USERS MANUAL	NR9000 **Kronos 1**
REVISION	C
DATE	2/22/23

NR9000

Kronos I

10MHz Rubidium Frequency Reference, High Performance, Low Noise, GNSS-Locked

Table of Contents

Safety

This product has been designed and manufactured to recognized safety standards and rules.

This product is a sophisticated electronic instrument that should be installed and operated by highly trained professionals.

Installation of this equipment should comply with all local electrical codes.

Utilization of this equipment in a manner inconsistent with the operating instructions can be dangerous.

DANGER

There are no user-serviceable parts within the unit. Removal of the cover to access interior parts will expose the user to dangerous voltages.

DANGER

The unit may be powered from more than one power source. Care must be taken to be certain all power sources are removed before installation or during removal of the equipment.

DANGER

The unit must be operated with a secure earth ground to the chassis. The electrical path for earth ground is through the power connector. The power switching device that controls power to the equipment must never interrupt the chassis ground connection.

The equipment contains complex electronic components that can be damaged by electrostatic discharge. Observe all recognized standards for the handling of complex electronic devices to avoid high voltage discharge to the equipment. Be certain the equipment chassis and operator are at equipotential before handling the equipment.

Mounting

The equipment is meant to operate in a horizontal - top up configuration.

The equipment is meant to mounted into a 19-inch standard NMEA cabinet. The unit occupies a single “1RU”. Mounting spaces above and below the equipment may be used as required.

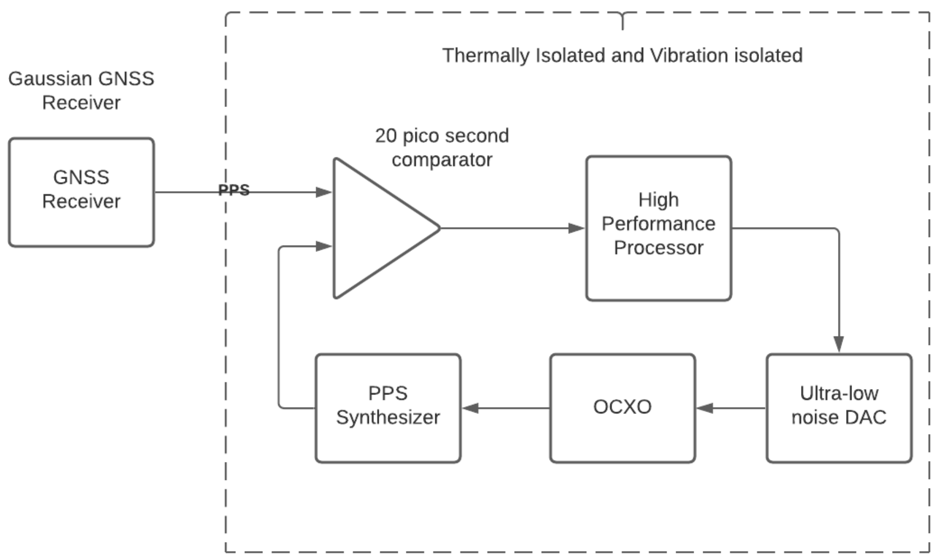
Please observe the operating temperature range for the equipment. If mounted into a closed rack, be certain that the total heat load in the cabinet does not result in an interior operating temperature that exceeds the equipment maximum rated temperature.

If cooling must be used, care should be given to prevent cooling mechanical vibration from the coupling into the equipment. Mechanical shock and vibration may introduce noise into the electronic signals inside the equipment that may degrade the performance of the equipment. For applications where there is significant shock and vibration, Novus offers equipment with interior mechanical design features to minimize the effects of vibration and shock on the equipment performance.

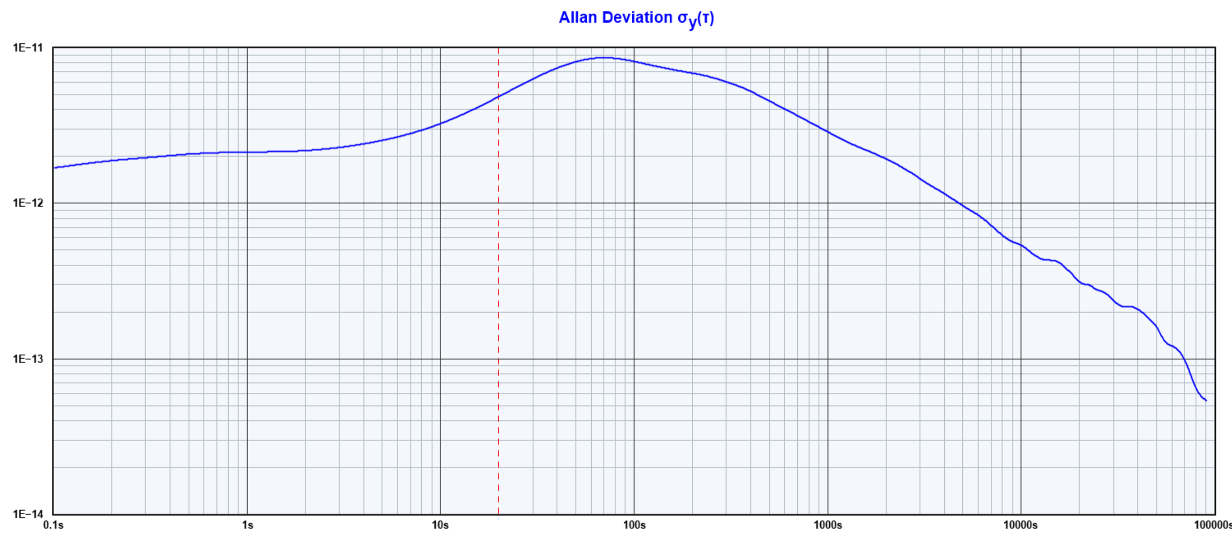
Summary

The Novus *Kronos I* represents our highest performance reference for the most demanding master reference applications.

The 184 channel GNSS receiver provides critical timing information that is highly processed to minimize reference jitter and noise. The receiver supports GPS L1C/A L2C, GLO L1OF L2OF, GAL E1B/C E5b, BDS B1I B2I, QZSS L1C/A L1S L2C, SBAS L1C/A. To assure the integrity of the reference, a separate GNSS receiver is used as an independent time base for an internal gapless frequency counter to monitor the master reference.

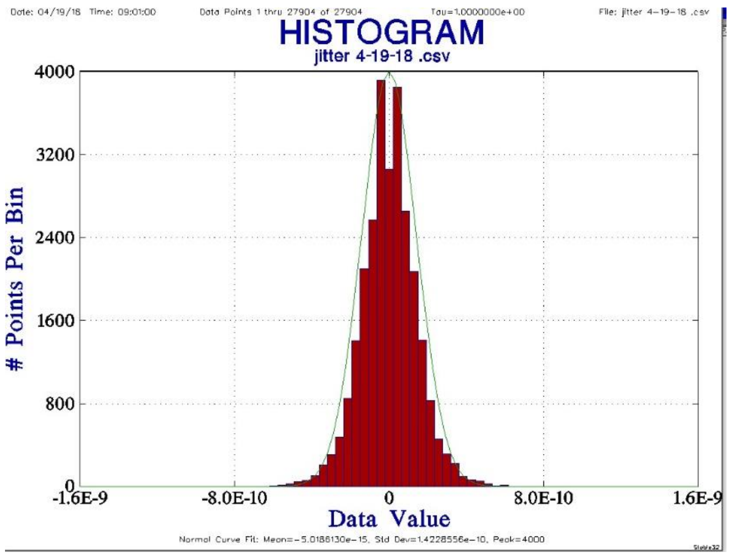


Our most advanced designs address long time constants digitally. High performance picosecond measurement techniques provide greater timing resolution. Advanced algorithms coupled with precise analog designs that are thermally controlled, and vibration-isolated allow Allan Deviation performance approaching E-14. Performance over a standard loop is improved by almost two orders of magnitude.



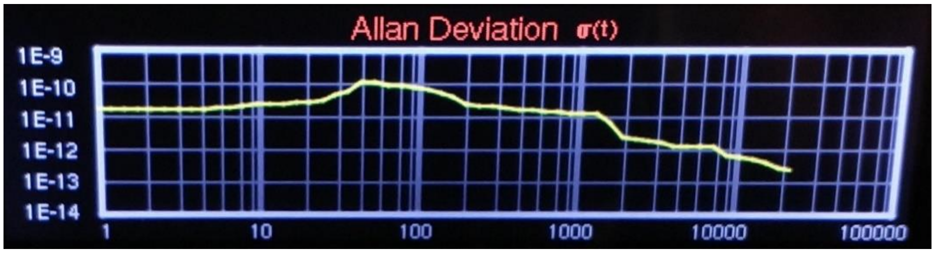
Trace	Notes	Input Freq	Sample Interval	ADEV at 20s	RMS Noise (degs, 300 Hz-3 kHz)	RMS Jitter (300 Hz-3 kHz)	Duration	Elapsed	Acquired	Instrument
PCB78		10.0 MHz	0.100 s	4.93E−12	5.59E−5	1.6E−14 s	4d 14h 56m 50s	4d 14h 56m 50s	3994098 pts	Microchip 53100A

Our algorithms process the radio information to achieve a more stable reference. The curve below is a plot of timing jitter after processing:

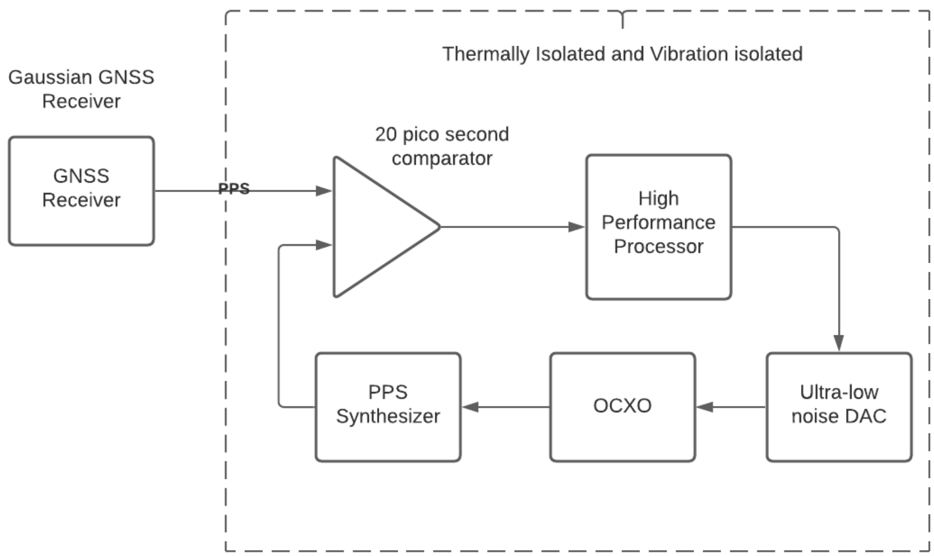


The standard deviation improved from 17 ns to approximately 400 picoseconds. The most advanced loop reports calculated Allan Deviation between the filtered PPS and the OCXO output on real time basis locally on a display and/or a selected serial port. This level of monitoring will quickly detect a reference variation far in advance of a complete failure, avoiding system outages. No one in the industry - that we are aware of - provides this level of monitoring.

To represent the Allan Deviation, we compare the real time deviation of an OCXO derived pulse to the filtered PPS of the GNSS locked source. To see this calculation, read the section titled “Allan Deviation.”



Thermally Isolated Reference (HS3)

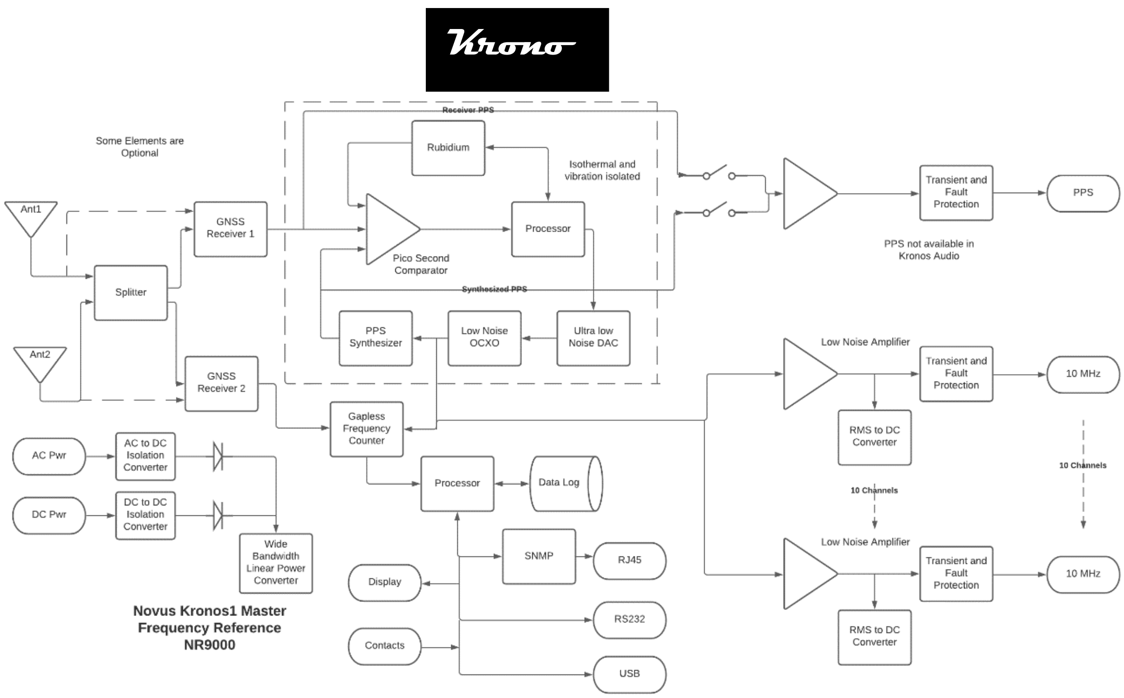


A real time continuous calculation of Allan Deviation is performed and is likely the best indicator of reference health one could have. Data logging allows the user to review timing performance on any day from a performance log that is more than a year deep.

To further enhance stability, the timing control network and reference are vibration and thermally- isolated. The timing loop operates with a 40 ps resolution to enhance process control. Power supplies include wide bandwidth linear regulators to eliminate ripple noise from the amplifiers. Amplifiers are further isolated with individual passive filters and the amplifiers have over 100 dB of 60 Hz rejection. Every element of the design is focused on stability and noise reduction.

- dual time base
- Rubidium stability
- low phase noise OCXO
- real-time Allan Deviation calculation
- low noise linear regulators
- 184 channel GNSS receiver
- 10 channels
- low jitter PPS
- 40 psec control loop
- Allan Deviation less than <E-13
- phase noise <-160dBc/Hz @ 1kHz

The unit features extensive reporting via the rear panel RS232 port - equipment status, output voltage on each channel and redundancy status. By being able to monitor the output voltage, the user can detect cabling issues that cause an impedance change and replace cabling before it completely fails. Reporting is also easily accessible via the front panel display.



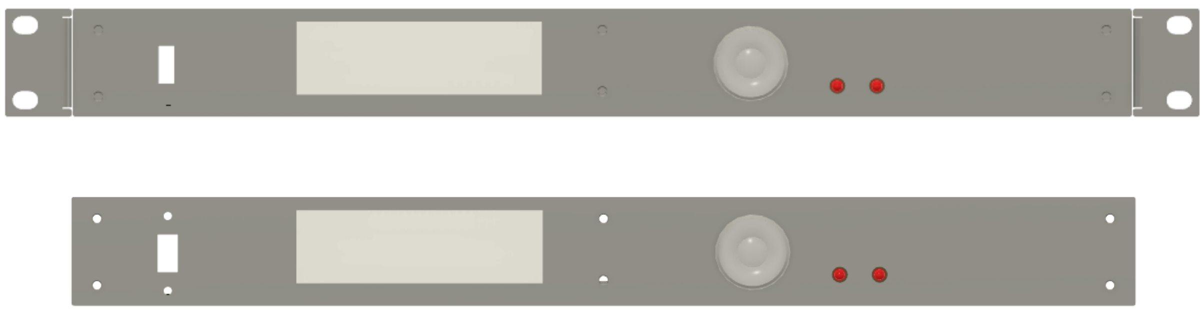
Nominal power is global AC power, but a DC power option can be ordered that acts as the back-up power supply. Nominally 24 Vdc, this port is used for power when AC power fails. Switching between power sources is automatic and there is no transient power outage at the equipment level. The primary power supply is followed by low noise linear converter assemblies.

There will be one in a non-redundant configuration. Each power supply supplies one of the amplifier assemblies.

Controls and Indicators

Front Panel

This section describes the functionality of the front panel controls and indicators.



LEDs

Two front panel LEDs provide a quick indication of the Kronos' status.

The **LOCK** indicator will illuminate solid green if both GNSS receivers have acquired GPS lock, and are actively controlling the respective modules.

The **STATUS** indicator will illuminate solid green if no faults are detected. If a channel output is faulted, or any hardware condition detects a fault, the STATUS indicator will blink red.

Navigation Paddle

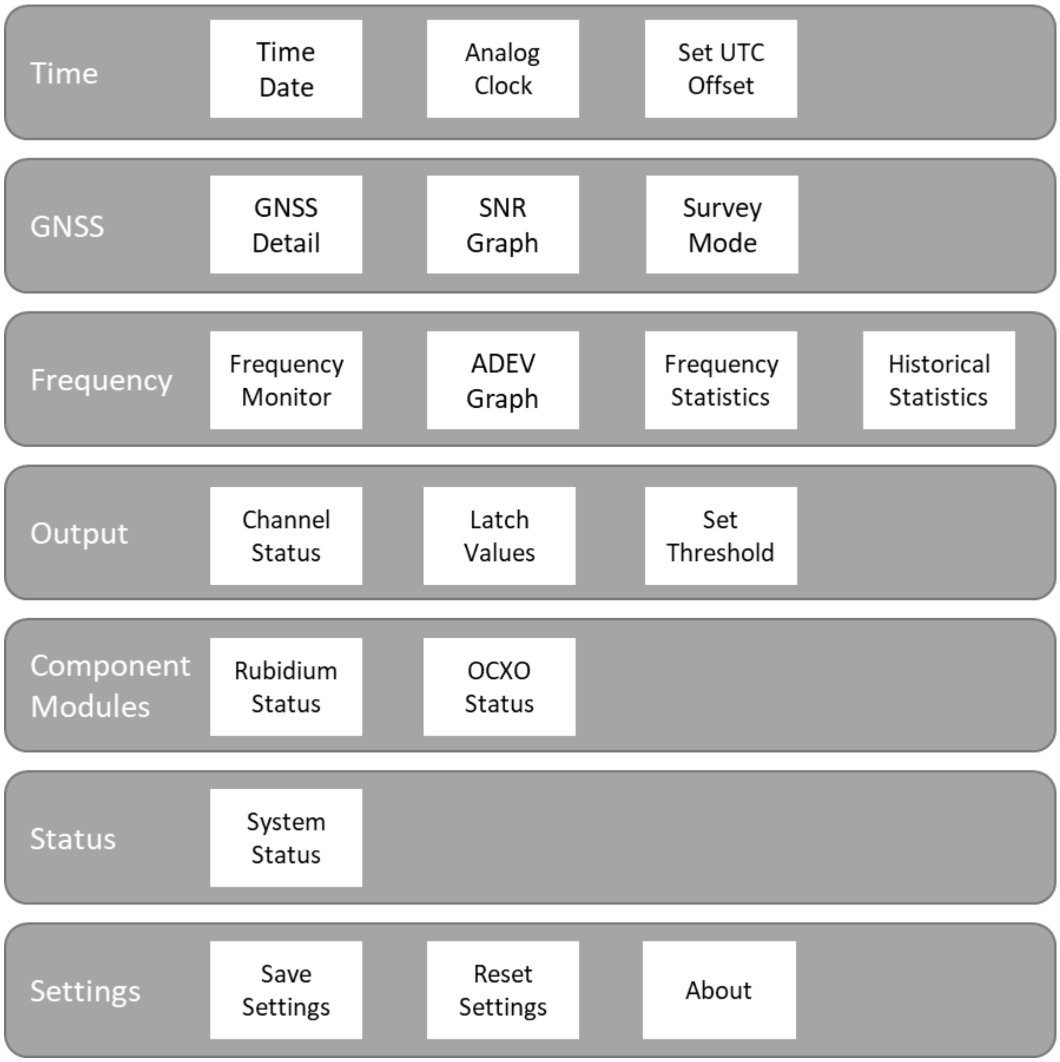
A single navigation paddle above the status LEDs provides navigation through the menus.

In general, pressing the navigation paddle UP or DOWN advances through the menu layers by function:

- Time
- GNSS
- Frequency
- Output
- Component Modules
- Status
- Settings

Pressing the navigation paddle LEFT or RIGHT accesses further functionality within each menu layer.

Menu Layers



Time
Time Date
Analog Clock
Set UTC Offset
GNSS
GNSS Detail
SNR Graph
Survey Mode
Frequency
Frequency Monitor
ADEV Graph
Frequency Statistics
Historical Statistics
Output
Channel Status
Latch Values
Set Threshold
Component Modules
Rubidium Status
OCXO Status
Status
System Status
Settings
Save Settings
Reset Settings
About

Display Navigation

Time and Date

Time and Date Screen

The initial Time and Date screen provides an offset adjusted reference to UTC as delivered by the primary GNSS unit. The lock status of both GPS 1 and GPS 2 are also provided as a quick reference check to see that both modules are GNSS locked and are reporting as healthy. On startup, when the unit is connected to a properly matched GNSS antenna, both internal GNSS units should be locked within 15 minutes.

GPS is locked

GPS is tracking or is unlocked

To adjust UTC offset (to local time zone), use the navigation paddle to move to the Time Display Preference screen.

Analog Clock Face

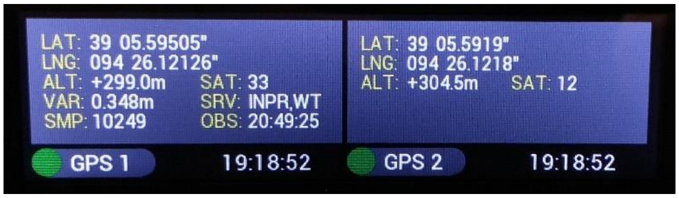
The offset adjusted UTC time is displayed as an analog clock face. To adjust UTC offset (to local time zone), use the navigation paddle to move to the Time Display Preference screen.

Time Display Preference

The Time Display Preference screen allows the user to choose 12 hour or 24 hour time display. Simply use the touchscreen to select “12” or “24”. In addition, the user can adjust the displayed time to a local offset, in hours, by using the touchscreen to navigate between UTC-11 to UTC+12. When a selection has been made, press the “Save” button on the touchscreen to save the preference to non-volatile memory.

Note that the time offset provides a friendly presentation for display of UTC corrected time. It does not change the UTC synchronized data from the NMEA strings or other timestamping.

GNSS Data Display



GNSS data is provided that consists of 3D positioning (Latitude, Longitude, Altitude). The primary GNSS satellite count displays the number of GNSS constellation satellites that are currently being used in the fix calculation.

The Kronos maintains two internal GNSS radios. The primary GNSS module is an ultra-high precision 184 channel timing module with 2.0m CEP, 5ns (1 sigma) timing accuracy, with multiband GPS, GLONASS, Galileo, Beidou reception. The secondary GNSS unit is a high precision timing module with 15ns (1 sigma) timing accuracy, using GPS and GLONASS. The primary GNSS provides the source for loop discipline of the Rubidium and OCXO modules. The secondary GNSS provides a long-term averaging frequency counter to monitor the output of the entire primary module at better than 1mHz.

Both the primary and secondary GNSS data sample are provided in real time to monitor the health of the unit.

The primary GNSS requires a 36hr Survey-In period by default. During this period, the primary GNSS continuously acquires position samples until a minimum radius of 0.400m is achieved (default setting) and the 36hr minimum is completed. During this process, the status of the Survey-In is displayed on the GNSS Data Display with the following parameters:

VAR: Square root of the mean variance of position accuracy. This is the estimate (1 Sigma) of the 3D position indicators.

SRV: Status of the Survey-In process. There are three possible states: FIXED, INPR, DONE.

> **FIXED**: The receiver is in fixed position mode and is not using the Survey-In feature. Fixed mode is useful if the unit is power-cycled frequently but does not move. In general, it is recommended to keep the unit in Survey-In mode and powered on. To reach optimum performance, a Survey-In period should be completed and the minimum mean variance achieved.
>
> **INPR**: The receiver has not yet completed the requirements for Survey-In period or minimum accuracy. Survey-In is in process.

DONE: The Survey-In process has completed both minimum time and minimum accuracy requirement. The position will now be fixed at the current solution and the unit enters time mode.

In addition, two indicators relate the validity of the position fix:

OK: This indicates the receiver is reporting a valid Survey-In indicator.

WT: The receiver is not reporting a valid Survey-In indicator.

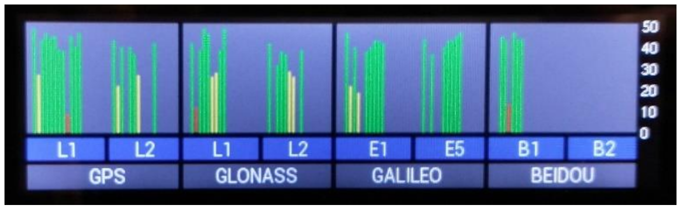
SMP: The number of samples used in the 3D positioning fix.

OBS: The amount of observation time in the Survey-In period that has been completed.

The secondary receiver is a 26-channel multiband GNSS receiver with GPS, GLONASS, SBAS capabilities. It is normal to see fewer satellites used in the position calculation for the secondary receiver relative to the primary receiver.

The unit can be configured to operate from a single antenna by using an internal splitter or two completely independent antennas can be used.

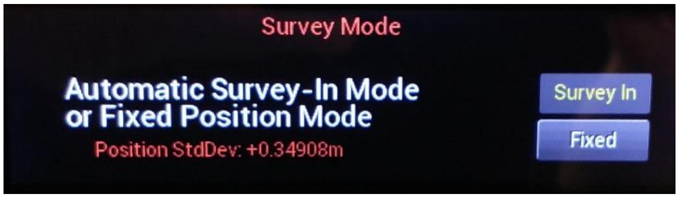
GNSS MultiBand SNR Meter



The primary GNSS provides Signal-to-Noise ratio in dB as per the NMEA 0183 GSV standard. The ratio is expressed in dB as a representation of the strength of the RF signal above the noise floor. The display provides an SNR meter for health and signal monitoring as well as to diagnose antenna issues or compare antenna placement options. For each satellite PRN in the GNSS system constellation, a single bar is provided to show that satellite's SNR.

The SNR meter divides the satellite data into its respective frequency bands. To make use of both bands that the GNSS module is capable of, a dual band (L1/L2) antenna can be purchased.

Survey Mode



The Survey Mode screen allows the user to choose between fixed position and the initial Survey-In requirement on startup. To use the fixed-position mode, first complete a Survey-In period of 36 hours at the intended antenna location. The GNSS Data Display screen will indicate that the survey in is complete when the "SRV" field indicates

SRV: DONE,OK

This confirms the sampling is complete and the receiver is in time mode. To change to fixed mode, press the "Fixed" button on the touchscreen, and allow the receiver to confirm the changes. This selection saves 3D position data and fixed position accuracy to non-volatile memory. Until it is changed back, the unit will enter fixed mode on power up, using the same position and accuracy values.

When changing back to Survey-In mode, the Kronos should be power-cycled after the selection is made to allow the GNSS to reacquire position data.

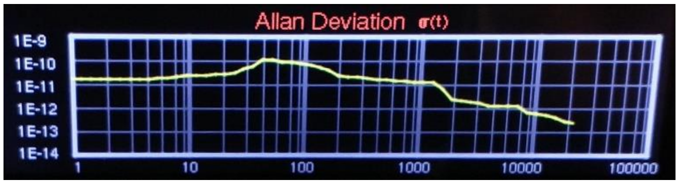
Frequency Data, Reporting, and Monitoring

The Kronos unit contains a second GNSS locked radio to monitor the output of the GPS locked Rb or OCXO source. This monitor is labeled as GPS 2, and provides a one-second frequency count of the source input. The counts are accumulated for a running average of 1, 10, and 100 seconds. The accumulation and averaging of samples for this period will result in a measurement accuracy of approximately 8e-11, which provides a reasonable independent verification of the source accuracy.

To see the Frequency Monitor in real time, both GNSS sources must have achieved lock, and have begun reporting frequency.

The GPS lock status of both GNSS sources is displayed along with the frequency of the source as reported from both the source itself, and the secondary monitor.

Allan Deviation



To display a representation of Allan Deviation with respect to the GNSS locked pulse-per-second, we use the following method.

The difference between the GNSS provided pulse-per-second and the OCXO synthesized pulse-per-second are captured at each period to a precision of ±40 picoseconds. The GNSS pulse provides 5ns (1σ) accuracy with ±4.5ns of noise. The results are filtered with a proprietary FIR algorithm to provide the most accuracy while mitigating the GNSS pulse-to-pulse jitter.

Between two temperature stabilized units, the resulting frequency difference is on the order of 0.00005Hz with 0.0003Hz standard deviation. The synthesized PPS difference between two temperature-controlled units is on the order of 3ns (1σ). This provides a worst case 1σ accuracy measurement of 8ns = (5ns + 3ns) with a pulse-to-pulse jitter measurement of 350ps pk-pk.

The frequency statistics and Allan Deviation representation are derived from the following process:

$$Filtered\ PPSDiff(ns) = FIR\left\{LPF\{SynthPPS(ns) - GPSPPS(ns)\}\right\}$$

$$Frequency\ Error(Hz) = (PPSDiff[i] - PPSDiff[i-1]) \times \left(\frac{0.01Hz}{ns}\right)$$

$$Frequency(Hz) = 10000000.000 - Frequency\ Error$$

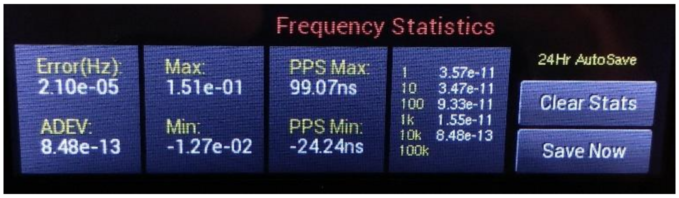
$$Allan\ Variance = {\sigma_y}^2(\tau) = \frac{1}{2(M-1)}\sum_{i=1}^{M-1}(y_{i+1} - y_i)^2$$

$$Allan\ Deviation = \sigma_y(\tau) = \sqrt{{\sigma_y}^2(\tau)}$$

Where y_i is the *ith* of M fractional frequency values averaged over the measurement (sampling) interval of τ. [1]

[1] NIST Special Publication 1065 *"Handbook of Frequency Stability Analysis"* July 2008

Frequency Statistics



Frequency statistics are continuously monitored and saved to non-volatile memory every twenty-four hours. The Frequency Statistics screen displays the current parameters and includes the parameters that are saved to non-volatile memory. The values on this screen are not valid during warmup, nor while achieving GNSS lock. These should be cleared after the unit warms up and is stable, to ensure that long term statistics are the most accurate possible. The sampling depth for each bin is 64, so the longer tau samples persist for up to two months. Statistics captured include the following:

- Frequency Error (in Hz as described above)
- ADEV (10ks or best available if sample period is not adequate)
- Frequency Error Maximum (Hz)
- Frequency Error Minimum (Hz)
- PPS Error Maximum (ns)
- PPS Error Minimum (ns)
- ADEV Points (1s, 10s, 100s, 1ks, 10ks, 100ks)
-

The Frequency error is a 1s calculation based on the above-described method and is not averaged. The minimum and maximum frequency are also displayed.

ADEV sample points are taken from the values calculated at 1s, 10s, 100s, 1ks, 10ks, 100ks. The value at 10ks is stored and displayed as a representation of the previous day's performance. This is equivalent to seven two-sample readings.

Save Now Button

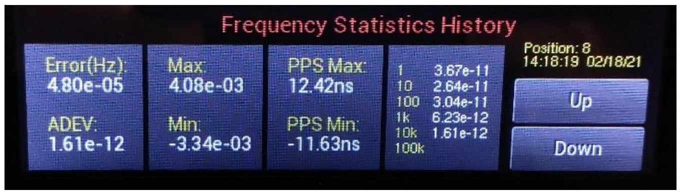
The frequency statistics are saved daily at 00:00:00 UTC. They can also be saved arbitrarily at any time by pressing the “Save Now” button. The current ADEV statistics will be saved to non-volatile memory and can be accessed from the serial port or viewed on the “Frequency Statistics History” screen.

The daily save of the frequency statistics will clear the Max/Min values for the PPS and frequency. This is done to have a reference point for each 24-hour period. The ADEV points, however, are not cleared on each daily save because of how many data points are used in the calculation. For example, the 100ks calculation requires two consecutive samples (2 to 3 days), and the readings contain up to 64 samples.

Clear Stats Button

To clear the current statistics readings, press the “Clear Stats” button. This will clear all frequency statistics data including the Allan Deviation.

Frequency Statistics History



The Frequency Statistics History screen displays the historical values with a Time and Date stamp. With the time and date, a “Position” value is labeled for direct access from the serial port.

To navigate onscreen display of Frequency Statistics, press “Up” to move to later captures, and press “Down” to move to earlier captures. The position number, date, and time are shown above the navigation buttons.

Output Channel Status Monitoring

The channel status is determined by reading the actual RMS value in volts on the output of each stage. This value is compared to a threshold limit that is set by the user as a percentage variation from a saved value. The default variation value is set at ±55% from the current state of the amplifier, and is user-programmable from ±10% to ±60%.

To optimize this feature, the range of acceptable channel amplitude can be narrowed around a connected balanced line, so that a channel status below the Alert Threshold indicates a shorted line, while a channel status above the Alert Threshold window indicates a potential disconnected cable.

The threshold value at which a channel alert is triggered can be programmed on the Alert Threshold screen or programmed via the RS232 port. Once set, the unit would continue to monitor each channel and a deviation beyond the set limits would be reported as a failure on the front panel and via RS232.

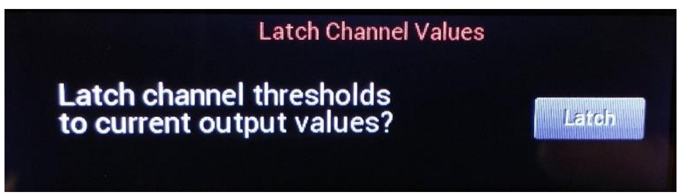
The channel status feature can quickly detect a cabling failure. Any change in the load impedance will change the output voltage with respect to the divider formed by the output impedance of the amplifier and the load impedance. Failing cables and connectors can be detected early.

On the Output Channels screen, the current threshold limits are displayed in addition to the actual measured value. These values reflect the percentage threshold defined in the Alert Threshold settings. If the output value is too low to give a valid reading, the display will read "LOW." The status is displayed on the front panel and is accessible over the RS232 serial bus via DB9.

For example, "Ch 5" indicates the monitored channel output value in Vrms in white. Above and below the channel value, the High and Low thresholds are shown.

If the channel output exceeds either the high or low threshold, the output value will illuminate in red, and the STATUS LED will blink red.

Latch Channel Values



The Latch Channel Values Screen allows the user to save the current channel output values for use as the reference value for alert settings. A channel alert is triggered when a channel output voltage exceeds or falls below a percentage of the reference value. This reference value is 1.10Vrms as a default, but can be set by the user.

To latch the current output values as the center of the acceptable output range, press the "Latch" button, and press "Ok". The high and low thresholds will now be centered at the value currently measured for each channel.

There are two ways to set the reference voltage. The RS232 serial port allows for setting an individual channel's reference voltage with the $SET command. The user can also use the Latch Channel Values to take a snapshot of all current outputs and use these as the reference values.

Setting Amplitude and Threshold Alert

The Amplitude and Threshold screen allows the user to adjust the tolerance from the reference voltage which, if exceeded in either direction, the output channels will report a fault status. The default threshold value is set at ±55% from the current state of the amplifier, and is user-programmable from ±10% to ±60%.

Each channel has a reference voltage which can be set, all at once, by latching the channels' current value in the Latch Channel Average Screen. Each channel's reference voltage can be set individually by writing the value serially with the $SET command, or by using this screen.

Amplitude Reference Point

To change an individual channel's amplitude reference point:

1. Press the "Amplitude" button on the touchscreen.

2. Press the input for which this channel reference relates. For reference applications, use A only
    a. Choose "In A" if you want this reference point active when Input A is active.
    b. Choose "In B" if you want this reference point active when Input B is active.
        i. If the unit has only one source, Input B is not used.

3. Use the "Up" and "Down" button to select the appropriate channel.

4. Enter the desired reference point (*example:* 0.75. This is the target value that the channel output should deliver while loaded, 0.75Vrms)

5. Press Enter.
    a. If the value is not in a valid range, the number will turn red.
    b. "BkSp" will delete the last character. "Clear" will clear the number entry completely.

6. The Amplitude indicator will be updated to display the new value.

Threshold Alert Point

For each input, A and B, the threshold can be set. This value represents the multiplier for the +/- range calculation. For example, to set the threshold at 35% of the current value for a channel, the user would enter 0.35.

To change the threshold for all channels on a given input:

1. Press the "Threshold" button.

2. Select Input A ("In A") or Input B ("In B").
    a. For units with one source, Input B is not used.

3. Enter the desired percentage in decimal terms from 5% (0.05) to 70% (0.70).
    a. If the value is not in a valid range, the number will turn red.

   b. "BkSp" will delete the last character. "Clear" will clear the number entry completely.

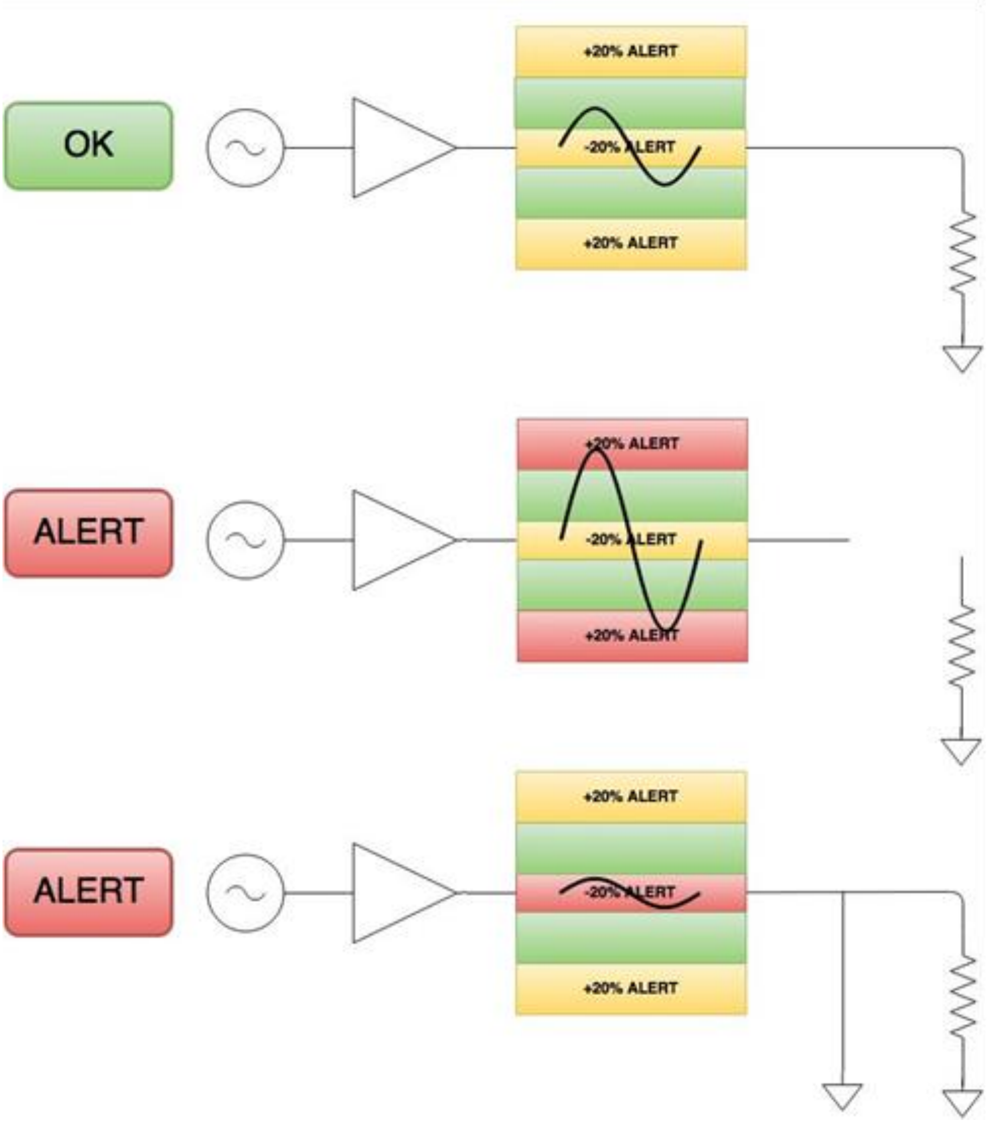
4. The Threshold indicator will be updated to display the new value.

After saving the current configuration on a channel, any subsequent deviation on that channel which exceeds the alert threshold percentage will trigger an alert.

When desired settings are complete, navigate to the "Save Settings" screen and press "Save" on the touchscreen.

To get the most out of the alerting system, consider the following steps to ensure correct alert configuration:

1. Connect distribution cabling to channels 1 through 10.
2. Set Alert Threshold to desired range.
3. Save current channel voltages with the Latch Channel Values screen.
4. Save current settings on the Save Configuration screen.



The alert threshold can be optimized so that a channel short or an impedance change will cause an Alert.

Example:

The output of channel 1 is connected to a high impedance input and reports 1.25Vrms at the output. The output of channel 2 is connected to a 50ohm terminated input and reports 0.90Vrms at the output.

Alert threshold is set to +/-20%.

The current state is saved in the Save Configuration screen.

The Channel 1 alert will report when:

- *The Channel 1 output is higher than 1.50Vrms*
- *The Channel 1 output is lower than 1.00Vrms*

The Channel 2 Alert will report when:

- *The Channel 2 output is higher than 1.08Vrms*
- *The Channel 2 output is lower than 0.72Vrms*

Rubidium Module Status

The Rubidium screen provides several key indicators for Rb module health. Under normal conditions, the Rubidium module will progress through Heating/Initialization and Laser Lock within minutes and the unit will be fully locked within thirty minutes. The fully locked Rb module will, without further discipline, use the best-known coefficients and provide a stable source for the OCXO to discipline.

Note that “Lock” in this context represents the state of the Rb internal TCXO to the Rubidium physics package. The word “Discipline” refers to the input of a valid 1 PPS pulse to the Rubidium module.

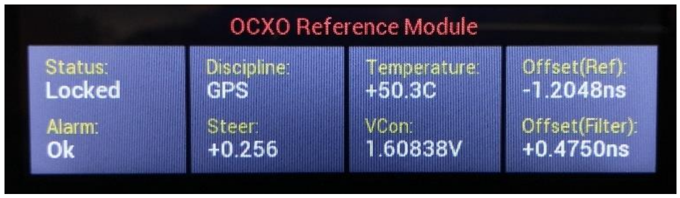
When GNSS lock is acquired and the GNSS pulse-per-second begins, usually within fifteen minutes, the Rb will begin discipline to the GNSS and indicate “Discipline Wait”. Within thirty minutes of continuous discipline, the Rb module should report “Discipline Good.”

The Rubidium module reports several measurement parameters that indicate lock status, health, etc. A selection of these parameters is reported here and available on the serial port by analyzing the $GPNVS,14 string. The parameters and descriptions are as follows:

Rubidium Status

Field	Reading	Description
Status	Heat/Init	Initialization and Warmup
	Laser Lock	Initial State, Frequency not yet valid
	Locked	System Lock
	Error	Rb is reporting, but an error exists
Alarm	Ok	No alarm
	uWave Lost	Indicates that the microwave signal is lost
	Temp Alarm	Indicates the laser cavity temperature alarm
	Bulb Alarm	Indicates that the absorption bulb cavity temperature alarm
	Temp/Blb	Indicates that the laser cavity temperature, absorption bubble
	uWave/T/B	Cavity temperature alarm;Indicates that the microwave signal is lost, the laser cavity is warm, and the temperature of the cavity is absorbed
	Error	Rb is reporting, but an error exists
Discipline	Discipline Wait	RB has pulse input for discipline, but is not yet guaranteed to specification
	Discipline Good	Rb has pulse input for discipline, and is within spec
	Holdover	Rb has no input for discipline
	Error	Rb is reporting, but an error exists
Offset (Ref)	<nn>ns	Distance Rb reports from disciplining input Ref PPS
Offset (MCU)	<nn.nn>ns	Distance MCU reports between Rb PPS and Ref PPS

OCXO Module Status



The OXCO module maintains an ultra-low phase noise OCXO locked to GNSS in a temperature stabilized unit. The module reports extensive data that is available via the serial port. To view detailed OCXO module status, the $GPNVS strings can be viewed (strings 7-30) and remotely monitored. A selection of the parameters is displayed on the OCXO Module Status screen.

The primary GNSS module may require up to 15 minutes after lock to begin output of a reference pulse-per-second. Once the pulse is present, oscillator discipline begins, and may continue for up to 30 minutes before stable mode is fully engaged.

The parameters and descriptions are as follows:

OCXO Reference Module Status

Field	Reading	Description
Status	Locked Stbl	GNSS locked and frequency within nominal range. PPS is in stable mode and derived from OCXO.
	Locked Disc	GNSS locked and frequency within nominal range but still disciplining. PPS is synced to GNSS while stable mode is acquiring frequency data.
	Unlocked	GNSS unlocked or frequency outside nominal range
Alarm	Ok	No alarm
	0xHH	Hex value error code
Discipline	GPS	OCXO is locked to GNSS source
	Rb Holdover	OCXO is slaved to Rb for holdover stability
Steer	<n.nnn>	Applied PID steering
Temperature	<nn.n>C	Internal OCXO Module temperature
Vcon	<n.nnnnn>	OCXO Loop Control Voltage
Offset (Ref)	<nn.nnnn>ns	Distance PPS input from GNSS
Offset (Filter)	<nn.nnnn>ns	Distance Filtered PPS

System Status

The overall system status is easily viewed from this screen, which reports power supply status, system faults, and channel alerts in one place. To monitor status on the serial port, $GPNVS strings 1-6 provide extensive information.

Power Supply Status

Power Supply Status screen provides a reading of selected onboard power supplies for monitoring. The actual values depend on options and some are reserved/not yet implemented.

Power Supplies

Field	Description	Units
DC	DC Power Input	Vdc
In A	Input A	Vrms
In B	Input B	Vrms
Ant	Antenna Supply	Vdc
Dig	Digital Power Supply	Vdc
An+	Analog Power Supply (+)	Vdc
An-	Analog Power Supply (-)	Vdc

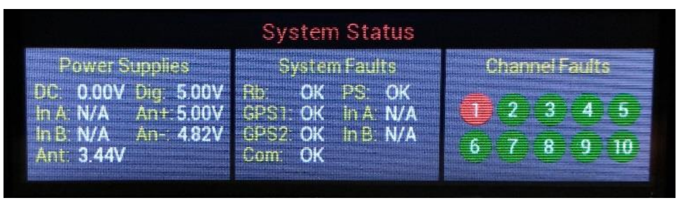
System Faults

The system faults listing gives a quick glance at the reporting of internal submodules. If a submodule is reporting an error or failure, the fault can be quickly seen here as "FLT". Normal operation will report as "OK", with GPS modules indicating "UL" if they are not locked. For detailed status reporting, see the Appendix C "$GPNVS Definitions"

Channel Faults

A view of the channel faults is presented by showing an individual channel in red if faulted. During normal operation, channel values will appear with green background.

Fault thresholds and amplitude settings can be adjusted as described in the "Setting Amplitude and Threshold Alert" section.



In the above picture, the user in notified that channel 1 is faulted. Either the channel is shorted (amplitude below bottom threshold), or the channel is not connected (amplitude above top threshold). This occurs when the output amplitude exceeds the range of the threshold in either direction.

Rear Panel

Channel Outputs – BNC or SMA

There are ten outputs across the lefthand side of the rear panel. They are labeled 1 through 10. These can be sine or square depending upon the factory configuration. Nominally the outputs are 50 Ohm impedance (optional 75 Ohm). The unit can be configured for the output connectors to be SMA or BNC. The nominal connector configuration is BNC.

Antenna Input A/B – SMA

SMA female – Internal 3.5V Supply, 45mA max. The unit can be configured to operate from two separate antenna or a single antenna by using an internal splitter.

AC Input

The AC input accepts 90-250Vac, 50-60Hz. IEC 320-C14 Compliant.

Power Switch / Circuit Breaker

The power switch is a two-pole circuit breaker which disconnects the AC power input and the DC power input simultaneously. When the power switch is in the Off position, no power is applied to the unit.

DC Input

RT060102SNH – mating connector

https://www.amphenol-sine.com/RT06102SNH-Plug-Female-4-Contacts-Contact-Sizes-16-20-13A-5A350V-Shell-Size-10_p_1056.html

RT0L-10CG-S2 – Strain Relief

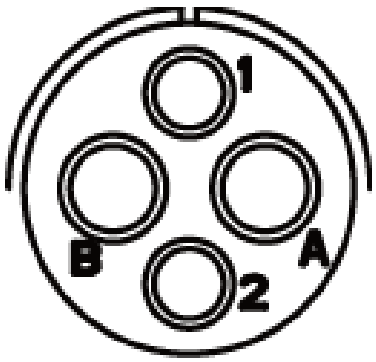
https://www.amphenol-sine.com/RT0L-10CG-S2-Long-Backshell-straight-Shell-Size-10-Cable-Range-50-85mm_p_1340.html

MS16M23F – Socket Contact for Holes A & B

https://www.amphenol-sine.com/MS16M23F-Socket-Contact-Size-16-Machined-Gold-Flash-Wire-Range-75-15mm%C2%B2-16-18-AWG-Compatible-to-part-RC16M23J-192991-0041_p_921.html

MS20W23F - Socket Contact for Holes 1 & 2

https://www.amphenol-sine.com/_p_941.html



Note this view is the back of the RT060102SNH mating connector.

A is V+ and is a Red 18 AWG wire

B is V- and a Black 18 AWG wire

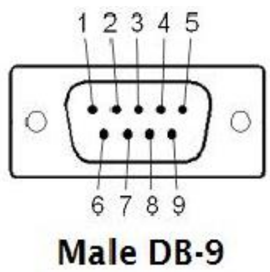
1 is Ground is a Green 22 AWG wire

2 is Chassis Ground is a Green 22 AWG wire

RS232 DB9

An RS232 port is provided for local setup, and status monitoring. The embedded processor provides status strings, as well as command responses. Configuration and status commands are detailed in the NR9000 Programmer's Manual Section 5.0.

RS232 Serial Port: Rear Panel Pin Connections



Pin	Function	I/O
1	NC	
2	Command Port TX	O
3	Command Port RX	I
4	NC	
5	GND	GND
6	NC	
7	NC	
8	NC	
9	NC	

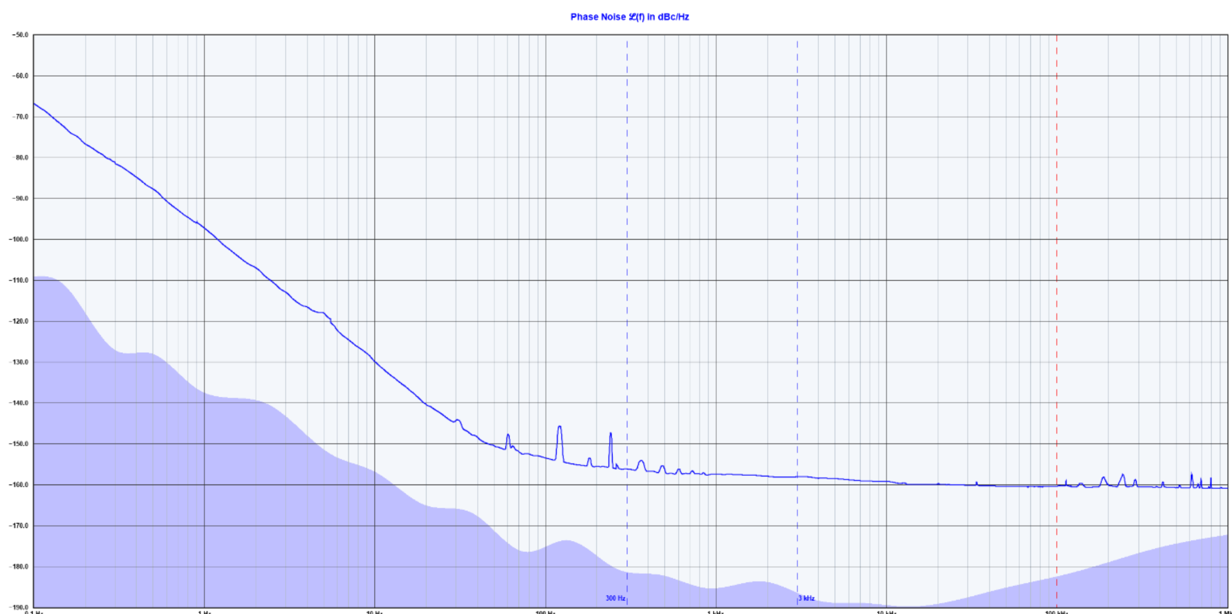
The default settings for the rear panel RS232 port are 115200 baud, 8 bits, 1 stop bit, no parity.

Performance

Phase Noise

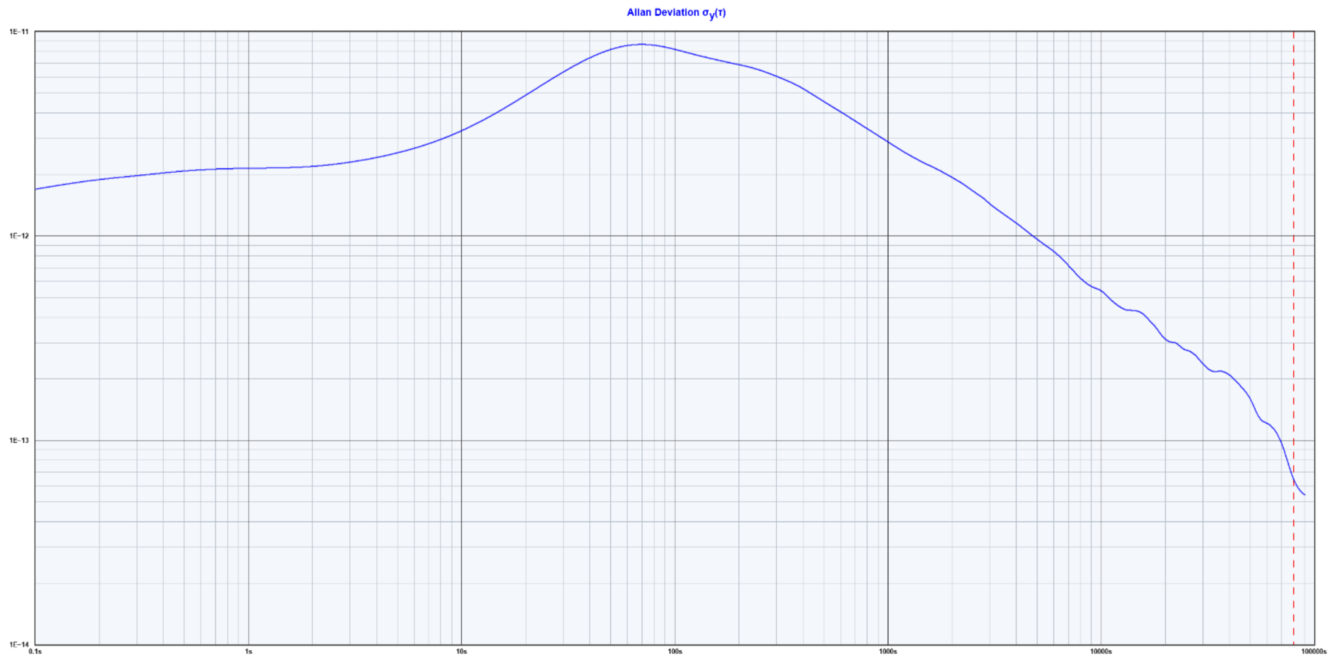
Low phase noise contribution is achieved through careful PCB design, component selection and minimization of power supply noise.

Below is a typical phase noise performance for a 10 MHz reference application:



Trace	Notes	Input Freq	Input Amplitude	dBc/Hz at 100 kHz	RMS Noise (degs)	Duration	Elapsed	Acquired	Instrument
PCB78		10.0 MHz	11 dBm	−160.3	5.59E−5	4d 14h 56m 50s	4d 14h 56m 50s	3994098 pts	Microchip 53100A

Allan Deviation



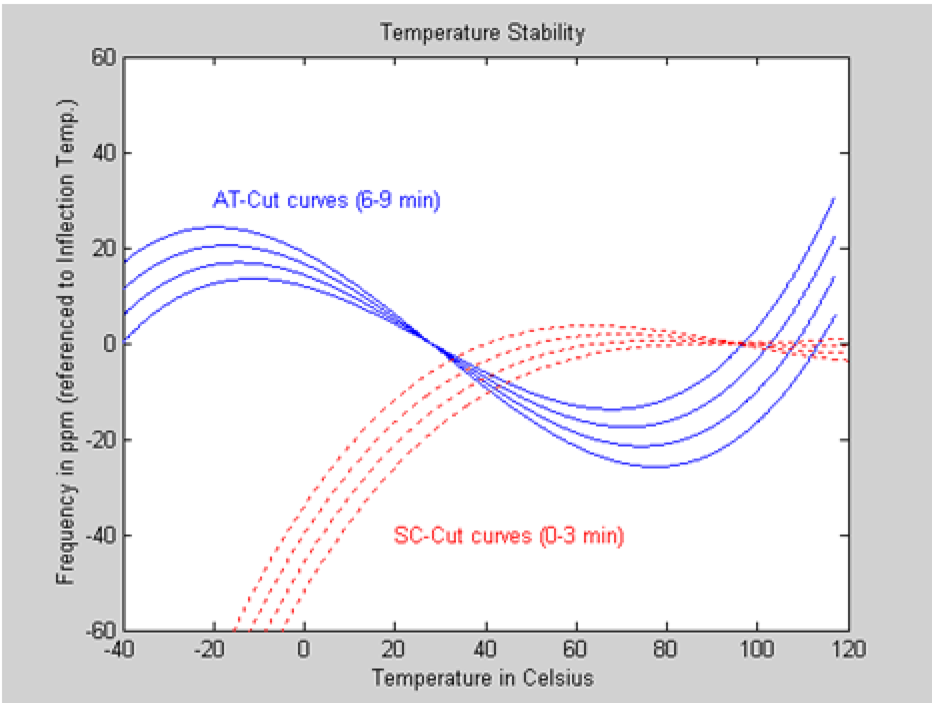
Trace	Notes	Input Freq	Input Amplitude	ADEV at 80000s	RMS Noise (degs, 300 Hz-3 kHz)	Duration	Elapsed	Acquired	Instrument
PCB78		10.0 MHz	11 dBm	6.35E-14	5.59E-5	4d 14h 56m 50s	4d 14h 56m 50s	3994098 pts	Microchip 53100A

Crystal

Novus crystal-based frequency reference products are based upon either TCXO or OCXO technology. Temperature compensated crystal oscillators will normally use an AT cut crystal and electronically compensate the device with temperature. An OCXO device uses a SC (stress compensated) crystal and the part is held at a fixed temperature to minimize temperature drift.

The TCXO implementation results in a temperature-stable reference in the single digit parts per million. An OCXO device affords a reference that is almost two orders of magnitude more stable than the TCXO.

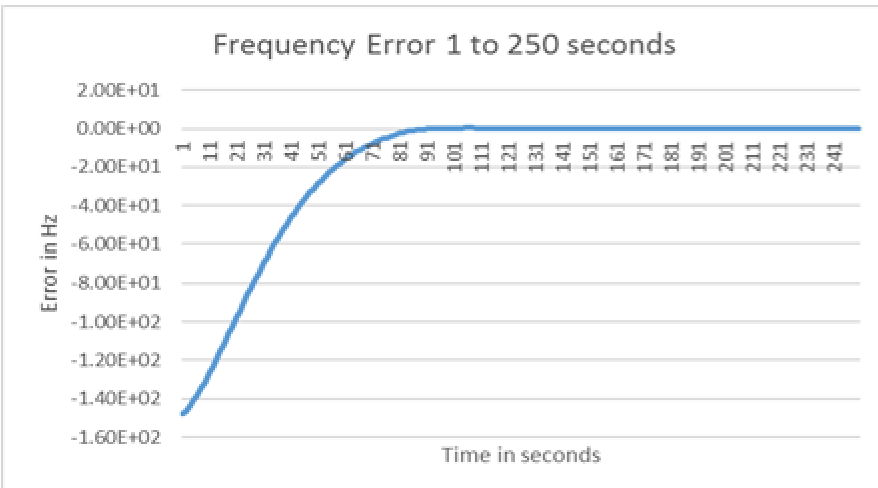
Comparison of an AT versus a SC Cut Crystal



Over a broad temperature range, an AT performs very well and much easier to compensate electronically. It is also a simpler crystal to manufacture than a SC cut device. For applications where a stability of a few ppm is acceptable, a TCXO can be a cost-effective alternative.

The SC cut results in a much higher Q device and achieves much lower phase noise than the AT cut. The device is also more sensitive to pressure and temperature variation and is mounted in a temperature-controlled hermetic chamber.

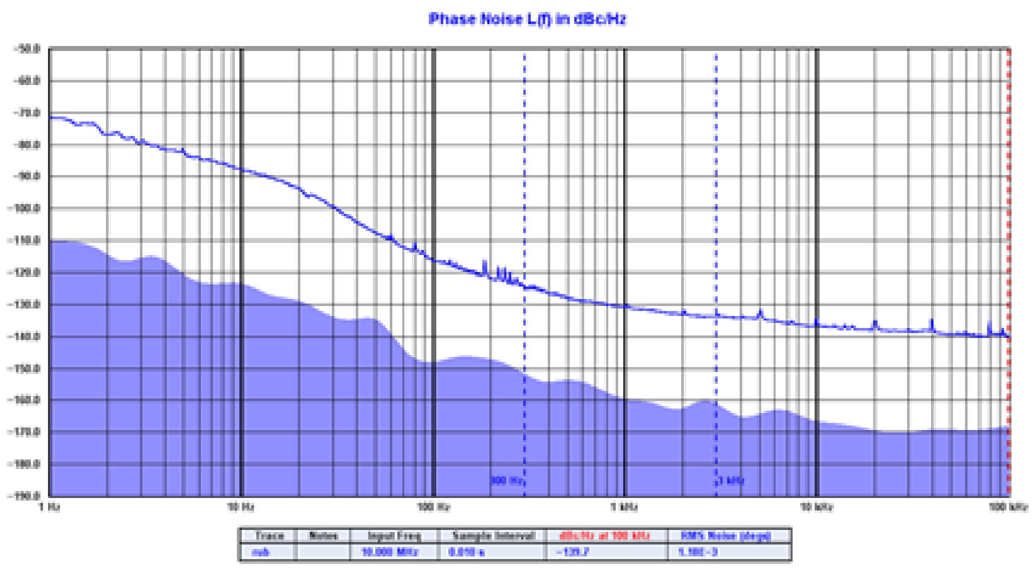
OCXO oven temperature is in the range of 90°C. The devices heat-up and become stable within ~ 5 minutes.



Another alternative for a frequency reference is an atomic reference. These devices use a change in atomic state of an isotope of Cesium or Rubidium for stability. Instead of a stability of ±50 ppb/year for a typical OCXO, stability of ±1 ppb/year is very common.

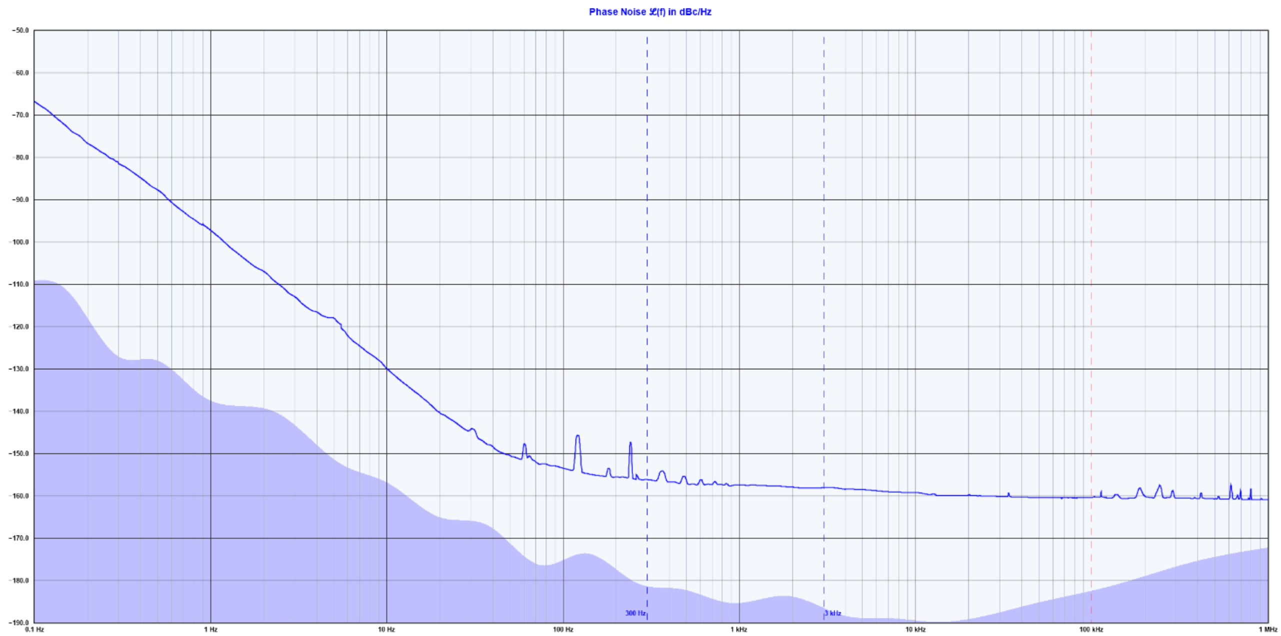
Atomic sources are very complex and while a very stable source, phase noise performance may not be acceptable for many applications.

Typical Phase Noise Performance for a Rubidium Source



For applications requiring the stability of an atomic source but also requiring low phase noise, a low phase noise OCXO is disciplined to an atomic source. The phase noise for the NR9000 has phase noise improved by well over 20 dB by this technique.

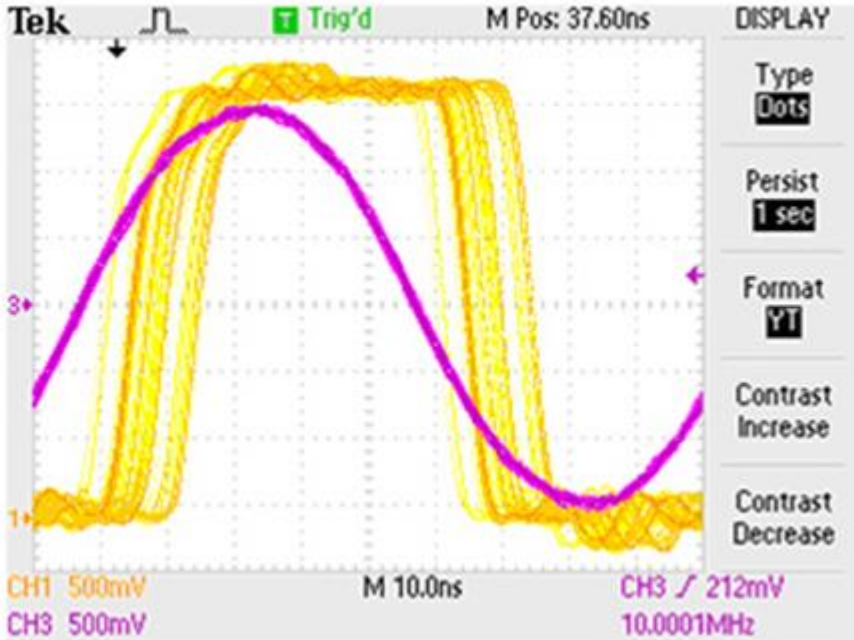
Typical Phase Noise Performance-Rubidium with OCXO



Trace	Notes	Input Freq	Input Amplitude	dBc/Hz at 100 kHz	RMS Noise (degs)	Duration	Elapsed	Acquired	Instrument
PCB78		10.0 MHz	11 dBm	−160.3	5.59E−5	4d 14h 56m 50s	4d 14h 56m 50s	3994098 pts	Microchip 53100A

When the stability of an atomic or crystal source is not sufficient, a GNSS disciplined source is an option. A GNSS receiver is installed and timing information from the GNSS is used to discipline the timing device. Timing accuracy to a few ppb is readily achievable.

The GNSS is used to provide timing for a DDS (direct digital waveform synthesizer). While the DDS has outstanding long-term accuracy, the short-term stability is very poor due to the nature of the timing source. A GNSS timing source has considerable short-term instability due to the numerous radio effects - multi-path, signal weakness etc. In order to develop a stable reference, the GNSS timing waveform is used to discipline a low noise source with a Kalman filter. A good example of the improved jitter performance of a Kalman filter is shown as follows::



Calibration

The frequency is phase-locked to the GPS signal and no adjustment is required. The Auto-Calibration feature tunes the OCXO and stores the calibration coefficients in non-volatile memory.

Programming Guide (RS232 Port)

The Kronos can accept user commands which will provide specific fault detection performance which may be customized by the user. The settings can be saved in non-volatile flash memory.

If the user makes changes which are intended to be kept between power off cycles, the command “$SAVEFLASH*51 <CR><LF>” will update flash to reflect all current settings.

Table 1 shows a complete list of input commands and descriptions. In general, a command may be input without “=” or an additional value and the unit will respond with the current setting’s value. If the input is not understood, the microcontroller will return the value “$?*3F<CR><LF>”

NOTE: All commands should be prefixed with “$” and followed by <cr><lf>. Checksum can be enabled which requires the command to be followed by an asterisk (*) and a two-digit hex value.

Example: $<COMMAND>*XX<cr><lf>.

The checksum can be required for all input commands and the requirement for a checksum can be enabled or disabled (default setting is disabled). The checksum method is the two-hexadecimal character representation of an XOR of all characters in the sentence between, but not including, the $ and the * character.

Example: $NVS1=1*76

Table 1

Setting	Command	Response	Description
STATUS OUTPUT	$STAT<n>	<$GPNVS,1….>	Query NVS<n> String. Useful for status output on demand when user does not require regular string output.
	$STAT1		Outputs current $GPNVS,1 string on demand.
	$STAT2	<$GPNVS,2….>	Outputs current $GPNVS,2 string on demand.
	$STAT14	<$GPNVS,14….>	Outputs current $GPNVS,14 string on demand.
SAVE ALL VALUES TO FLASH MEMORY	$SAVEFLASH	$SAVED TO FLASH. $FLASH SAVE FAILED.	This command will translate all current variables to flash string and write. Data is then read back for verification, and result reported.
RESET ALL TO DEFAULT	$RESETALL	$RESET FLASH VARIABLES.	Resets all user settings to default values and overwrites flash memory with defaults.
INVALID INPUT		$?	Command not recognized.
REQUIRE CHECKSUM	$CSUM	$CSUM=<current CSUM>	Query or set mandatory checksum on all incoming STATUS port communication. For $PERD commands, checksum is always required. 1 = Enabled, 0 = Disabled. Default = 0.
	$CSUM=1		
ID	$IDN?	$IDN	Returns PCB and SW version information
WARM UP PERIOD	$WUP	$WUP=600	Set warm up period for OCXO tuning in seconds. Must be > 360.
FORCE PPS DISCIPLINE	$DSC	$DSC=1	Enable PPS discipline to align the synthesized PPS to the GPS PPS within 50ns. The synthesized PPS will remain available even with loss of GPS lock. If PPS stabilization is enabled, the output will remain as the OCXO derived PPS.
(PPS STABILIZATION OFF)			1 = Enable discipline of synthesized PPS
			2 = Disable discipline
$GPNVS	$NVS<n>	$NVS7=1	Enables/Disables output of $GPNVS strings. For $NVS<n>=<m>, where <n> is the $GPNVS string ID, and <m> is the output frequency in seconds.
		$NVS9=1	Example: $NVS9=0 disables output of $GPNVS,9.
		$NVS10=1	
		$NVS11=1	
$GPNVS	$PERDCFG,NMEAOUT		Same function as $NVS but uses format of GPS Appendix A. Must include checksum. Example: $PERDCFG,NMEAOUT,NVS,9,1*4B sets $GPNVS,9 to output at a 1 second frequency. For format usage, see Appendix A.

AUXILIARY FREQUENCY OUTPUT	$AUXFR=<INTEGER>	$AUXFR=<INTEGER>	Sets the auxiliary frequency output. Even integer devisors of 200,000,000 are recommended. Remainders of the calculation 200,000,000/AUXFR are truncated. Enter $AUXFR=0 to disable output. If disabled, allow 10 seconds for an enabled output to restart.
PPS PULSEWIDTH	$PULSW=<FLOAT>	$PULSW=<FLOAT>	Sets or returns the current PPS pulsewidth in ms.
			Range: 0.0001 to 500 [ms]
FREQUENCY TOLERANCE	$FQTOL	$FQTOL=0.01	Sets the frequency tolerance of the lock indication in Hz. (float)
RS232 REAR PANEL BAUD RATE	$BAUDNV	$BAUDNV=<current Baud Rate>	Query Baud Rate on rear panel RS232. (Default = 115200). Front Panel is 115200 baud.
	$BAUDNV=38400		Assign Baud rate to Rear Panel RS232 port. Default is 115200. Available baudrates are 9600, 19200, 38400, 57600, 115200, 230400. Note: Front panel baud rate is set to 115200.
CHANNEL FAULT THRESHOLD FACTOR	$FLTTHRA $FLTTHRB	$FLTTHR<n>=<current Channel Fault threshold factor (from 0.05 to 0.95)>	Query or set the ratio at which the Channel output monitors report a fault. For example, if the FLTTHRA is set to "0.15", the Channel Fault Word will report an error if the measured value is greater or less than ±15% of its target value, when sourced from Input A. Number format must be in the form <n.nn>
	$FLTTHRA=0.15		
INPUT LOW THRESHOLD VALUE (V)	$INPTHRA $INPTHRB	$INPTHR<n>=<current InputThreshold (from 0.05V to 1.00V)>	Query or set the absolute voltage at which the Input monitor reports a llow input fault. For example, if the THR is set to "0.3", the Channel Fault Byte will report an error if the measured Vpp is lower than 0.3V.
	$INPTHRA=0.20		
TFT DISPLAY SCREEN SAVER TIMER	$DIMTM	$DIMTM=14400	The $DIMTM command sets the amount of time in seconds after which the TFT display will dim. The timer is reset after any button press. The default setting is 14400 seconds (4 hrs).

SET INDIVIDUAL CHANNEL REFERENCE VOLTAGE	$SET<nn>=n.nn $SET01=1.00 $SET02=1.00 $SET03=1.00 . . . $SET15=1.00	$SET<nn>=nn.nn	Set or query the Reference Voltage for a perticular channel with respect to the active input. Use in combination with the Channel Fault Threshold Factor to define Alert on an individual Channel. Reference Voltages are set with respect to the active input, allowing for variation in amplitude between Input A and Input B. *Example: Set Channel 4 to Alert if it is beyond +/-20% of 0.90Vrms when relayed to Input A:* $INP=A<CR><LF> $SET04=0.90<CR><LF> $FLTTHRA=0.20<CR><LF> (To set all channel Reference values to their current average amplitude, use the Latch Average Channel Values command.)
LATCH AVERAGE CHANNEL VALUES	$LATCHAVG	$LATCHAVG=<currently Selected input>	Latches the current Channel Vrms measurement averages into memory as the average value to set the Channel Fault Threshold for each channel. Latches in all outputs with respect to the active input. Example: Response of "LATCHAVG=A" indicates input A is active, and the channel fault thresholds for Input A will now measure against the current output values. Use this command during setup, after cabling, to take a snapshot of the nominal system state.
CAL FACTORS	$CAL<n>=nn.nn $CAL1=11.10	$CAL<n>=nn.nn	Query or set Cal Factors for specific ADC conversions. See list of Cal Factors numbered for appropriate measurement parameters. These settings should only be changed by an authorized technician.
SAVE ALL CAL FACTORS TO FLASH MEMORY	$SAVECAL	$SAVED CAL. $SAVE CAL FAILED.	This command will translate all Calibration Factors to flash string and write. Data is then read back for verification, and result reported. This will update Cal Factors in flash to the current Cal Settings.
CLEAR FREQUENCY STATISTICS	$CLRST	$CLRST=1	The $CLRST command clear all current ADEV and frequency statistics from SRAM, and starts from the current data. This is useful after startup/warmup to provide the best results for long term data.

	Hex Value (OR'd)	Channel ID	Channel Status Word
Channel Status Byte	0x1<<0	Channel 1 Fault	General Channel Fault
	0x1<<1	Channel 2 Fault	
	0x1<<2	Channel 3 Fault	
	0x1<<3	Channel 4 Fault	
	0x1<<4	Channel 5 Fault	
	0x1<<5	Channel 6 Fault	
	0x1<<6	Channel 7 Fault	
	0x1<<7	Channel 8 Fault	
	0x1<<8	Channel 9 Fault	
	0x1<<9	Channel 10 Fault	

	Hex Value (OR'd)	Channel ID	Channel Fault Bin
Channel Fault Bin	0x1<<0	Channel 1 Fault	External Fault: The NR9000 has completed an internal amplifier gain test and both primary and backup assemblies are functional. The fault is external to the NR9000 (cabling, short, etc)
	0x1<<1	Channel 2 Fault	
	0x1<<2	Channel 3 Fault	
	0x1<<3	Channel 4 Fault	
	0x1<<4	Channel 5 Fault	
	0x1<<5	Channel 6 Fault	
	0x1<<6	Channel 7 Fault	
	0x1<<7	Channel 8 Fault	
	0x1<<8	Channel 9 Fault	
	0x1<<9	Channel 10 Fault	

	Hex Value (OR'd)	Status Message
Primary and Secondary Power Supply Status	0x1<<0	AnV(-) PS out of range
	0x1<<1	Reserved
	0x1<<2	Reserved
	0x1<<3	AnV(+) PS out of range
	0x1<<4	5V PS out of range
	0x1<<5	Communication Failure
	0x1<<6	Reserved
	0x1<<7	Reserved

	Hex Value (OR'd)	Status Message
Active Board Status	0x1<<0	Flash Read Boot Error (Deprecated)
	0x1<<1	Potentiometer Read/Set Fail
	0x1<<2	Reserved
	0x1<<3	Reserved
	0x1<<4	PCB Assembly Input A/B Select Fail
	0x1<<5	Reserved
	0x1<<6	Reserved
	0x1<<7	Reserved

Technical Specifications

Output	10 MHz,1.0 Vrms ±0.2, into 50 Ohms, 10 channels, Sine
Harmonic distortion	< -30 dBc
Rubidium Atomic	
Accuracy at shipment	+/-5.0E-11
Warm-up time	<15 minutes
Time of lock	<5 minutes -130 dBm
Time to achieve accuracy	<±1E-9<20 minutes
Aging - monthly	<±5E-11
Aging - yearly	<±1.0E-9
PPS	**PPS is optional on Kronos Audio**
Amplitude for 1PPS	3.3 Vdc CMOS (5 Vdc option) ±100 mA
Pulse width for 1PPS	Programmable 1 to 500ms in 1 ms steps
Rise time for 1PPS	<5 ns (faster edge available)
Jitter	GNSS-PPS < 10ns SYTH-PPS <250 psec
Connector	SMA
Load Impedance	50 Ohm
Location	rear
Typical Allan Deviation	
1	4E-12
10	6E-12
100	3E-12
1000	2E-12
10000	3E-13
Standard Phase Noise	
1 Hz	-105
10 Hz	-130
100 Hz	-155
1000 Hz	-160
Remote interface & control	
Protocol	RS232 NMEA-0183
Connector	DB-9
Location	rear panel
Protocol	Bit plus stop
Standard Baud Rates	Selectable 4800, 9600, 19200, 38400, 57600 or 115200 bps

SNMP (option)		
Remote monitoring & control	Internet	
Parameters monitored Locally – present on remote interface for monitoring	Output amplitude, all power supplies, GNSS lock status, number of satellites, Built-In test status,	
Transaction/decodable commands	English format	
Single monitoring command	Updated every second	
Connector	RJ-11	
GNSS receiver	GPS, BeiDou, Galileo, and GLONASS reception	
Cold start acquisition	< 30 seconds	
Sensitivity		
Tracking	-167 dBm	
Reacquisition	-160 dBm	
Cold start	-148 dBm	
Hot start	-157 dBm	
Signals Supported		
GPS	L1C/A (1575.42 MHz), L2C (1227.60 MHz)	
GLONASS	L1OF (1602 MHz + k*562.5 kHz, k = –7,..., 5, 6), L2OF (1246 MHz + k*437.5 kHz, k = –7,..., 5, 6)	
Galileo	E1-B/C (1575.42 MHz), E5b (1207.140 MHz)	
BeiDou	B1I (1561.098 MHz), B2I (1207.140 MHz)	
Antenna with LNA	**184 channel receiver**	
	L-1 Band	L2/ESb/B2i Band
Frequency	1559-1606	1197-1249 MHz
Impedance	50 Ohm	50 Ohm
Gain	Typ 3.5 dBic (Zenith)	Typ 0 to 2 dBic (Zenith)
Axial rotation	Max 2 dB (Zenith)	Max 2 dB (Zenith)
Polarization	RHCP	RHCP
LNA gain	Typ 28 +-3 dB	28 +- 3 dB
LNA noise figure	Max 2.8 dB	Max 3.2 dB
Output VSWR	Max 2.0	Max 2.0 dB
Cable insertion loss	Typ 6.6 dB	Typ 6.6 dB
Total gain	Typ 21 dB	Typ 21 dB
Max current consumption	25 mA	

Antenna with LNA	**26 Channel Receiver**
Antenna power	3.5 Vdc, < 20 mA (on center conductor) (factory configurable to 5 Vdc)
Frequency	1574-1607 MHz
Nominal Gain	2 dBic
Amplifier gain	26 dB
Noise Figure	< 2.0 dB
Out-of-Band rejection	Fo±50MHz=60 dBc, Fo±60 MHz
DC current	<25 mA@3.5 Vdc

Environmental and Mechanical

Operating temperature	0 to 50°C non-condensing
Storage temperature	-40 to 70°C
Height	1RU (~1.73)
Width	19.0 inches
Depth	12.0 inches
Weight	≈5.5 lbs.
AC input	90 to 250 Vac, 50/60hz, less than 10 Watts

LIMITED HARDWARE WARRANTY

Novus Power Products (hereinafter Novus) warrants its products to the original end user ("original purchaser") and warranty is not transferrable. Novus guarantees that the NOVUS hardware products that you have purchased from NOVUS are free from defects in materials or workmanship under normal use during the LIMITED WARRANTY PERIOD. The LIMITED WARRANTY PERIOD starts on the date of shipment and for the period of 1 (one) year to be free from defects caused by faulty materials or poor workmanship, provided:

(a) NOVUS is notified in writing by Buyer of such defect prior to the expiration of the warranty period, and

(b) after receiving return authorization –RMA- from NOVUS, the defective item is returned with transportation prepaid to NOVUS, Independence, Missouri, with transportation charges prepaid by Buyer …see RMA policy in Terms and conditions, and

(c) NOVUSs' examination of such unit shall disclose to its satisfaction that such defect(s) exist and have not been caused by misuse, neglect, improper installation, improper storage, unauthorized modifications, inadequate maintenance, operation outside the environmental specifications for the product, repair alteration, or accident. NOVUS assumes no risk or liability for results of the use of products purchased from it, including but without limiting the generality of the foregoing: (1) the use in combination with any electrical or electronic components, circuits, systems, assemblies or any other materials or substances; (2) unsuitability of any product for use in any circuit or assembly. Removal or tampering with tamper-proof label on merchandise will void warranty coverage unless with the written authorization from NOVUS

(d) an evaluation fee will be charged to Buyer to cover inspection and testing costs for any item returned by Buyer under this paragraph which is found to be within specifications and/or otherwise not the responsibility of NOVUS under the terms and conditions of this paragraph or any other part of this Agreement..

Your dated sales or delivery receipt is your proof of the purchase date. You may be required to provide proof of purchase as a condition of receiving warranty service. You are entitled to hardware warranty service according to the terms and conditions of this document if a repair to your NOVUS product is required during the limited warranty period. Our obligation at NOVUS is limited to repair or replace products which prove to be defective.

Should Novus be unable to repair or replace the product within a reasonable amount of time, the customer's alternate remedy shall be a refund of the purchase price upon return of the product to Novus. The liability of NOVUS under this warranty is limited to replacing, repairing or issuing a credit, at its option, for any such item returned by Buyer under the terms of this warranty.

EXCLUSIONS: The above warranty shall not apply to defects resulting from improper or inadequate maintenance by the customer, customer-supplied software or interfacing, unauthorized modification or misuse, operation outside of the environmental specifications for the product or improper site preparation and maintenance (if applicable). For probes, cables, antennas and accessories, the warranty period is 90 (ninety) days.

PRODUCT SPECIFICATIONS: Published specifications whether contained herein or in any other materials or documents distributed to Buyer by Novus do not become final or binding on NOVUS until approved by NOVUS. NOVUS expressly reserves the right to change or modify specifications at any time without prior notice.

WARRANTY LIMITATIONS: NOVUS MAKES NO OTHER WARRANTY, EITHER EXPRESSED OR IMPLIED, WITH RESPECT TO THIS PRODUCT. NOVUS SPECIFICALLY DISCLAIMS THE IMPLIED WARRANTIES OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE.

IN ALL CIRCUMSTANCES NOVUS' MAXIMUM LIABILITY IS LIMITED TO THE PURCHASE PRICE OF THE PRODUCTS SOLD. NOVUS SHALL NOT, UNDER ANY CIRCUMSTANCES BE LIABLE UPON A CLAIM OR ACTION IN CONTRACT, TORT, INDEMNITY OR

CONTRIBUTION OR OTHER CLAIMS RELATING TO THE PRODUCTS IT SELLS WHICH EXCEEDS THIS LIABILITY LIMIT. NOVUS SHALL NOT BE LIABLE FOR THIRD PARTY CLAIMS FOR DAMAGES AGAINST THE CUSTOMER, OR FOR MALFUNCTION, DELAYS, INTERRUPTION OF SERVICE, LOSS OF BUSINESS, LOSS OR DAMAGE TO EXEMPLARY DAMAGES, WHETHER OR NOT NOVUS HAS BEEN MADE AWARE OF THE POSSIBILITY OF SUCH CLAIMS OR DAMAGES..

LIMITATION OF REMEDIES: REGARDLESS OF WHETHER ANY REMEDY SET FORTH HEREIN FAILS OF ITS ESSENTIAL PURPOSE, IN NO EVENT WILL NOVUS BE LIABLE TO YOU FOR ANY SPECIAL, CONSEQUENTIAL, INDIRECT OR SIMILAR DAMAGES, INCLUDING, WITHOUT LIMITATION, DAMAGES FOR LOSS OF BUSINESS PROFITS, BUSINESS INTERRUPTION, LOSS OF DATA OR BUSINESS INFORMATION (OR OTHER PECUNIARY LOSS) ARISING OUT OF THE USE OF OR INABILITY TO USE THE HARDWARE SUPPLIED THEREWITH EVEN IF NOVUS OR ANYONE ELSE HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES, OR FOR ANY CLAIM BY ANY OTHER PARTY. EXCLUDED DAMAGES SHALL INCLUDE, BUT ARE NOT LIMITED TO: COSTS OF REMOVAL AND INSTALLATION, LOSSES SUSTAINED AS THE RESULT OF INJURY TO ANY PERSON, OR DAMAGE TO PROPERTY.

EXCLUSIVE REMEDIES: THE REMEDIES PROVIDED HEREIN ARE THE CUSTOMERS' SOLE AND EXCLUSIVE REMEDIES. IN NO EVENT SHALL NOVUS BE LIABLE FOR ANY DIRECT, INDIRECT, SPECIAL, INCIDENTAL, OR CONNSEQUENTIAL DAMAGES, WHETHER BASED ON CONTRACT, TORT, OR ANY OTHER LEGAL THEORY.