PicoPak Phase and Frequency Tracking Dynamics

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• Introduction

The PicoPak clock measurement module uses a phase tracking loop to make its measurements. This is an effective technique, but it does impose some limitations for dynamically following phase fluctuations and frequency changes.

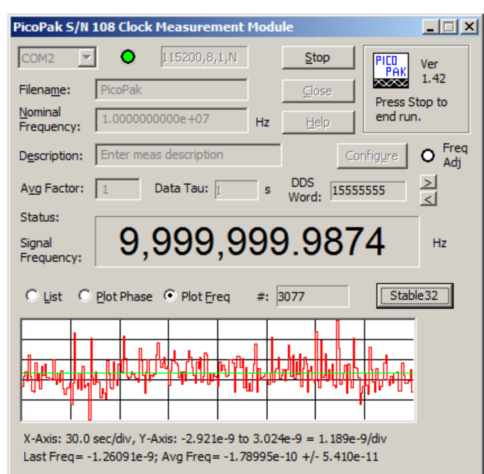
• Phase Tracking

The PicoPak clock measurement module makes its phase corrections at a 2.5 kHz rate. These are equal to one LSB of the AD9951 DDS phase control word, 6.10 ps at 10 MHz. Without noise or other source phase variations, this allows the phase tracking loop to follow a phase ramp having a slope up to about $\pm 1.5 \times 10^{-8}$ s/s, equivalent to a fractional frequency offset, $\Delta f/f$, of that same amount. The DDS has a finite frequency resolution that imposes a frequency error of up to about 1.4×10^{-9} (one-half of a tuning step). System and source noise uses some of the phase tracking dynamic range, and the loop is able to handle frequency offsets somewhat greater than $\pm 6 \times 10^{-9}$ or about ±2 DDS tuning steps. That can be confirmed by operating a PicoPak module with coherent inputs and varying the DDS word with the user interface < and > tuning controls. The loop with stay locked for ±2 but not ±3 DDS tuning steps.

That limit also imposes an accuracy requirement on the initial frequency setting, and it can be helpful in some cases to manually trim the initial DDS setting before starting a run.

The phase tracking limit can be observed by simulating a noisy source by applying analog baseband noise to the frequency control input of an otherwise stable ovenized crystal oscillator. For example, DC-coupled pseudo-random white noise applied to the frequency control input of an OCVCXO via an attenuator network can provide an adjustable level of simulated white FM noise. A programmable DC source can be summed in to provide a nominal frequency adjustment. The figure below shows the PicoPak main screen for a 10 MHz OCVCXO with noise applied to its varactor tuning line producing an ADEV of about 1×10^{-9}.

An ADEV of about 1×10^{-9} is about the limit without PicoPak frequency adjustments. This makes sense statistically since there will be occasional excursions of x3 that ADEV value that would cause a frequency adjustment. It is better to operate the PicoPak with its frequency adjustments disabled in this situation with a noisy source having a stable average frequency. The PicoPak therefore provides a dynamic range for frequency excursions of about two orders-of-magnitude covering the stability of most precision and semi-precision sources.



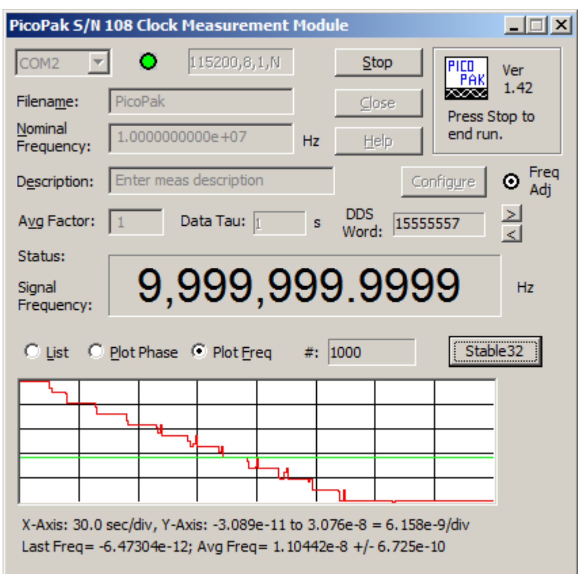
Precision and most semi-precision frequency sources have much smaller frequency excursions than the PicoPak phase tracking limit, so it does not impose a severe limitation on its use, even without frequency adjustments.

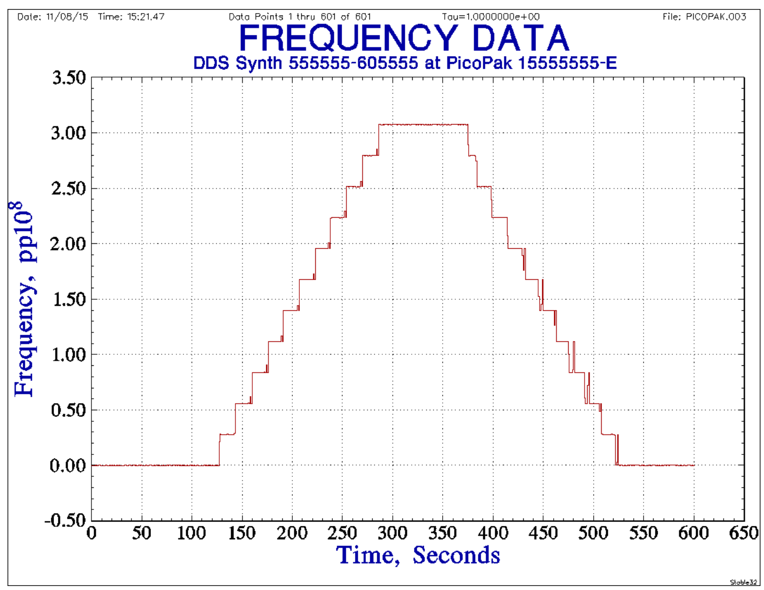
• Frequency Tracking

The PicoPak clock measurement module makes its optional frequency adjustments at a 100 Hz rate. Those adjustments can be set at 1, 2 or 3 DDS tuning increments, which imposes a maximum frequency slew limit of about $\pm 8.4 \times 10^{-7}$/s; it most cases the frequency adjustment size is set to 1, so the limit becomes about $\pm 2.8 \times 10^{-7}$/s. Several other factors are involved in the module's ability to track frequency slew, including the operation of its firmware and user interface, and tests have shown that the practical limit is about $\pm 1 \times 10^{-7}$/s for a frequency adjustment step size of 1.

In most cases for precision and semi-precision frequency sources, no frequency adjustments are required and no frequency slew limit applies. But this factor may preclude using the module for such purposes as measuring the warmup frequency characteristic of an ovenized crystal oscillator which can have a frequency slew an order-of-magnitude larger than the module can track.

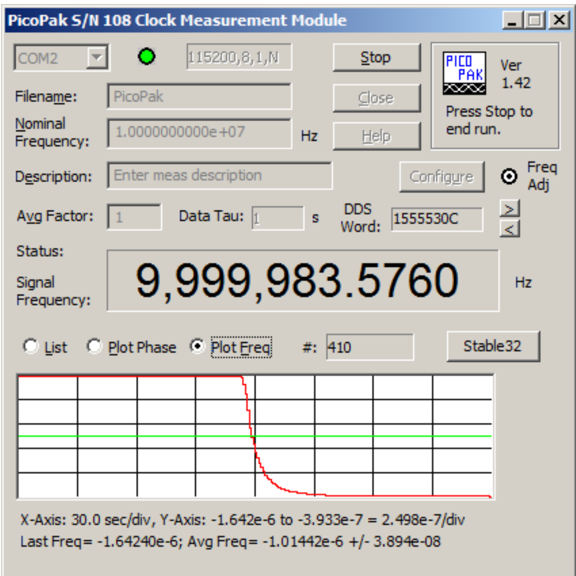
The example of a slow frequency sweep in the figure below shows how the PicoPak frequency adjustments can track a varying source frequency. There are eleven steps of 2.8×10^{-9} and back, each approximately equal to one DDS tuning increment, a total range of 3.07×10^{-8}, and about 10 s apart. This test was conducted by using an external high-resolution DDS synthesizer as the signal source. The static PicoPak frequency tracking range is essentially unlimited.



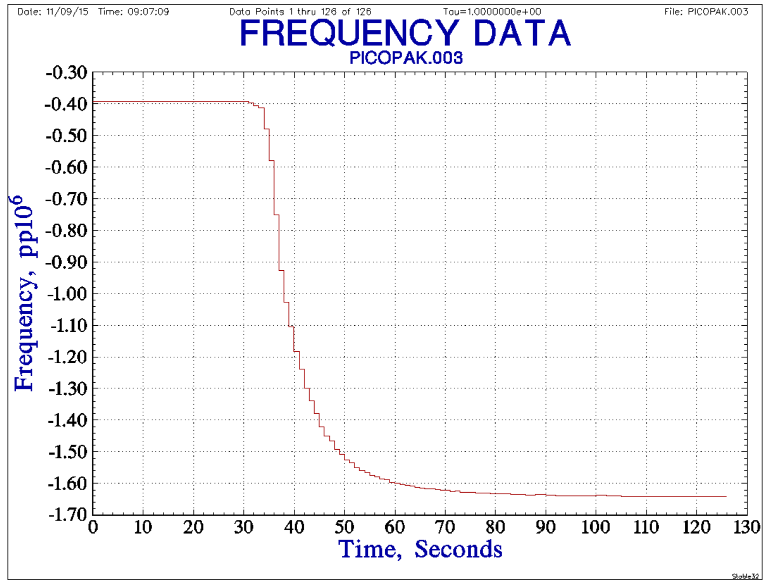


The first two or three steps in a series of slow source frequency steps approximately equal to one DDS tuning increment don't cause module tuning adjustments until the frequency error threshold is reached. Subsequent source frequency steps are then tracked by the module. If the direction of the steps is then reversed, there will again be a lag before frequency adjustments are needed. This hysteresis behavior is fine as long as the measured frequency always remains correct, and the reading will retrace completely when the source frequency is returned to its original value even though the DDS setting may be different. However, if the steps occur too quickly, there can be a tracking error if fast steps occur more rapidly than a few $pp10^9$ per second.

The PicoPak response to frequency slew can be simulated by applying a voltage step to the frequency control input of an OCVCXO via an RC filter to set the slew rate. An example of this test is shown in the figures below for an initial slew rate of about 1.4×10^{-7}/s, about the limit for unlocking with the adjustment step size set to 1.

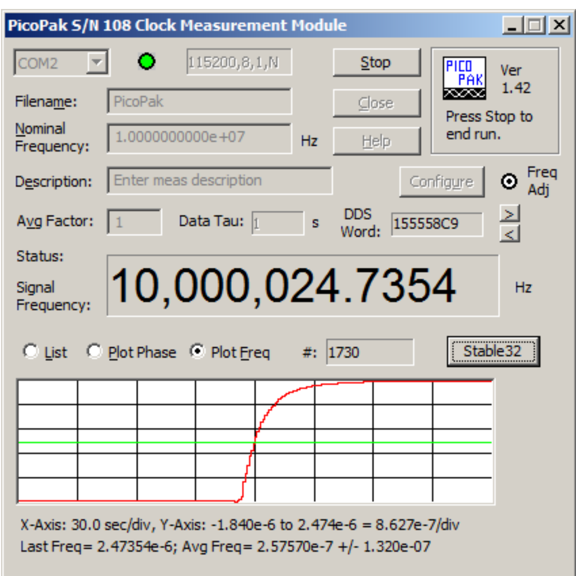


PicoPak Screen During Frequency Slew

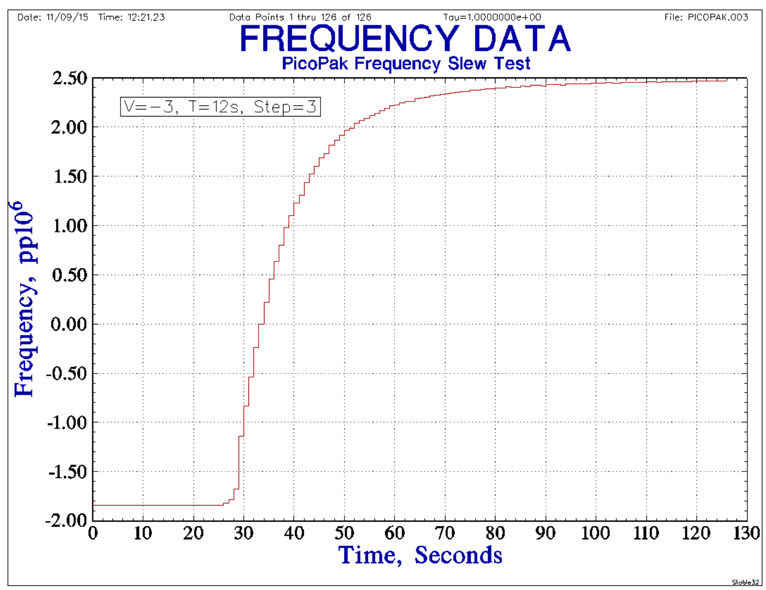


Frequency Record During Frequency Slew

If the frequency adjustment step size is raised to 3, the tolerable amount of frequency slew increases accordingly, and became 2.62×10^{-7}/s in the test shown below.



PicoPak Screen During Frequency Slew



Frequency Record During Frequency Slew

• Acquisition

PicoPak lock acquisition can be difficult or impossible if the signal frequency is rapidly changing.

• Conclusion

Unlocking due to excessive signal frequency slew rate is a fundamental limitation of the DDS clock measurement concept.

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