Novus Frequency Reference Considerations

There are several attributes regarding a 10 MHz reference that have a significant impact on the performance (Novus offers references to 100MHz).

A Rubidium reference has outstanding long-term stability ~<1ppb/year compared to an OCXO at 50ppb/year. However, when considering a reference for a demanding data capture or recovery system - long-term stability is one of several attributes that impact performance.

Noise on the clock will cause clocking errors that degrade system performance. The noise on the clock can be characterized in several ways:

Long-Term Accuracy

This is likely the least complicated aspect. A Rubidium affords excellent stability and is an excellent choice when a GNSS-locking approach is not possible. The device will drift approximately 1 ppb/year. Adding a GNSS-locking system will improve long-term stability by approximately three orders of magnitude.

Stability - Allan Deviation

This is a measurement of stability at periodic measurement points. Imagine measuring the standard deviation of a timing source at 1,10,100,1000 second intervals. You may have outstanding long-term stability, but your short-term stability might be very poor. With the design, there are numerous factors that impact stability:

Following are two Allan Deviation curves for a standard and high-performance GNSS-locked timing system:

Trace	Input Freq	Input Amplitude	ADEV at 2000s	RMS Jitter (300 Hz-3 kHz)	Duration	Acquired	Instrument
NR3620-	10.000 MHz	13.8 dBm	5.36E−12	5.0E−14 s	2h 27m 41s	88612 pts	TimePod 5330A

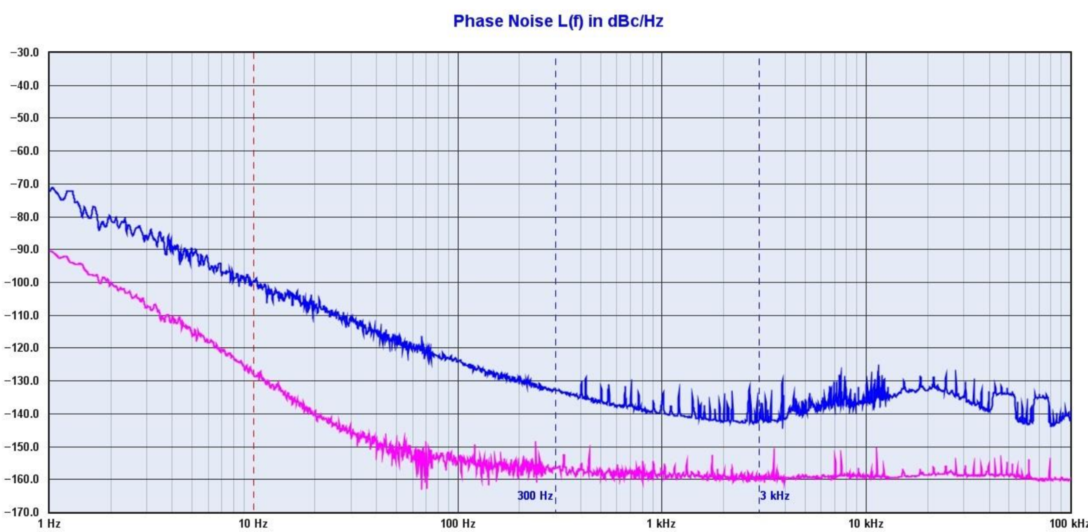
Trace	Notes	Input Freq	Sample Interval	ADEV at 10000s	Duration	Elapsed	Acquired	Instrument
78v395		10.000 MHz	0.100 s	2.76E−13	14h	14h	504000 pts	TimePod 5330A

As can be observed, the high-performance unit is more than an order of magnitude better.

The Basic Timing Source

The low frequency elements of noise start with the master source. The design of the oscillator, the power supplies - all contribute. The master oscillator is key, and a SC cut crystal, while more expensive, results in the best performance. A Rubidium source, while being very stable, is a noisy source.

Most advanced systems follow a Rubidium source with a low noise OCXO (oven controlled oscillator). The best crystal cuts from a noise standpoint are the least temperature stable. Therefore, to obtain the low noise performance, the crystal is placed in an oven at a constant temperature. By locking the OCXO to the Rubidium, you get the long-term stability of the Rubidium and the low phase noise of the OCXO. Below is a phase noise plot shows the phase noise of a Rubidium and the phase noise of Rubidium/OCXO pair:

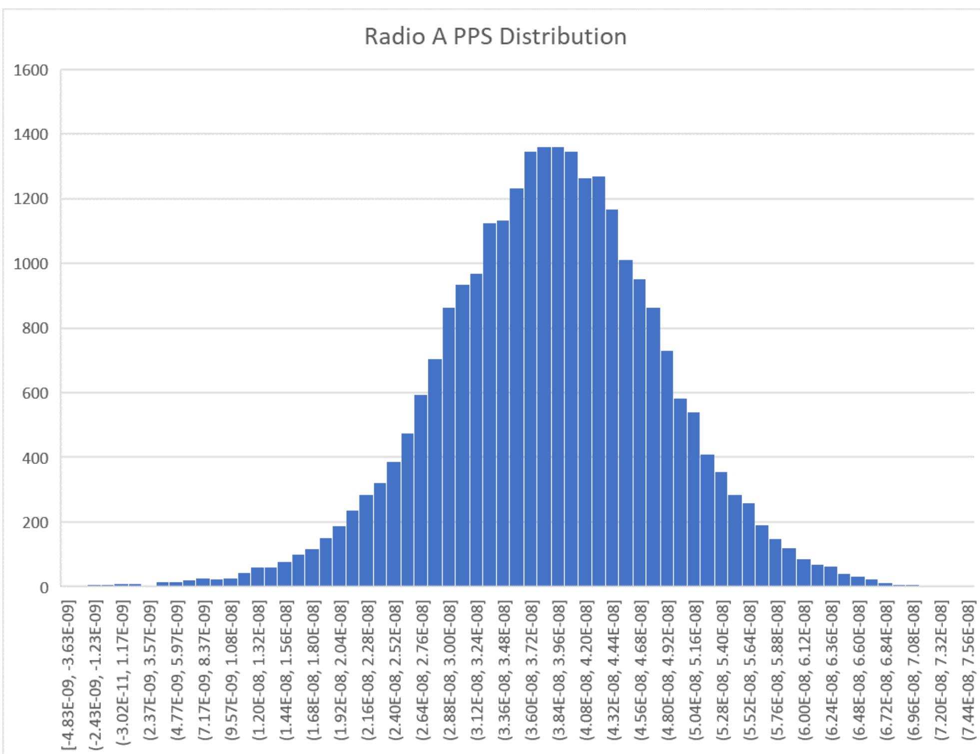


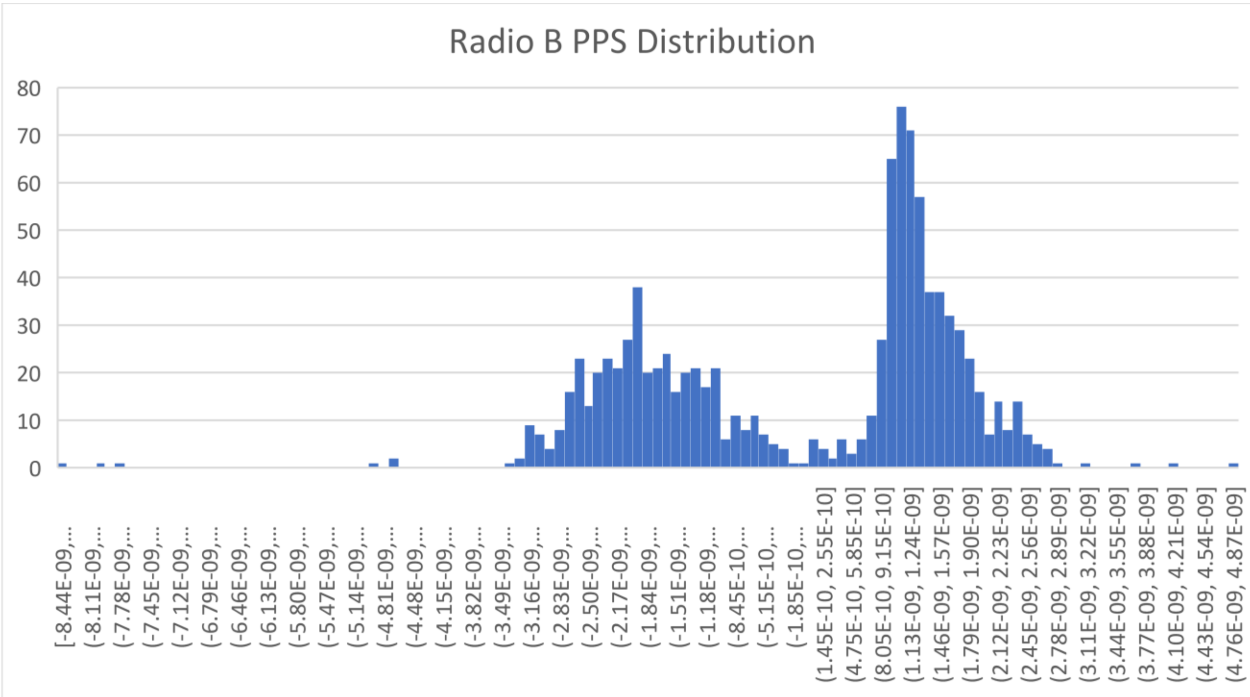
Trace	Notes	Input Freq	Input Amplitude	dBc/Hz at 10 Hz	RMS Noise (degs)	RMS Jitter	Duration	Acquired
NR8403-R		10.000 MHz	7.3 dBm	−99.6	4.81E−4	1.3E−13 s	3m 0s	180 pts
NR8403-RO		10.000 MHz	8.1 dBm	−128.0	4.98E−5	1.4E−14 s	10m 0s	600 pts

The Receiver

There are likely hundreds of GNSS receivers available with a range of functionality. Novus uses a few that are selected to meet the needs of our reference and PPS (pulse per second) sources. PPS stability and accuracy varies with each radio and cost rises with performance.

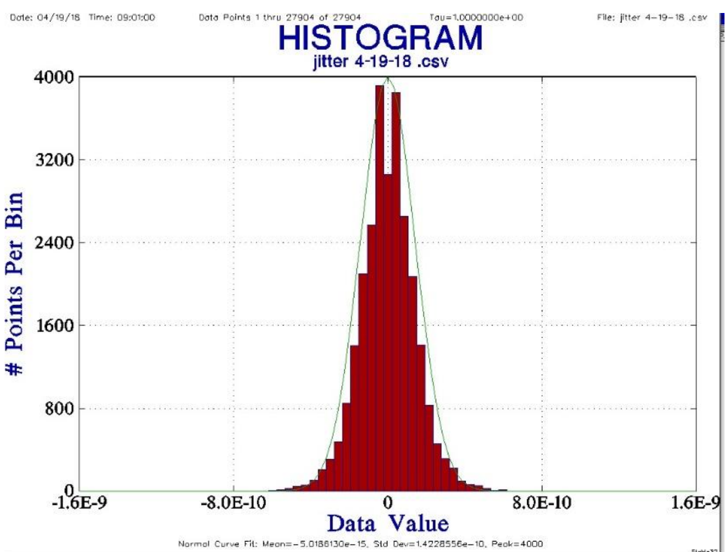
A significant part of the problem is the PPS being generated by the radio. No two radio designs are the same and the algorithms that generate the PPS vary widely. Below are two histograms for two different radios and their PPS performance. One is Gaussian and the other is not. Also, the spectral content of the PPS can vary greatly - often with low frequency content that adds to the close-in phase noise of the reference.





Depending upon the locking algorithm, the radio PPS variation can contribute directly to phase noise and instability.

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



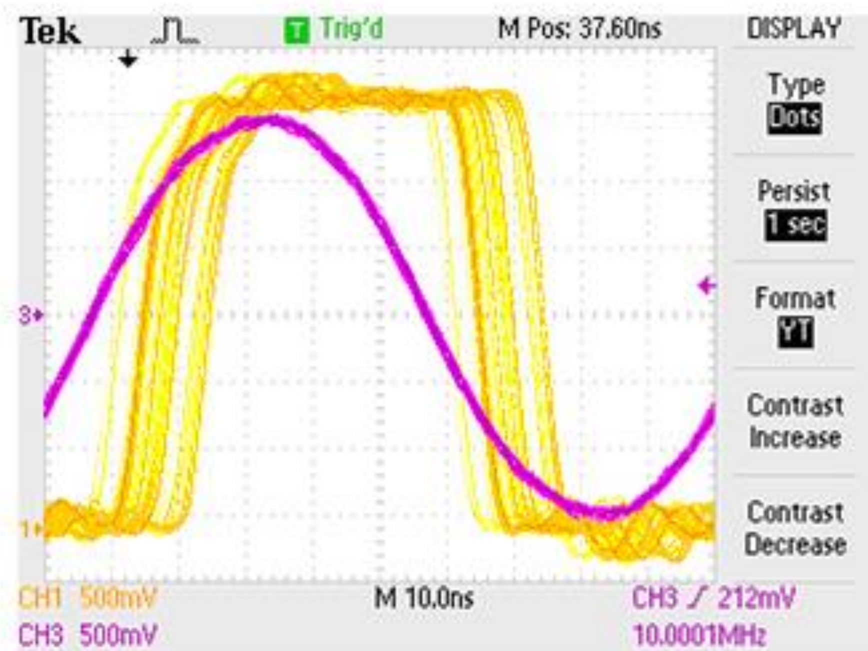
The standard deviation improved from 17 ns to approximately 400 picoseconds.

Timing Source Control

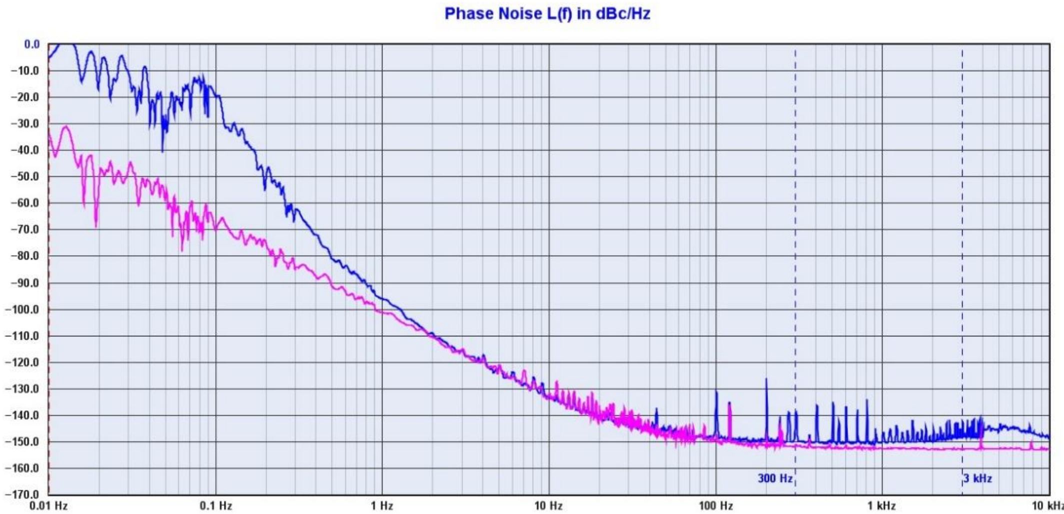
The means by which the timing source is controlled adds to the noise. Any correction made causes a change to the timing that adds to noise.

Novus has spent years developing complex timing algorithms that operate on the statistical characteristics of the receiver and the attributes of the master timing source.

The control mechanism must use the timing information from the receiver and disregard the noise and correct the master source. The curve below is a good illustration of the noisy timing information and the locked reference without the noise:



The close- in phase noise is especially challenging. If you can imagine a PLL loop implementation, the loop elements become too large when handling very low frequency noise. The problem is further exacerbated by the limitations of the mixer and the output currents. A digital loop can easily handle long time constants. Following is a phase noise plot of PLL and digital loop comparison:

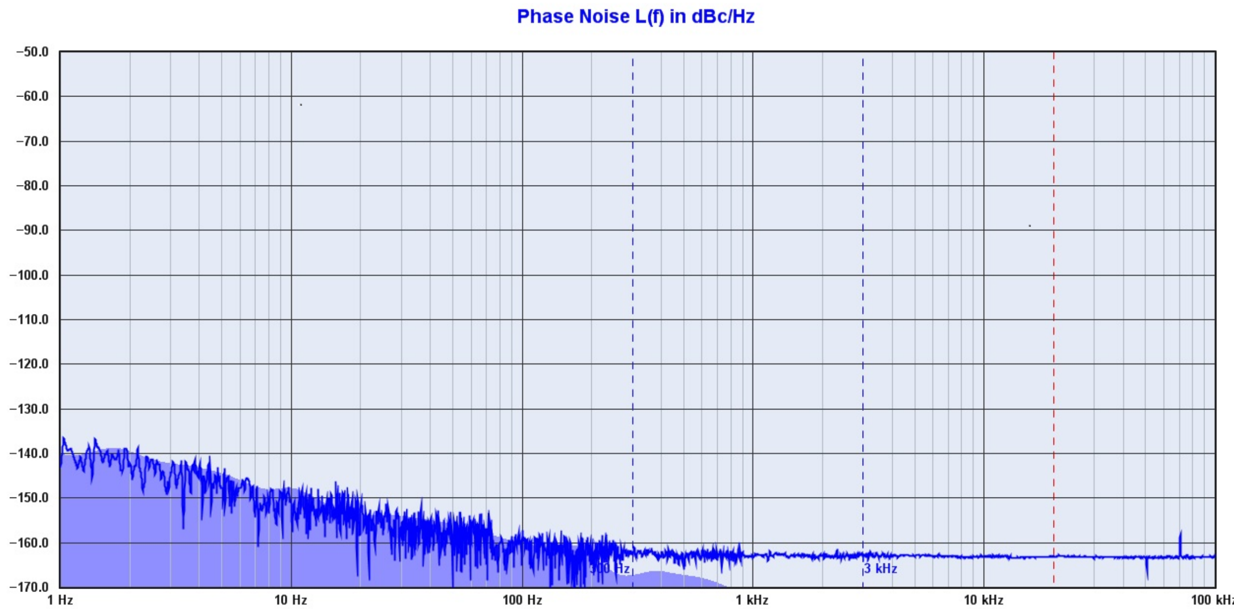


Trace	Input Freq	Input Amplitude	dBc/Hz at 0.01 Hz	RMS Jitter	Duration	Acquired	Instrument
NR3620 (Unsaved)	10.000 MHz	12.7 dBm	−4.9	5.2E−14 s	28m 41s	17214 pts	TimePod 5330A
NR6720–HS (Unsaved)	10.000 MHz	6.9 dBm	−33.7	2.8E−14 s	30m 0s	18000 pts	TimePod 5330A

Beyond the elements discussed, the core mechanical design of the reference must reduce the impact of the environment. Our most demanding references isolate the OCXO mechanically. This prevents fan vibration and other mechanical shocks from contributing to jitter. To minimize drift due to temperature changes, our control loop is housed in a temperature-controlled environment for our most advanced designs.

<u>Amplifiers</u>

Most applications require more than a single reference and PPS source. Ten channel references are a popular product. The amplifier must be robust and be able to withstand the transients as well as faults on each output. The amplifier should introduce minimal noise. Any amplifier will degrade the noise floor of the reference, but the level must be minimized. Following is the phase noise measurement for a Novus reference distribution amplifier:



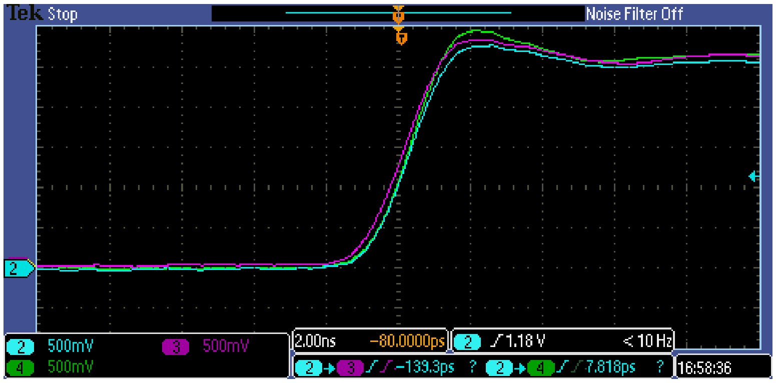
Trace	Input Freq	Input Amplitude	dBc/Hz at 20 kHz	RMS Noise (degs)	RMS Jitter	Duration	Acquired	Instrument
ND2306 amp pn (Unsaved)	10.000 MHz	14.8 dBm	−163.1	3.04E−5	8.4E−15 s	20m 0s	12000 pts	TimePod 5330A

Another consideration is the latency through the amplifier and skewing between channels. Typical latency is on the order of 20 ns and skew is normally below 5 ns.

Some applications require a 10 MHz square wave and Novus also offers LVDS (Low Voltage Differential Signal) signal levels. Novus offers both in different form factors.

PPS distribution presents a different set of problems. A first consideration is the voltage level. PPS levels can be CMOS 3.3 or 5 Vdc. The load level can be a significant challenge. Many applications have a 50 Ohm input impedance. A normal CMOS driver will not be able to drive a 50 Ohm load. Novus PPS distribution amplifiers were designed to drive a 50 Ohm load. Voltage levels are factory configurable.

Skewing and latency are major consideration. In a ten channel PPS distribution amplifier, skewing between channels can cause timing errors. Novus PPS distribution amplifiers have a channel skewing of under 200 ps. See following graph:



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Other Features

As is true of most electronic instruments, there are a range of ancillary features:

Remote status and Control: available over an RS232 port or the Internet. The Internet access can be a serial port or a full SNMP implementation. Outputs are monitored and faults and opens can be detected. Internal power supply status, GNSS receiver lock. Local digital displays and controls allow local access to key parameters.

Dual-Time Base: a question an auditor might ask - “How do you know the reference is correct?” To answer that question, Novus offers an optional dual time base on several units. We add a separate GNSS receiver that becomes the time base for an internal frequency counter. It can then detect an out-of-tolerance state and alert the user.

Statistical Analysis: A continuous reporting of the Allan Deviation.

$GPNVS,26,3.07e-11,2.41e-11,5.29e-11,7.03e-12,6.07e-13,0.00e+00*7B

Redundancy: Novus offers a ten channel redundancy switch that will detect and select a valid reference source. Our ten channel distribution amplifiers offer dual inputs that can manually or automatically select the active source.

AC or DC Power: platforms that operate from an AC power source that are basically “diode or’d”.

Mechanical: Optional mechanical Isolation of the reference to prevent vibration and/or shock from compromising phase noise and to avoid a loss-of-lock noise.

Extended Temperature Ranges: -40 to 70°C.

External locking: lock the reference to an external frequency, GNSS or PPS.

Lock-In Amplifiers: lock a low phase OCXO to a degraded reference to clean-up phase noise while maintaining synchronization to an external timing system.

Portable References: battery powered references to take timing where you need it.

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