Transferring GPS Long-Term Stability to the Repetition Rate of a Vescent RUBRIComb™ Optical Frequency Comb with a SLICE-OPL

Thomas M. Bersano, Henry Timmers, Alina Spiess, Bennett Sodergren, Andrew Attar, Kevin Knabe

SUMMARY

We demonstrate how a SLICE-OPL Offset Phase Lock Servo can facilitate a Vescent RUBRIComb™ Fiber Frequency Comb repetition rate lock to a user-supplied RF oscillator. In the following example, the SLICE-OPL clock is disciplined to an SRS FS752 GPS-disciplined oven-controlled crystal oscillator (OCXO). In this configuration, the stability of the SRS FS752 is transferred to the frequency comb modes resulting in < 3E-12 fractional instability on timescales > 2 hours.

INTRODUCTION

Frequency combs are prized for their ability to couple frequencies from the microwave and radio-frequency (RF) domain to optical domain. Each "tooth," or mode, of a frequency comb is tied together by the relationship,

$$(1)\quad f_n = f_{CEO} + n \cdot f_{rep} \,.$$

The frequency of every comb mode, f_n, depends on just two comb parameters: the carrier envelope offset frequency, f_{CEO}, and the repetition frequency, f_{rep}. The stability in these two parameters is passed along to every comb mode according to the equation

$$(2)\quad \delta f_n = \sqrt{(\delta f_{CEO})^2 + \left(n \cdot \delta f_{rep}\right)^2} \,.$$

By locking these parameters to stable frequency standards, a comb becomes a precision frequency reference for all other lasers in a lab.

Repetition rate locking is the method by which both these parameters are directly locked to RF sources. In this method, the focus is on using a stable frequency source for locking f_{rep} because, as indicated by the equation above, the instability of each comb mode is approximately scaled up by its mode number n. For the optical modes, this factor is often greater than $\sim 10^6$. Fortunately, GPS-disciplined oscillators are easily accessible, cost-effective frequency

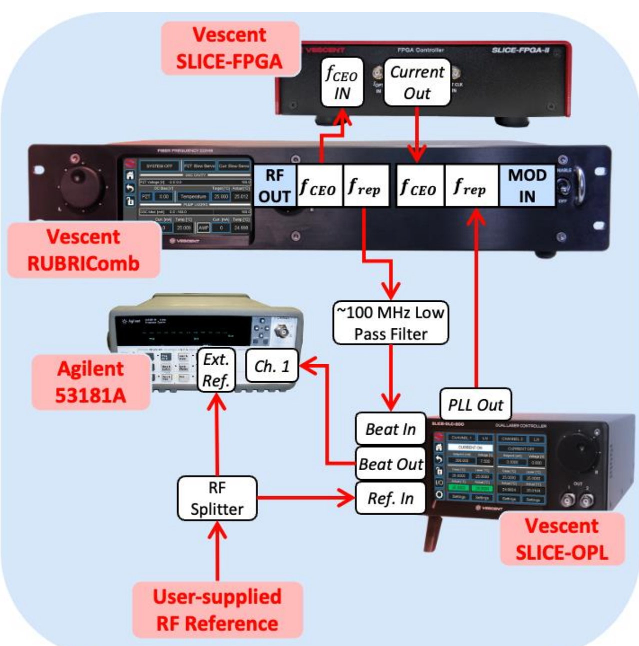

Figure 1. General scheme for repetition-rate locking the RUBRIComb to an RF reference signal as facilitated by a SLICE-OPL. During setup, a frequency counter that is also referenced to the GPS signal aids with comb tuning.

standards that can be relied on for frequency locking. Additionally, even though the frequency instability is multiplied up to the optical domain by a large number, n, the *fractional* frequency instability is maintained, allowing for the exceptional performance of these low-cost RF sources to be transferred to the optical domain via the comb.

Here we demonstrate a straightforward method for locking the f_{rep} of a Vescent RUBRIComb-100 Frequency Comb to a GPS-derived signal as facilitated by a Vescent SLICE-OPL Offset Phase Lock Servo. The SLICE-OPL is designed to phase-lock an RF signal, in this case f_{rep}, to a programmable signal generated by its internal direct digital synthesizer (DDS). Referencing the DDS clock to the 10 MHz tone of a GPS-disciplined OCXO, links the stability of f_{rep} to the GPS signal, as we will show with an out-of-loop instability measurement.

LOCKING f_{rep} TO A GPS-DISCIPLINED OCXO

The setup for locking the comb repetition rate to a user-supplied RF reference signal is shown in Figure 1. The f_{CEO} parameter of a RUBRIComb-100 is locked using a Vescent SLICE-FPGA-II digital feedback controller and a SLICE-OPL controls the f_{rep} feedback loop. Since the instability in f_{CEO} is not scaled up by mode number n, as shown in equation (2), the instability of the RF source to which this parameter is locked has a negligible contribution to the overall optical mode instability. Therefore, we emphasize the comb f_{rep} RF Out signal, which is filtered to isolate the fundamental mode. A 10 MHz signal from an SRS FS752 GPS-disciplined OCXO is connected to the SLICE-OPL reference port (Ref. In). The SLICE-OPL is configured to use this signal to stabilize the frequency of its internal DDS. The SLICE-OPL target frequency, which determines the DDS frequency, is set to the nominal repetition rate of the comb (100 MHz).

During lock capture, the SLICE-OPL signal filter is initially set to apply a simple proportional-integrator filter with a PI corner at 200 Hz and a proportional gain of -10 dB. After the lock is initiated, both these values can be tuned to balance the juxtaposed demands of sustaining the lock and retaining the short-term stability, i.e. instantaneous linewidth, of the optical comb teeth. By purposefully setting the PI corner to a low frequency, the superior fractional frequency stability of the free-running frequency comb can be preserved while gaining the advantage of the long-term stability of the RF reference [1]. For lock capture to be successful, the comb f_{rep} must be within several Hz of the DDS frequency. To verify f_{rep} is within range, a frequency counter is temporarily connected to the SLICE-OPL monitor port (Beat Out). We use an RF splitter so the

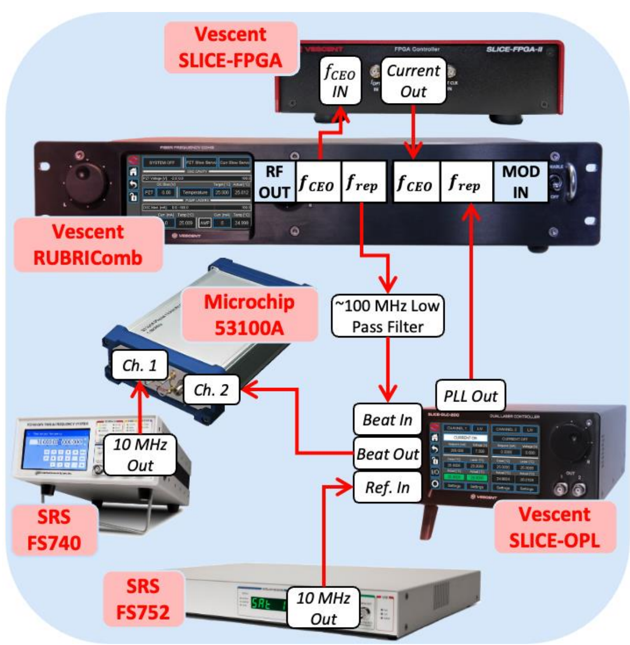

Figure 2. Configuration for the out-of-loop frequency instability measurement. A phase noise analyzer (Microchip 53100A) compares the f_{rep} signal to the 10 MHz signal from a second GPS-disciplined oscillator.

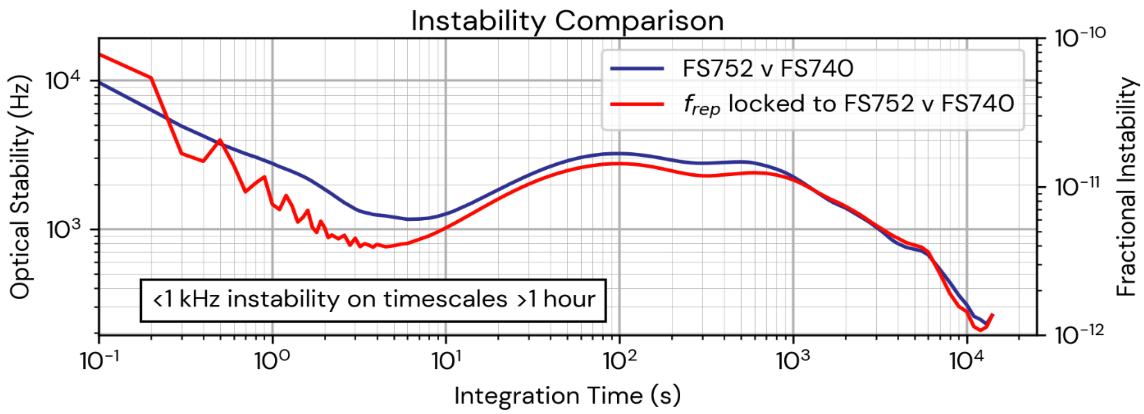

Figure 3. Allan Deviation measurements. The measured fractional instability between the repetition rate and the SRS FS752 GPS signal (red) is comparable to the fractional instability when the two GPS signals are directly measured against one another (blue). The optical instability is measured near 1550 nm.

counter can reference the same GPS-disciplined source as the SLICE-OPL. The RUBRIComb oscillator cavity temperature is manually tuned to bring the free-running f_{rep} to within 10 Hz of 100 MHz. Once this condition is met, the comb oscillator cavity PZT is enabled and the f_{rep} lock is initiated by turning on the SLICE-OPL servo. The comb PZT slow servo, which maintains the lock over long times by slowly adjusting the temperature of the oscillator cavity to keep the PZT voltage centered in its modulation range, is enabled.

OUT-OF-LOOP INSTABILITY MEASUREMENT

In the first of two Allan deviation measurements, the configuration in Figure 2 is used to compare f_{rep} to a second GPS-derived signal. The RF splitter is removed, and the counter is replaced with a phase noise analyzer (Microchip 53100a). Another GPS-disciplined OCXO device (SRS FS740) is connected to the other channel of the phase noise analyzer. In a second Allan deviation measurement, the SRS FS752 signal is directly compared to the SRS FS740 signal. The choice of these GPS units was based on the available equipment at hand.

The results from these measurements clearly demonstrate that the frequency stability of the SRS FS752 is transferred faithfully to the frequency comb repetition rate. The fractional stability for each measurement is shown in Figure 3. Since the instability in f_{rep} dominates in the optical regime, we can approximate the optical instability at the center comb frequency (left axis) based on the measured fractional instability of f_{rep} (right axis).

CONCLUSION

We demonstrated how to lock the Vescent RUBRIComb repetition rate to a GPS-disciplined OCXO with a SLICE-OPL. This configuration transfers the long-term stability of GPS to the optical comb teeth.

REFERENCES

[1] A. Attar, "Transferring the Long-Term Stability of a GPS-Discipline OCXO to Vescent's FFC-100 Optical Frequency Comb by Repetition Rate Locking," Application Notes, 3 March 2023.