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APN-002 Rev 1 February 3, 2000

GPSCard™ OCXO, MiLLennium® Cesium or Rubidium Options

Should You Be Using One In Your Applications?

The NovAtel® GPSCards are high performance state-of-the-art GPS receivers utilizing C/A code and carrier phase tracking. Our patented C/A code Narrow Correlator® tracking technology achieves pseudo-range accuracy of near P-code performance while providing improved resistance against errors introduced by multipath signals. The NovAtel GPSCard is able to achieve this performance using a standard off-the-shelf TCXO master oscillator. Even further improvement on accuracy and frequency stability can be achieved with the aid of atomic clocks (rubidium or cesium).

Crystal Oscillator Overview

While the GPSCard's standard TCXO (temperature compensated crystal oscillator) surpasses the needs of most GPSCard users, NovAtel offers a high stability OCXO (oven controlled crystal oscillator) option for applications requiring the highest levels of stability and accuracy available from crystal oscillator technology. Substantial improvements in performance are achieved when using the OCXO option:

- Short term frequency stability improvements from 1×10^{-6} (TCXO) to 2×10^{-11} (OCXO)
- Significantly lower reference oscillator phase noise over the standard TCXO
- GPS RF down-conversion signal-to-noise ratio (S/N) improvement of 3-5 dB
- Greater precision and stability of the 1-PPS output time pulse
- More stable and precise pseudo-range and carrier phase measurements
- Cleaner doppler measurements resulting in more accurate and stable velocity calculations
- Enhances the receiver tracking loop stability, allowing reduced bandwidth tracking (monitor station and static surveys) from 15 Hz down to 2.5 Hz.

Atomic Clock Overview

In any physical system, simple systems are easier to understand, mathematically model, and control than complex systems. The pendulum in a grandfather clock is physically larger and more complicated, in a quantum mechanical sense, than the crystal in a crystal oscillator. There are more ways that it can vary and more factors (such as friction, temperature, gravity, air resistance, etc.) that affect its operation in complicated ways. Therefore we can learn to make a better clock out of crystal with the improvements as explained above. Similarly, atomic frequency standards and atomic clocks have still fewer and simpler components and interactions in them. Using atomic clocks, we can achieve still greater accuracies. Extending this concept, the theoretical ultimate atomic clock would depend on the behavior of a single stationary, isolated atom.

An atomic clock is a clock that uses the resonance frequencies of atoms as its resonator. The advantage of this approach is that atoms resonate at extremely consistent frequencies. If you take any atom of

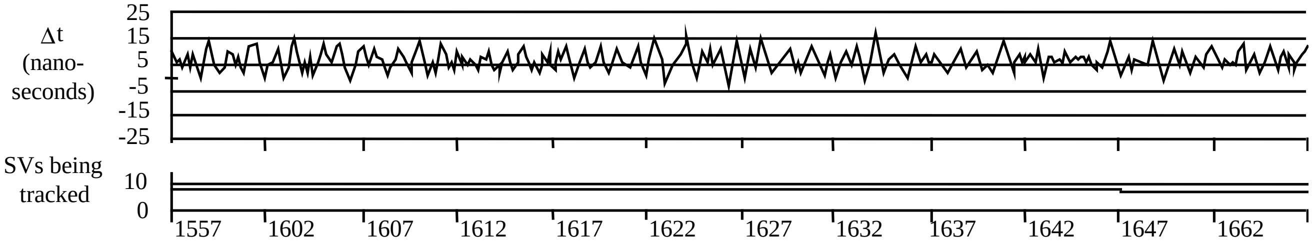
cesium and ask it to resonate, it will resonate at exactly the same frequency as any other atom of cesium (in cycles per second). The rubidium clock employs the same basic principles as the cesium clock.
This sort of accuracy is completely different from the accuracy of a crystal clock. In a crystal clock the crystal is manufactured so that its oscillating frequency is close to some standard frequency. Manufacturing tolerances will cause every crystal to be slightly different, and things like temperature will change the frequency. A cesium or rubidium atom always resonates at the same known frequency - that is what makes atomic clocks so precise.

1-PPS Stability Tests

A very precise procedure to gauge the advantage of OCXO over the TCXO is to examine the stability of the 1-PPS (pulse per second) output. Tests were conducted comparing the 1-PPS outputs from two NovAtel GPSCards. The first set of data represents the GPSCards running from their own standard TCXO. The time differential between the two corrected* 1-PPS output pulses is illustrated in Figure 1 below. The data was collected over a one-hour period and the time differences are in nanoseconds.

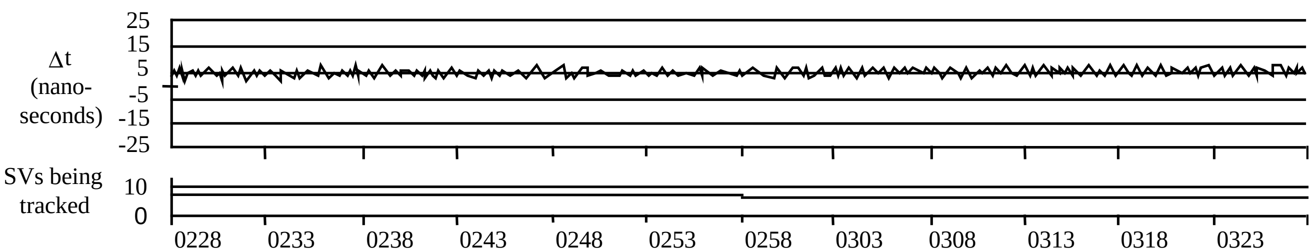
* Corrected for clock offset errors available via COM ports.

Figure 1 1-PPS Comparison Of Two GPSCards Using Standard TCXO



The second set of test data compares two GPSCards, each using the NovAtel OCXO option. This set of measurements shows a significant improvement in timing differences between the two GPSCards. Test results are illustrated in Figure 2 below.

Figure 2 1-PPS Comparison Of Two GPSCards Using NovAtel OCXO



The 1-PPS timing stability is directly related to the reference oscillator stability. The timing improvements realized by the NovAtel OCXO option will ensure more precise data sampling times which in turn provide more accuracy and confidence in pseudo-range and doppler measurements.

Phase Noise Comparison

Phase noise of any local oscillator that is used for down conversion of radio signals has some impact on the receiver's ability to detect or decode signals at or near the receiver's noise floor. This is because the phase noise of the local oscillator mixes with the received RF signal and produces an intermediate frequency (IF) signal, which now contains elements of the original RF signal and the local oscillator. Therefore, the cleaner the local oscillator signal is, the cleaner will be the down-converted IF signal.

Because GPS signal levels at the antenna are already near the noise floor of the GPS receiver, any added noise by the local oscillator pushes the signal even further into the noise floor. The following table provides a comparison between the standard GPSCard TCXO (which can be considered typical among GPS receivers) and the NovAtel optional OCXO.

Table 1 NovAtel GPSCard TCXO and OCXO Phase Noise Comparisons

Measurement Offset From Carrier F_0	Phase Noise Level Offset From F_0		
	TCXO	**OCXO**	**OCXO Phase Noise Improvement**
1 Hz	-56 dBc	-80 dBc	24 dB
10 Hz	-81 dBc	-114 dBc	33 dB
100 Hz	-102 dBc	-139 dBc	37 dB
1 kHz	-121 dBc	-152 dBc	31 dB

The above paragraphs clearly illustrate a significant reduction of close-in phase noise realized by using an OCXO versus a TCXO. When the benefits of lower phase noise are combined with greater frequency stability, significant improvement in receiver performance will be achieved.

MiLLennium GPSCard Receivers

For certain applications requiring greater precision than what is possible using the on-board 20 MHz, voltage-controlled, temperature-compensated crystal oscillator (VCTCXO), you may wish to connect the MiLLennium to an external, high-stability oscillator. This is only possible with a MiLLennium GPSCard on its own or in a PowerPak® II enclosure, not if the MiLLennium GPSCard is in a ProPak® II enclosure. The external oscillator can be either 5 MHz or 10 MHz. MiLLennium has built in clock models for OCXO, rubidium and cesium oscillators. You can also set custom clock model parameters for other types of oscillators.

The two commands EXTERNALCLOCK and EXTERNALCLOCK FREQUENCY relate to external oscillator operation. See the *Using the EXTERNALCLOCK Commands* section below. When a MiLLennium is powered on, the external oscillator input is disabled. Therefore, if an external oscillator is never used, these commands are not needed.

Installation consists of simply connecting the cable from the external oscillator to connector P301 on the MiLLennium. The MiLLennium does not have to be powered down during this procedure. If handling the MiLLennium directly, anti-static practices must be observed. On the PowerPak II, connect the coaxial cable from the external oscillator output port to the *Ext. Osc*. input port (SMB male jack) on the front panel of the PowerPak II. Please refer to the MiLLennium *GPSCard and Enclosures Guide to Installation and Operation* (NovAtel part number OM-20000016).

USING THE EXTERNALCLOCK COMMANDS

The EXTERNALCLOCK command determines whether the MiLLennium uses its own internal temperature-compensated crystal oscillator, or that of an external oscillator, as a frequency reference. It also sets which clock model is used for an external oscillator:

Command	Reference Oscillator	Clock Model
EXTERNALCLOCK DISABLE	Internal	—
EXTERNALCLOCK OCXO	External	OCXO
EXTERNALCLOCK CESIUM	External	Cesium
EXTERNALCLOCK RUBIDIUM	External	Rubidium
EXTERNALCLOCK CUSTOM	External	User-defined parameters

The EXTERNALCLOCK DISABLE command forces the MiLLennium to use the internal oscillator, whether or not there is an external oscillator connected to it. Do not use the EXTERNALCLOCK OCXO, CESIUM, RUBIDIUM or CUSTOM if there is no external oscillator connected to the MiLLennium.

The EXTERNALCLOCK FREQUENCY command sets the MiLLennium to accept either a 5 MHz or 10 MHz external oscillator frequency.

Example:

```
externalclock frequency 5
externalclock frequency 10
```

Also…

A reference station transmitting RTCM Type 9 corrections must be operating with a high-stability clock to prevent degradation of navigation accuracy due to the unmodeled clock drift that can occur between Type 9 messages.

NovAtel recommends a high-stability clock such as the PIEZO Model 2900082 whose 2-sample (Allan) variance meets the following stability requirements:

3.24×10^{-24} s^2/s^2 between 0.5 - 2.0 seconds, and

1.69×10^{-22} T s^2/s^2 between 2.0 - 100.0 seconds

An external clock such as an OCXO requires approximately 10 minutes to warm up and become fully stabilized after power is applied; do not broadcast RTCM Type 9 corrections during this warm-up period.

Advanced…

Using the SETTIMESYNC command to synchronize two GPSCards in a master/slave relationship to a common external clock.

```
MASTER:
~~~~~~~
LOG COM2 TM1A ONTIME 10
CLOCKADJUST DISABLE
EXTERNALCLOCK OCXO            (or RUBIDIUM, CESIUM, USER)
EXTERNALCLOCK FREQUENCY 10    (or 5)

SLAVE:
~~~~~~
ACCEPT COM2 COMMANDS
CLOCKADJUST DISABLE
```

```
SETTIMESYNC ENABLE
EXTERNALCLOCK OCXO             (or RUBIDIUM, CESIUM, USER)
EXTERNALCLOCK FREQUENCY 10     (or 5)
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CONNECTIONS:
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- Null Modem cable connects MASTER COM2 and SLAVE COM2
- OCXO signal is sent through a splitter to feed both the MASTE and the SLAVE external clock inputs.
- MASTER 1PPS (pin2) connected to SLAVE MKI (Mark Input, pin4)
- GPS signal is sent through another splitter to feed both the MASTER and the SLAVE RF connector; i.e., both GPS units must share the same antenna (zero baseline).

Make sure that you connect everything first before applying power; if power is applied and the GPS receivers have acquired satellites before the OCXO and/or 1PPS ≥ MKI is set up, then the times reported by the TM1A log will still diverge. We noted that after the clock model was stabilized at state 0, the time difference between MASTER and SLAVE reported by the TM1A log was less than 10 ns.