET (the Polar Earth Observing Network) is a global network of scientific instrumentation dedicated to observing the polar regions in a changing world. It comprises two main subnetworks: ANET in the Antarctic and GNET in Greenland.
Portable Station	Also known as a campaign-style station, this station is intended for short-term deployment on the order of days to months and may or may not be telemetered.
PV	Photovoltaic.
SAGE	Seismic Facility for the Advancement of Geoscience.
Site	A geographic area of scientific interest where one or more stations are located.
Station	A collection of instruments and equipment used for one scientific purpose.
VPN	Virtual Private Network.

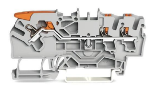
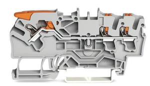
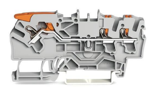
Appendix B - Materials and Components

Site Infrastructure			
Framing and Mounting			
Strut channel -Unistrut		A versatile framing system composed of lengths of metal framing channel and a wide variety of connectors and fittings.	Various Suppliers
1.5” Schedule 40 Aluminum Piping		Used primarily in polar regions where reinforced framing is needed.	Various Suppliers

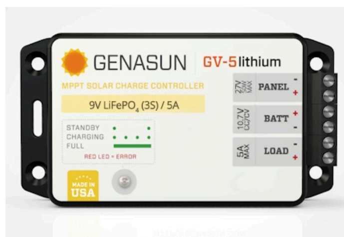
2.5”-3” Schedule 40 Galvanized Steel post		Vertical post, cemented into the ground, is used to mount an enclosure and/or solar array.	Various Suppliers
Pipe-mount saddle clamp DX Engineering DXE-CAVS-3CE		Aluminum saddle clamp with V-bolts. Can be used to secure many different types of components to mounting hardware, including solar panels, communications antenna mounts, and weather stations.	DX Engineering
Enclosures			
NOTA Custom metal enclosure (Powder coated aluminum or stainless steel)		Secure housing for power distribution system, four batteries, sensor and communications hardware. 39.5Hx16Wx17D Security armor available.	A new supplier is needed. This document will be updated once obtained.

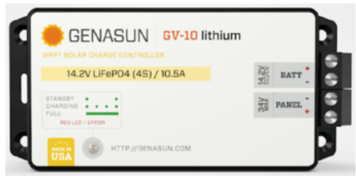
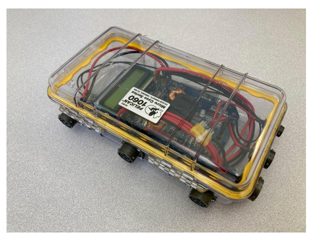
Polar GNSS enclosure Pelican-Hardigg MM24			Various Suppliers
Polar GNSS enclosure Pelican-Hardigg MM36			Various Suppliers
Polar Seismic Enclosure Pelican AL3434-2807		Supplemented with custom insulation (froth foam lining, extruded polystyrene foam, and/or vacuum-insulated panels).	Various Suppliers
Polar Seismic Enclosure Pelican AL3627-1505		Supplemented with custom insulation (froth foam lining, extruded polystyrene foam, and/or vacuum-insulated panels).	Various Suppliers

Power System			
Power Distribution Panel Components			
Back Plane (Custom)		HDPE panel, pre-drilled to mount to existing NOTA enclosure studs.	TAP Plastics
Panduit Wire Organizer C1LG6		Provides clean cable routing from the charge controller to the terminal block.	DigiKey
DIN Rail 1m DIN Rail		Easy mounting for terminals, breakers, and other DIN-rail compatible equipment.	Newark Electronics
WAGO End and Intermediate Plate End Plate		Terminal Block divider: separates different parts of the terminal block.	Online Electronics
TOPJOB®S feedthrough terminal block with Lever and Push-buttons Yellow Lever Lock Terminal		Wire connection terminal, rail mount; 3-conductor 5.2 mm wide; yellow.	Online Electronics

TOPJOB®S feedthrough terminal block with Lever and Push-buttons Black Lever Lock Terminal		Wire connection terminal, rail mount; 3-conductor; 5.2 mm wide; black	Online Electronics
TOPJOB®S feedthrough terminal block with Lever and Push-buttons Orange Lever Lock Terminal		Wire connection terminal, rail mount; 3-conductor; 5.2 mm wide; orange	Online Electronics
TOPJOB®S feedthrough terminal block with Lever and Push-buttons Red Lever Lock Terminal		Wire connection terminal, rail mount; 3-conductor; 5.2 mm wide; red	Online Electronics
TOPJOB®S endless jumper; for 2002 series; insulated; 2-way; light-gray Terminal Jumper		Jumper for terminal block; groups terminals together (PV, battery, common, load).	Online Electronics
Screwless end stop; 10 mm wide; for DIN-rail 35 x 15 and 35 x 7.5; gray End Stop			Online Electronics

Eaton FAZ-C30/1-NA - Miniature circuit breaker (MCB), 30A 30A Miniature Circuit Breaker		Overcurrent protection for batteries and PV panels.	Automation Direct
Eaton FAZ-C10/1-NA - Miniature circuit breaker (MCB), 10A 10A Miniature Circuit Breaker		Overcurrent protection for loads (sensors, receivers, comms).	Automation Direct
Power Input (DC, AC)			
Flexcharge NC30L12		30A Charge controller widely used in the NOTA GNSS network. Pulse Width Modulation (PWM) charging algorithm.	The Solar Store
Victron MPPT 75/15A Victron MPPT		15A Charge controller (other sizes widely available). Maximum Power Point Tracking (MPPT) charging algorithm.	Amazon

Phocos ECO Eco N-T		20A MPPT charge controller.	Solarflexion
Morningstar MPPT Tristar TS-60		60A MPPT charge controller.	The Solar Store
Sunforge High-speed MPPT Genasun GV-5 Lithium			Digikey
Sunforge High-speed MPPT Genasun GV-5 Lead Acid			Digikey

Sunforge High-speed MPPT Genasun GV-10			Solarflexion
Victron Energy LVD BP65			JBTools
IOTA AC-DC Converter DLS-15		15A output AC-DC charge controller, PWM charging algorithm.	Amazon
Genasun GV-15 Custom-Built Charge Controller		Low electrical noise, low self-power consumption charge controller used in polar and portable seismic applications	SunForge LLC
PV Panels (100W, 85W, 65W, 20W, 10W)			Various Suppliers

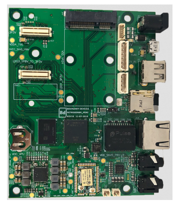
Batteries			
Rechargeable Sealed Lead Acid (SLA) Deka Solar 8G31-HST-DEKA		12V, 100Ah, deep cycle, sealed lead acid gel cell for solar applications. ST model with two threaded stud terminals.	[Ameresco]
Rechargeable Absorbent Glass Mat (AGM) SunXtender PVX-1290T		12V, 129Ah, deep cycle, AGM lead acid for solar applications. T model with M8 copper alloy threaded insert terminals.	[Copper State Battery, Inc.]
Rechargeable Absorbent Glass Mat (AGM) SunXtender PVX-340T		12V, 34Ah, deep cycle, AGM lead acid for solar applications. T model with M6 copper alloy threaded insert terminals.	[Copper State Battery, Inc.]

Rechargeable SLA PowerSonic PS-12400		12v, 40Ah sealed lead acid gel cell battery.	Various Suppliers
Rechargeable SLA PowerSonic PS-12200		12v, 20Ah sealed lead acid gel cell battery.	Various Suppliers
Single-Use Lithium Thionyl Chloride Batteries Tadiran TLP93101		18V, 190 amp-hour, non-rechargeable, LiTC battery pack.	Tadiran
Grounding and Power Surge Protection			
Grounding Rod		Standard ⅝” x 8’ high-carbon steel, copper-coated grounding rod.	Hardware Store

Huber-Suhner		Broadband DC to 3 GHz, DC continuity for remote powering, Gas discharge tube replaceable, Impedance 50 or 75 Ω.	Various Suppliers
Serial Port Surge Protector		Inline surge protector for serial communication lines. For use on GNSS receivers, weather stations, site computers, and Iridium modems.	Various Suppliers
Delta Lightning Arrestor LA302DC		Rapid response, high current, designed to protect solar or wind energy systems from nearby lightning strikes.	Various Suppliers

Communications Devices			
Cellular Modem: Sierra Wireless RV50x		Robust, low-power cellular modem capable of operating on LTE, 4G, 3G, and 2G networks. Up to about 10 - 15Mbps max upload speed.	Various Suppliers

Radio: Ubiquiti -Rocket -Bullet		2.4 and 5.8GHz, low power point to point communications with bandwidths up to 300Mbps.	Various Suppliers
StarLink Residential		Medium cost, LEO satellite communications, up to 25Mbps upload speed.	StarLink
StarLink Commercial		LEO satellite communications. Better uptime than residential units, up to 25Mbps upload speed. Higher power than the Residential unit.	StarLink commercial vendor
Iridium Antenna: AeroAntenna AT1621-142		Quad-helix omni design with structurally strong radome and mounting arrangement. Notes: Installed at numerous sites in Greenland and Antarctica with outstanding reliability.	AeroAntenna

Edge Computing			
Edge Computer Nitrogen8M-Mini	 	1.5-2GHz quad core ARM Cortex 2-4GB RAM, 8-128GB eMMC, microSD removable memory I2C/SPI/GPIO/PCIe Linux 4 port switch, 9-36V input 1.6W	Ezurio.com
Timing (Seismic Stations)			
GPS Bullet Antenna		5V, TNC connection.	Various Suppliers

Appendix C - Additional Station Resources

Communications Security Resources

The National Institute of Standards and Technology is an excellent resource for up to date federal security standards and resources.

Project Support Requests

GAGE Project Support Request PORTAL: The Portal is used for project support requests by PIs, project planning, and for station information and metadata for some of the stations and networks operated by EarthScope, in particular PI networks and the NASA GGN network.

SAGE Scheduling Database (SDB): The EPIC scheduling database (SDB) functions as a comprehensive platform facilitating coordination between Principal Investigators (PIs) and the EPIC facility. PIs utilize the system to request instrumentation and field support, communicate their project requirements, coordinate with the seismic source facility, and arrange international shipping support.

Typical Sensor Power Consumption

Power draw should meet station power budget requirements. Currently, the most commonly deployed Earthscope sensors operate at the following:

Sensor	Type	Typical Power Consumption
Septentrio PolaRx5	GNSS Receiver	2-4 W
Trimble NetR9	GPS/GNSS Receiver	3.8 W
XEOS Resolute	GNSS Receiver	1.2-2 W
Nanometrics Trillium (various models)	Seismometer	0.2-1 W

Kinematics STS-5a	Seismometer	0.9 W
Q330/Centaur/Pegasus/Marmot	Seismic Datalogger	2 W
Gladwin Tensor	StrainMeter	25 W
Vaisala WXT510	MetPack	1 W 8-9 W withheater enabled

Table 5. The most common sensors and their power consumption are shown above.