CRYSTAL INSTRUMENTS

GROUND RECORDER SYSTEM (GRS)

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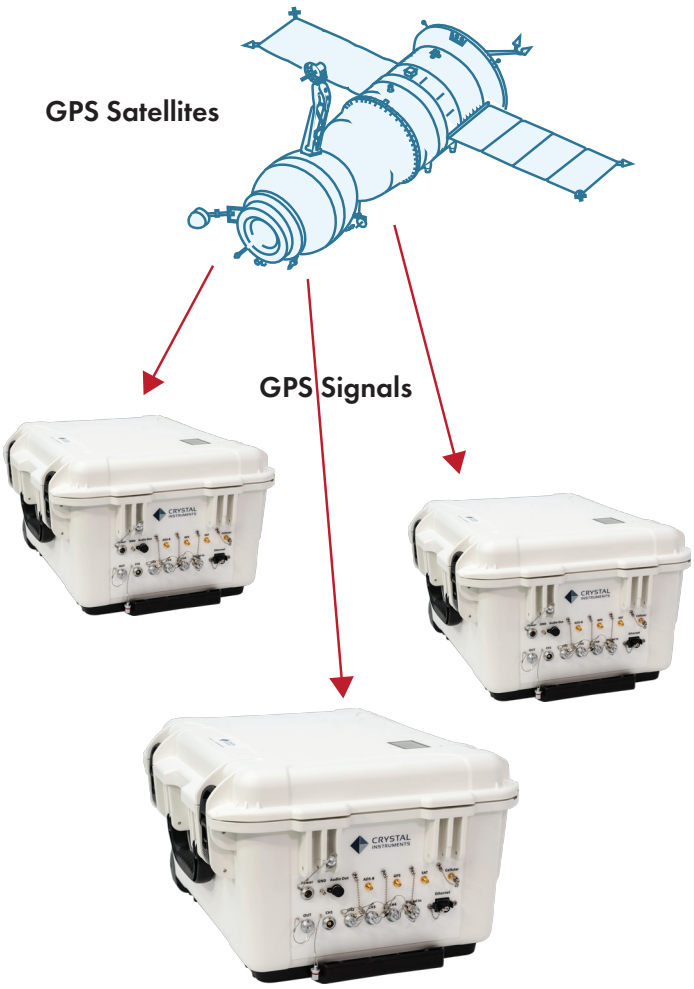
World's first ruggedized portable dynamic measurement system featuring full integration with space technology.

Ground Recorder System (GRS)

The GRS is a rugged, lightweight, battery-powered dynamic data recorder and real-time signal analyzer engineered for autonomous, remote deployment. Developed in collaboration with NASA, it combines precision acoustic and vibration measurement with GNSS timing, aircraft tracking, intelligent triggering, on-board processing, and cellular or satellite communications. The result is accurate, synchronized data collection with minimal field intervention, even across widely distributed measurement sites.

GRS Features	
Rugged, Weatherproof Design	21.5 in × 14 in × 8.3 in (54.5 cm × 35 cm × 21 cm) Ruggedized, weatherproof enclosure
Extended Battery Operation	Two removable 94 Wh rechargeable Li-ion batteries (188 Wh total) Provides up to 12 hours of full-operation runtime
Intelligent Power Management	Solar charging and low-power modes support extended unattended operation; hibernate draws 55 mW and supports scheduled wake-up
High-Dynamic-Range Acquisition	Four analog input channels, each with dual 24-bit ADCs, use patented dual-range technology to deliver 150 dBFS typical dynamic range and automatic range selection
Precision GNSS Timing and Positioning	Integrated multi-constellation GNSS provides location accuracy better than 2.5 m and hardware-level ADC time stamps accurate to 100 ns
Cellular and Satellite Connectivity	Integrated LTE and Inmarsat satellite communications enable remote status, control, and data transfer, with satellite service automatically disabled when cellular service is available
Fully Autonomous Operation	Master scheduling, configurable event/action logic, self-tests, watchdog recovery, and up to 300 seconds of pre-trigger buffering enable fully autonomous operation



Multi-Constellation GNSS and Precision Timing

The integrated GNSS receiver supports GPS, GLONASS, BeiDou, and Galileo, providing worldwide positioning with accuracy better than 2.5 m (8.2 ft). Timing is applied at the hardware layer to the ADC sampling clock, avoiding software latency and continuously storing a time-stamp stream alongside each recording. UTC time stamps are accurate to 100 ns, and better than 60 ns for 99% of time stamps.

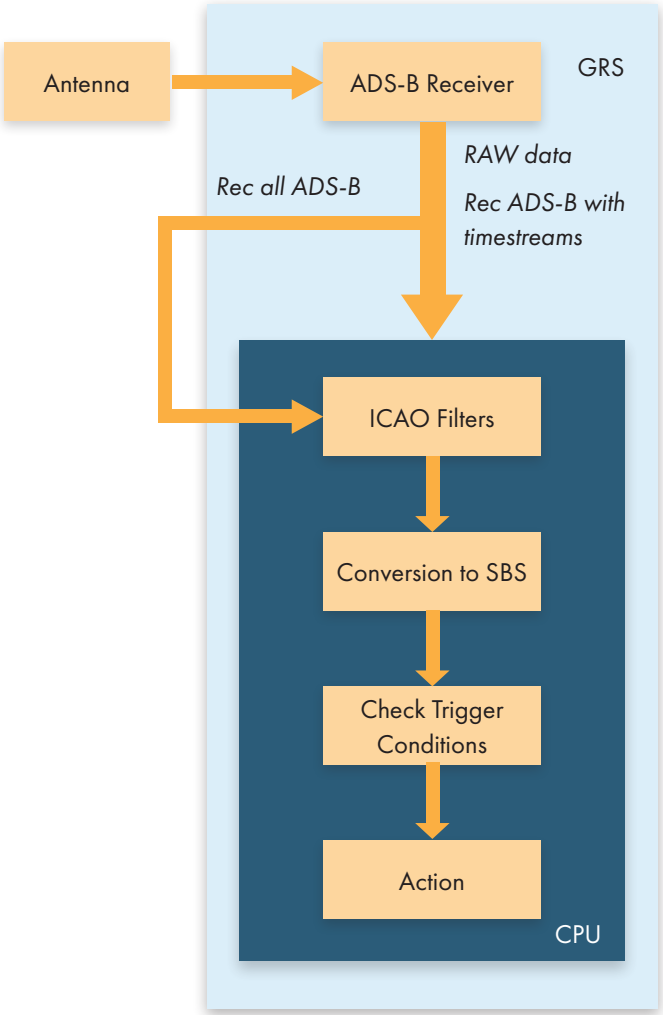
Hardware-level time stamping aligns recordings from geographically separated GRS units on a common time base. Post-processing can then apply sampling-rate correction and perform cross-spectral analysis between channels from different units, with equivalent phase match better than ±1° at 20 kHz.

Master Schedule

The Master Schedule executes and repeats user-defined tasks such as self-tests, in-situ calibration, configurable signal analyses (CSAs), recording, data transfer, and power-mode changes. It can start at power-on or in response to an event, and can switch among saved analysis configurations without on-site intervention.

Real-time Clock

A dedicated, battery-backed real-time clock supports scheduled wake-up after hibernation or an unexpected shutdown. Its backup battery is independent of the main batteries and rated for 10 years. Full-up, standby, and hibernate modes let the system balance readiness and endurance; hibernate consumes no more than 55 mW and can return to full operation in approximately 90 seconds.



Integrated ADS-B Aircraft Awareness

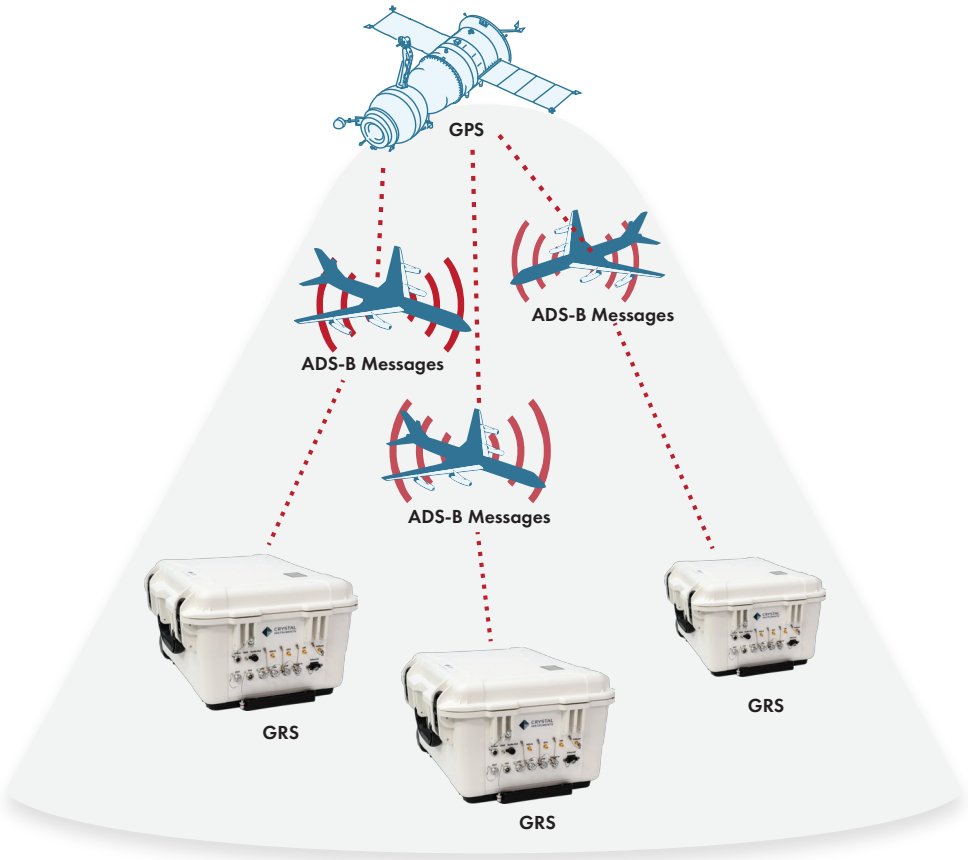
ADS-B (Automatic Dependent Surveillance–Broadcast) enables the GRS to identify and track nearby aircraft by position, altitude, velocity, and direction of travel. This aircraft awareness can be used as an autonomous event source so the system records acoustic or vibration data only when a target aircraft meets configured conditions.

An integrated Aerobits TT-MC1b receiver acquires 1090 MHz ADS-B messages at ranges up to 250 nautical miles under suitable conditions. The processor filters messages by aircraft identifier before decoding the required data, reducing processing load and power consumption.

Integrating the ADS-B receiver directly with the GRS improves connection stability under shock and vibration, eliminates separate receiver hardware, and allows the module to be powered down when it is not needed.

A weather-sealed SMA female connector supports an external ADS-B antenna. The IP67 antenna interface protects the enclosure against dust and water during outdoor deployments.

Initial setup of ADS-B antenna on the ground plane along with the GPS antenna

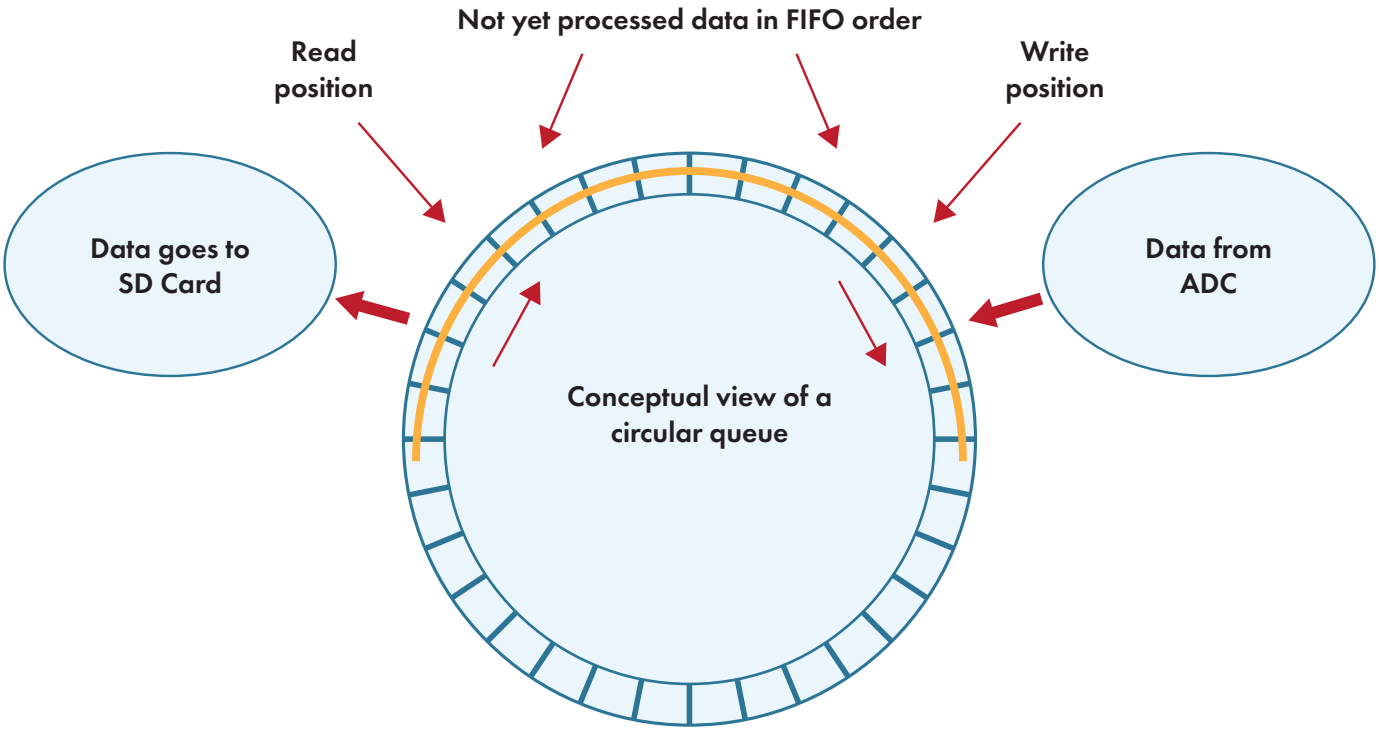


Failure Protection
Remote Connectivity and On-Board Processing

The GRS uses LTE for real-time remote operation where cellular coverage is available and can fall back to Inmarsat satellite communications in remote areas. Low-bandwidth command and status messaging reduces airtime and power demand. The dual-core ARM/DSP processor performs real-time filters, FFT, cross spectrum, octave and acoustic analysis, and shock response spectrum calculations so processed results—not only raw data—can be reviewed remotely.

The GRS is engineered for unattended deployment. A battery-backed RTC, watchdog timers, automatic health checks, and event logging work together to recover from intermittent power, temperature, or mechanical disturbances. If a shutdown occurs, the RTC continues issuing scheduled wake commands and the system restarts when sufficient power returns.

Pre- and Post-Event Recording



Recording

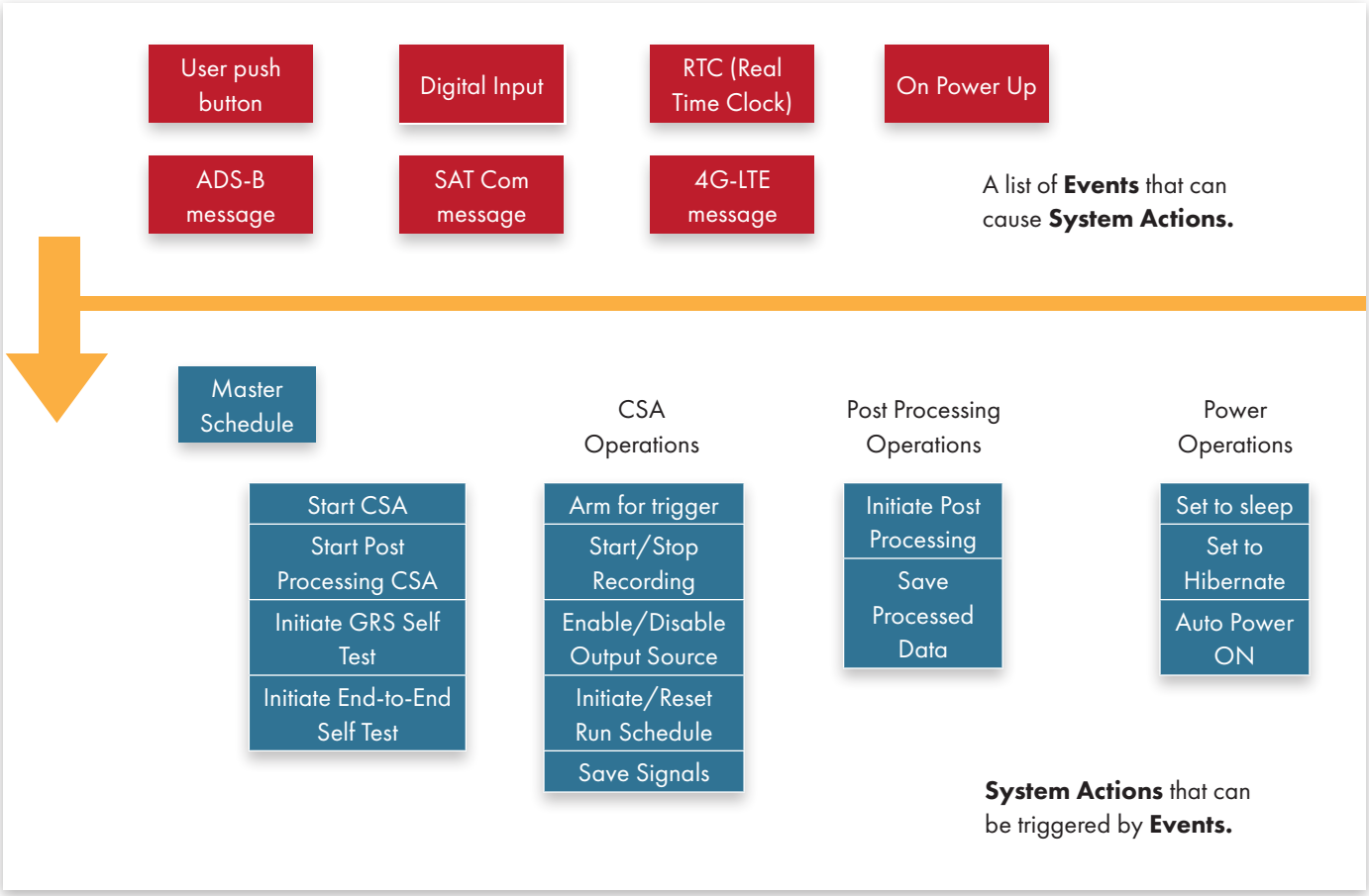
The GRS provides four analog inputs with two 24-bit ADCs per channel. Patented dual-ADC technology automatically selects the appropriate measurement range, preserving small-signal precision while retaining the headroom to capture large transients. Both low- and high-range ADC streams can also be recorded simultaneously.

A removable SD card supports capacities from 64 GB to 2 TB. At 51.2 kHz on four channels, a 2 TB card supports up to approximately 725 hours of continuous recording.

Circular Buffer

A dedicated circular buffer continuously retains up to 300 seconds of data. When a trigger occurs, the buffered pre-event data is appended to the recording so the lead-up to an event is preserved automatically.

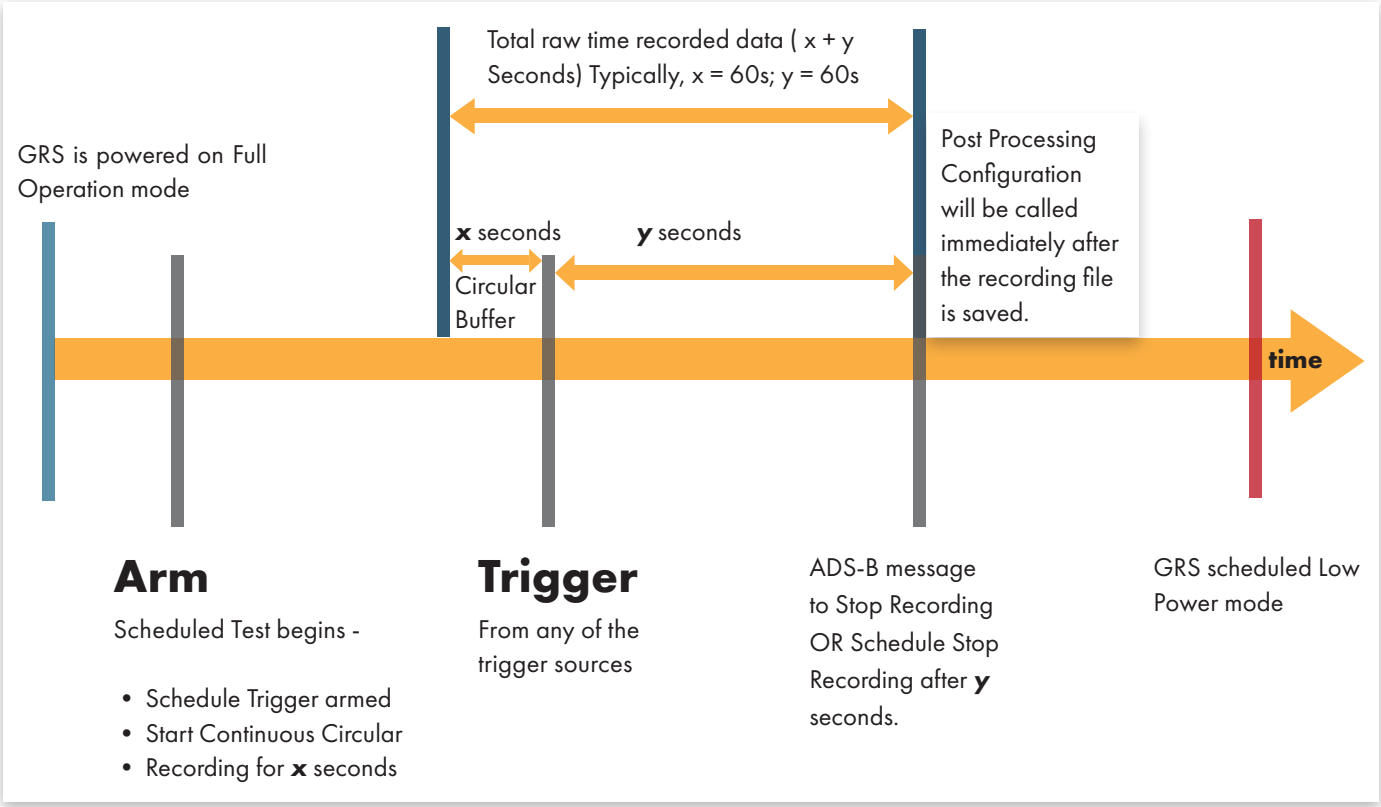
Event Triggered Recording

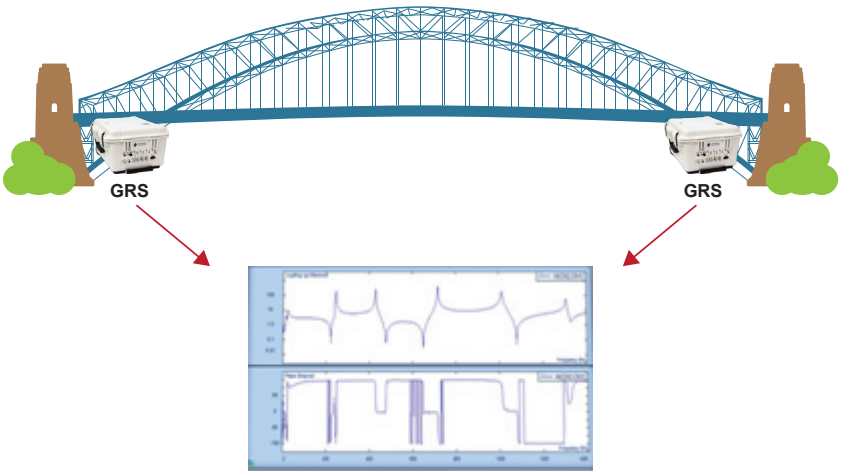


Trigger events are user-configurable conditions derived from analog inputs, ADS-B aircraft data, digital inputs, time schedules, hardware peripherals, or remote commands. Events can initiate actions such as arming, starting or stopping a recording, running a saved analysis, launching the Master Schedule, changing power modes, or initiating a self-test.

Continuous event monitoring and prioritized action handling allow the GRS to capture the desired waveform, include pre-trigger history, defer conflicting configuration or power changes until recording is complete, and operate for days or months with minimal intervention.

Recordings can be started manually, remotely, on a schedule, from a digital input, from measured signal criteria, or automatically when ADS-B data identifies a target aircraft and the configured flight conditions are met.





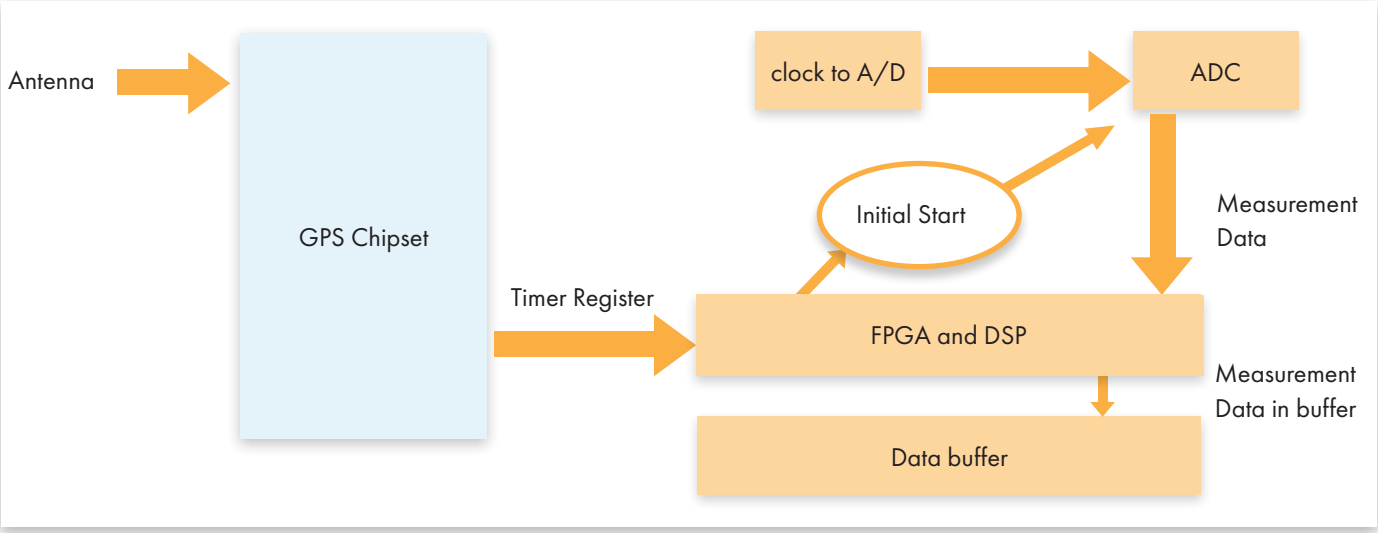
Compute the frequency response, phase, cross spectrum, or coherence functions between two distant points

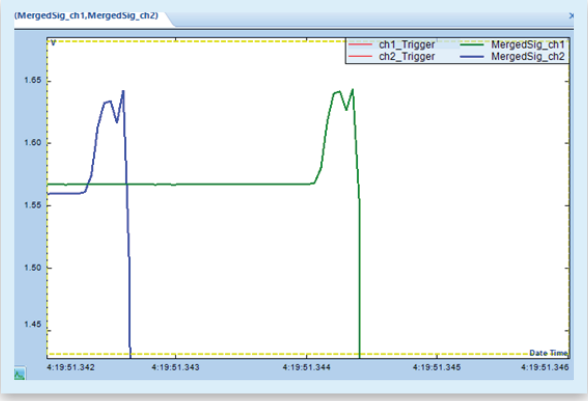
Memory & Encryption

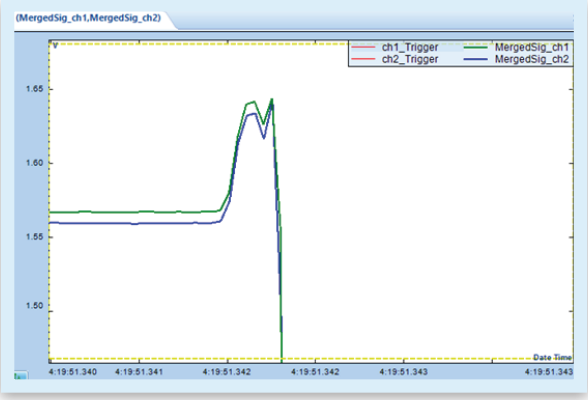
The GRS measures and records dynamic and static signals while performing real-time time- and frequency-domain calculations. Its removable SD interface supports cards up to 2 TB and simultaneous four-channel acquisition at rates up to 102.4 kHz.

Recordings on the removable SD card can be encrypted using a user-configurable passphrase. The implementation follows the FIPS PUB 140-2 standard for cryptographic modules, supporting secure unattended data collection.

Signal Analysis with Timestamped Data







Multiple GRS units can acquire simultaneously while distributed across hundreds of miles without direct hardware connections. Each unit derives timing from GNSS and stores hardware-level time stamps with the measurement data. Crystal Instruments post-processing software aligns the recordings, corrects sampling-rate differences, and supports cross-spectral analysis as though the distributed units were one synchronized DAQ system.

The following diagram illustrates the GRS hardware-level time-stamping workflow.

Example:
This example shows two remotely acquired signals before and after time-stamp-based sampling-rate correction.

The first plot depicts two signals in the time zone of the triggering point. Each signal was captured using different GRS units.

The time difference shown above is caused by using the nominal sampling rate of each GRS unit, which may vary slightly. The second plot shows the same transient event at the end of recording after the first order correction is applied to the sampling rate of both signals.

Integrated Cellular and Satellite Communications for Autonomous Operation

The Ground Recorder System (GRS) brings reliable remote connectivity directly into the data acquisition platform. By integrating cellular LTE and Inmarsat satellite communications, the GRS enables operators to deploy instruments across large geographic areas, monitor them from a central host station, and collect critical acoustic and vibration data without installing communication cables or making routine site visits.

High-Speed Remote Access over Cellular LTE

Where cellular service is available, the GRS uses an integrated, low-power LTE gateway to establish two-way communication with the host station. The cellular hardware supports two SIMs and a broad selection of LTE frequency bands, along with UMTS, HSPA, HSPA+, and DC-HSPA+ technologies for flexible deployment across different carriers and regions.

Using Crystal Instruments software, authorized operators can remotely:

- Configure acquisition and analysis parameters
- View live measurement signals
- Arm, start, and stop recordings
- Receive system status and health information
- Review recording lists and download acquired data
- Control power and autonomous operating functions

The integrated gateway provides sufficient bandwidth for real-time interaction with the GRS. A public static IP address from the cellular service provider allows the host station to identify and communicate directly with each deployed unit. Multiple GRS instruments can therefore operate hundreds of miles apart while remaining accessible through one centralized monitoring environment.

Satellite Connectivity Beyond Cellular Coverage

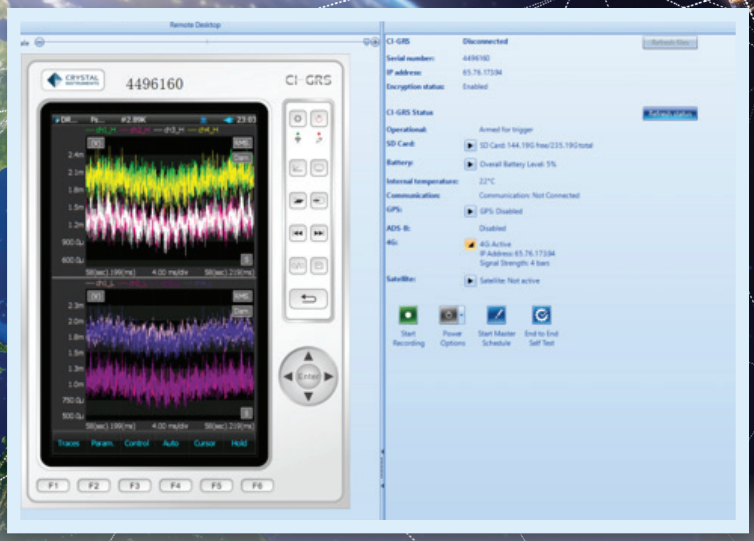
- Integrated Inmarsat connectivity supports remote, offshore, and isolated deployments.
- The GRS automatically uses satellite communication when cellular service is unavailable.
- Cellular connectivity is prioritized, and the satellite module is disabled when not needed to conserve power.

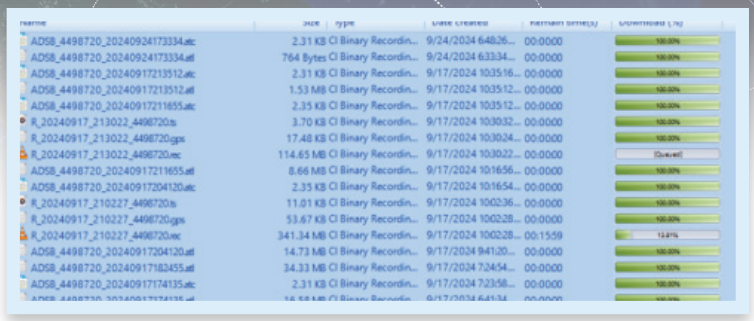
Optimized for Low-Bandwidth Operation

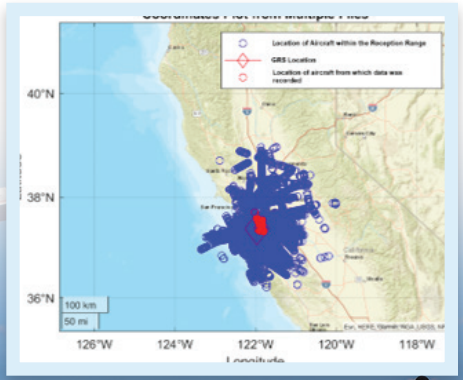
- The satellite module remains powered down or asleep until communication is required.
- Compact, encoded messages reduce connection time, bandwidth use, and power consumption.
- Operators can remotely configure the system, control recordings, manage power modes, and request status information.
- The GRS returns acknowledgements, health reports, operating results, selected recordings, and processed data.
- On-board processing minimizes the need to transfer large raw-data files.

Connected and Autonomous

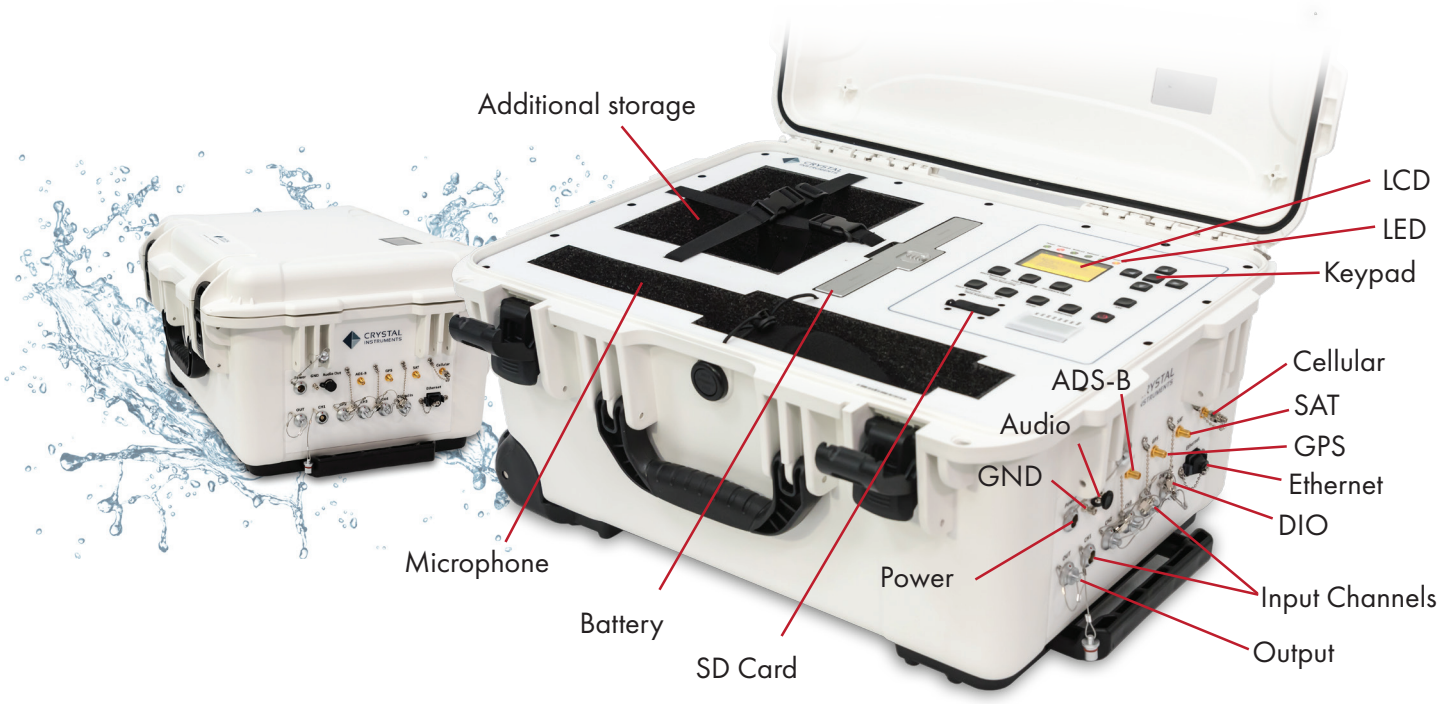
Cellular and satellite connectivity work with GRS scheduling, self-tests, automation, and failure recovery to keep the system operational, visible, and controllable throughout long-duration remote deployments.







Rugged, Weatherproof Enclosure



The GRS enclosure is ruggedized and weatherproof to protect the system and its accessories from extreme weather and severe environmental conditions. It is designed to sustain high winds, dust, and heavy rain.

All connectors are rated **IP67**. The LEMO connectors ensure stability during high winds or harsh environments in addition to providing dust and water protection. The enclosure structure is built using a combination of metal, plastic, and PelicanTM materials.

There are six digital input channels inside of the enclosure and two on the outside of the enclosure. All inputs can be used to generate various software events such as starting or stopping a recording.

The GRS operates from **-20 °C (-4 °F) to 55 °C (131 °F)** and is rated for storage from **-40 °C (-40 °F) to 70 °C (158 °F)**. It can power on and operate after a 24-hour cold soak at 0 °F. The light-gray enclosure helps limit solar heat gain during exposed deployments.

The GRS has undergone and passed shock and vibration tests compliant with the IEC 60068-2-27 International Standard – Shock Testing and -64 International Standard – Basic Environmental Testing. Passed tests include:

Random Vibration

- Overall RMS: 5 g
- Frequency Range: 10 Hz – 500 Hz
- Duration: 10 minutes per axis
- Axes: X, Y, Z

Shock Test

- Shock Type: Half-Sine
- Peak: 30 g
- Number of Pulses: 2
- Direction: ±Z

Shock Test

- Shock Type: Half-Sine
- Peak: 50 g
- Pulse Width: 3 milliseconds
- Direction: ±Z

Hardware Specifications

Analog Input Channels	
Number of Analog Input Channels	4
Connector Type	2-pin LEMO Connector
Coupling	AC, DC, or IEPE (ICP©)
IEPE Power	28 V/10 mA
TEDS	IEEE 1451.4 compliant
Input Range	±10 V, ±500 mV, Auto Switching, Dual Range
ADC Type	Sigma-Delta ADC
ADC Resolution	2 x 24-bit per input channel
Frequency Accuracy	Better than ±50 ppm
Sampling Rate	0.48 Hz to 102.4 kHz, with 54 stages
Maximum Bandwidth	45 kHz
Input Impedance	480 kΩ
AC Coupling	Analog high-pass filter (-0.06 dB @1.0 Hz, -3 dB @ 0.09 Hz)
Input Protection Voltage	±40 V
Analog Anti-Aliasing Filter	-3 dB @ 500 kHz
Digital Anti-Aliasing Filter	110 dB of alias attenuation
Pass-Band Ripple	Less than 0.05 dB
Digital Filter	Digital high-, low-, and band-pass filters
Dynamic Range	155 dBFS max, 150 dBFS typical, 140 dBFS min Tested in the Dual ADC mode
THD (High Range ADC)	• -92 dB at 1 kHz • -81 dB at 8 kHz
THD (Low Range ADC)	• -90 dB at 1 kHz • -91 dB at 8 kHz
Crosstalk	Less than -120 dB at 1 kHz
Amplitude Channel Match	Less than ±0.05 dB
Phase Channel Match	Less than 0.1 degrees at 20 kHz

Noise Applications

- Long-range acoustic source localization and distributed ground vibration testing
- Underwater and offshore acoustic or vibration monitoring without long data cables
- Seismic, bridge, and building vibration monitoring across large areas
- Airport and community noise monitoring with aircraft identification
- Sonic-boom and sonic-thump measurement for low-boom supersonic flight research

- Audio BW is defined as 20 Hz to 20 kHz.
- Full BW high frequency is 15 Hz to 40 kHz.
- All noise specs are typical.

Low Range ADC		High Range ADC	
Audio BW	Full BW	Audio BW	Full BW
5 µVrms	7 µVrms	70 µVrms	100 µVrms

- 30 nV/√Hz at 1 kHz (Low Range ADC)
- 500 nV/√Hz at 1 kHz (High Range ADC)

Global Navigation Satellite System (GNSS) Receiver (GPS)	
Type	Global navigation satellite system (GNSS) Non-removable Integrated Receiver module The built-in GNSS modules deliver high integrity, precision timing in demanding applications world-wide. Support for GPS, BeiDou, GLONASS and Galileo constellations
Location Accuracy	Better than 2.5 m (8.2 ft)
Time Accuracy	Better than 100 ns (99% of the time)
Maximum length of antenna cable	150 ft

Cellular Communications	
Number of SIMs	2
Cellular Technologies	LTE, UMTS, HSPA, HSPA+, DC-HSPA+
Supported LTE Bands	• LTE 700 MHz (likely covering Bands 12, 13, 14, 17, or 28) • LTE 800 MHz (Band 20 and/or 26) • LTE 850 MHz (Band 5 and/or 18) • LTE 900 MHz (Band 8) • LTE 1800 MHz (Band 3) • LTE 1900 MHz (Band 2, Band 25, or other regional bands) • LTE 2300 MHz (Band 40) • LTE 2600 MHz (Band 7)
Required IP address	Public Static IP from Cellular ISP

Satellite Communications	
Number of SIMs	1
Service Provider	Inmarsat
Power Saving	Auto disabled when cellular communication is available

Time Stamps for ADC Sampling Clocks	
Purpose	The sampling clocks of digitized measurement recordings can be continuously time stamped so the recordings from different GRS units can be analyzed on the same time base.
UTC Time Source	GPS satellites
UTC Time Accuracy	100 ns, (better than 60 ns for 99% of the time stamps)
Time Stamp Interval	5 seconds
Time Stamp Storage	Time stamp stream is stored in conjunction with ADC data recording in a *.TS file.
Time Stamp Format	yyyy/mm/dd/hh:mm:ss.mmm.uuu.nnn
Equivalent phase match between two GRS units:	Measured data from different GRS units can be analyzed using cross-spectral FFT technique. Their phase match can achieve better than: ±2°(degree) at 40 kHz ±1°(degree) at 20 kHz, ±0.5°(degree) at 2 kHz.

ADS-B Receiver	
Module	Aerobits TT-MC1b Module
Range	Up to 250 nm (without amplifier)
Antenna	
• Height	6.9 cm / 2.7 in
• Max. length of cable	50 ft.
Ground Plane dimensions	6 in x 6 in
Software Functionality	Arm trigger, start recording, stop recording

RTC (Real Time Clock)	
Function	RTC keeps the calendar time and provides a timer for specific task. The backup battery is independent to the main source battery.
Wake up after power-down	Allows for scheduled wake up (power on) after hibernating or failed shut-down.
Clock Accuracy	±3.5 ppm
Timer	Programmable with accuracy of second
Backup Battery life	Rated for 10 years

Output Channel (Analog Signal Source)	
Number of Output Channels	1
Connector type	2 Pin LEMO
Frequency Range	DC to 45 kHz
DAC Resolution	24 bits
Output Dynamic Range	140 dB (1 μV to 10 V)
Anti-Imaging Filtering	160 dB/octave digital filter and analog filters
Digital Filter	High-pass and low-pass digital filters
Types of Output	DC, Sine, White Noise, Pink Noise, User defined Waveform (Arbitrary Waveform)
Output Voltage Range	±10 V

Internal Digital Inputs	
Input Type	Terminal block inside of enclosure
Number of Inputs	6 (1 internal digital input is shared with external digital input)
Trigger type	Voltage edge trigger or level trigger user selectable
Edge threshold	2.7 V
Level trigger threshold	3.3 V
Software Functionality	Start custom CSA, start recording, stop recording, GRS sleep / hibernate, initiate master scheduler, initiate self-test / end-to-end self-test

External Digital Inputs	
Input Type	4-pin LEMO outside of enclosure
Number of Inputs	2 (1 External digital input is shared with internal digital input)
Trigger type	Voltage edge trigger or level trigger user selectable
Edge threshold	2.7 V
Level trigger threshold	3.3 V
Software Functionality	Arm trigger, start recording, stop recording

Interface Ports and Connectors	
Input Channels	Four 2-pin LEMO
Output Channel	2-pin LEMO
Power Supply	3-pin LEMO Male
Ethernet	1000Base-T Ethernet, connector: IP67 version RJ45
SD Card	SD Card Slot (Up to 10,000 mating cycles) supports up to 2TB
Grounding	Ground terminal to chassis, 3.5 mm metal circular connector
Acoustic Source	3.5 mm audio cable
GPS Antenna	SMA F Connector
ADS-B Antenna	SMA F Connector
Cellular/Satellite Antenna	SMA F Connector

System	
LED Indicators	• Power LED (Green – Full-Up, Yellow – Stand-by, Red – Hibernate, Off- Power Off) • Battery LED (Blinking Green – Charging, Solid Green – Fully Charged, Yellow – Not Charging, Red – Battery Low) • Recording Status LED (Green – Armed / Ready to Record, Blinking Green – Recording, Red – Not Armed.
LED Mounting	Mounted inside, user can see from outside through transparent panel
LCD Status Panel Type	LCD - 128 × 64 dot; Monochrome, mounted inside, user can view from outside the transparent panel
LCD Status Panel Size	LCD display size 61 × 31.3 mm
Hard Keypad	System Functions: Power, Start, Record and Stop keys Navigation for LCD: Left, Right, Up, Down, Enter, Esc
System Clock Accuracy	Automatically synchronized with GPS, better than 5 ms (Note: System clock is only used for OS or Scheduled Timer. It is not for ADC sampling or time-stamping of recordings.)

External SD Card Data Storage	
Storage Type	Removable SD Card
Number of Ports	1
SD Card format	SD/SDHC
Durability (Mating Cycles)	10,000 cycles (Insertions and Ejections)
User Accessible	Yes (Push to mount, Push to Eject)
Minimum Storage Size	64 GB
Maximum Storage Size	2 TB (Continuous recording @51.2 kHz for 4 channels up to 725 hours); Size of 256 GB will be shipped with each GRS unit
Encryption Method	FIPS PUB 140-2 standard, user configurable passphrase

Internal SD Card Data Storage	
Storage Type	Non-removable micro SD Card
Number of Ports	1
SD Card format	Micro SD/SDHC
User Accessible	No
Maximum Size	2 TB; 128 GB SD card will be included with each GRS unit
Encryption Method	No encryption

Recommended SD Cards	
Minimum UHS Speed Class	U3
Minimum Video Speed Class	V30 (Preferred: V90)
Factory recommended list of SD Cards	Preferred: • SanDisk Extreme Pro UHS-II V90 SDXC • Sony Tough UHS-II V90 SDXC • Lexar Professional 2000x UHS-II SDXC Minimum: • SanDisk Extreme Pro UHS-3, V30 SDXC (256GB or higher) • SanDisk Extreme Pro UHS-3, V30 A2 MicroSD (with SanDisk adapter) (256GB or higher) • Gigastone 4K camera Pro A2, V30 MicroSD (with Gigastone adapter) (128GB or higher) NOTE: SD Cards from other manufacturers and other models from listed manufacturers are not recommended for optimal recording purposes.

Environmental and General Specification	
Power Consumption (Max)	13 W
Internal Battery	Two pieces 94 WH rechargeable Li-ion type (Removable), totally 188 WH
Operating Time	12 hours (Full-up mode) with internal battery
Charging Time	• 5 hours with 15V / 3A • 6 hours with 100 W Solar Panel (14 V)
Power Supply	• DC power 15 V (±10%) / 3 A • CI provides AC voltage adapter.
Safety Standard	• EN 61326 1997+A1 1998+A2 2001 • EN61000-3-2 2000 • EN61000-3-3 1995 + A1 2001
Internal Sensors	Temperature
Cooling	Water Pipes and Heat sink, No cooling fan on the enclosure; One small cooling fan on CPU.
Temperature	
• Operational	-20 °C to +55 °C (-4 °F to 131 °F)
• Storage	-40 °C to +70 °C (-40°F to 158°F)
Vibration	
• Shock Non-operation, 6 sides	50 g, 3 ms half-sine; 30 g, 11 ms half-sine; 50 g, 50 ms (315 in/sec) half-sine
• Random Operational, 3 sides	0.3 grms from 5–500 Hz
• Random Non-operational, 3 sides	5 grms from 10–500 Hz

Enclosure Specification	
Dimensions	21.5 in × 14 in × 8.3 in (54.5 cm × 35 cm × 21 cm)
Weight	32 lbs including batteries
Transparent Panel	A rectangular transparent panel is mounted on the surface of enclosure. The user can see the Status Panel and LEDs mounted inside without opening the enclosure.

Environment / Weather Protection	
Temperature	-40 °C to +70 °C (-40 °F to 158 °F)
• Humidity	0 to 100% RH
• Rain	Protected against water intrusion from Heavy rain, Water immersion
• Environment	Protected against Dirt, Dust, Insects, Birds and Reptiles
Carrying Handles	Front (Foldable)
Security	Supports two padlocks of 8mm diameter shackle
Cooling strategy	Water Pipes and Heat sink (No cooling fan inside)
Max Noise Levels	< 35 dB(A)
Additional Storage	Storage space inside enclosure for Sensors, Cables, Antennas, etc.

Power Specifications

Power Consumption of GRS Unit

Version / Mode	Full-Up Mode	Standby mode	Hibernate mode
CIGRS-P02 / CIGRS-P04	13 W	10 W	55 mW

Power Modes and Detailed Power Budget

GRS operates in various modes to conserve power when not needed. Each mode is designed to help conserve power and quickly turns the device on when it needs to acquire data.

Power Mode	Specification	Details
Full-up	**Power Consumption**	**13 W**
	Time of Operation (with 100% Battery)	12 hours
	Features	GRS is fully operational
Stand By	**Power Consumption**	**10 W or less**
	Time of Operation (with 100% Battery)	16 hours
	Features	The Operating System is loaded and active in this mode. Peripheral modules and analog inputs are powered off.
	Time required to bring device to full-up	20 seconds (no bootup required)
Hibernate	**Power Consumption**	**55 mW (Max)**
	Time of Operation (with 100% Battery)	30 days
	Features	All GRS modules are powered down except RTC. Allows scheduled wake-ups.
	Time required to bring device to full-up	90 seconds (bootup required)

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