The PicoMult Frequency Error Multiplier

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• Introduction

This paper describes a frequency error multiplier (FEM) that provides an order-of-magnitude resolution enhancement for a PicoPak clock measurement module [1], lowering the white PM noise floor to $2x10^{-12}\tau^{-1/2}$. The PicoMult module is USB powered and is packaged the same as the PicoPak as shown in Figure 1.

Figure 1. PicoMult Frequency Error Multiplier

The lower noise floor of the PicoMult/PicoPak combination allows better short and medium-term measurements to be made for many types of frequency source, including rubidium frequency standards and high-performance ovenized crystal oscillators. The frequency display of the enhanced PicoMult/PicoPak user interface is expanded to show 12 digits/second.

• Design

The PicoMult uses the classic frequency error multiplier principle [2] to enhance the resolution of a phase or frequency measurement by first multiplying the signal to a higher frequency to increase its frequency deviation and then heterodyning it back to the original frequency to obtain an error-multiplied signal at the original frequency. This design differs from most such devices by using “nonstandard” frequencies to minimize problems with coherent phase interference by using frequencies that are not 10 MHz multiples.

More specifically, the PicoMult uses a 96.00 MHz multiplied reference frequency, a 106.25 MHz multiplied signal frequency, and a resulting 10.25 MHz output frequency having a x10.625 error multiplication factor. This improves the PicoPak phase resolution from 6.10 ps at 10 MHz to 0.56 ps at 10.25 MHz. A block diagram of the PicoMult frequency error multiplier system is shown in Figure 2.

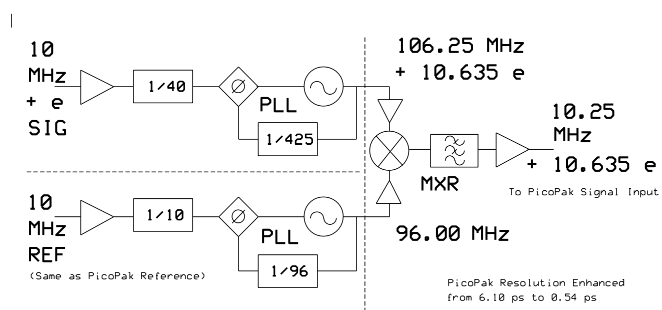

Figure 2. Block Diagram of PicoMult FEM

PicoMult frequency multiplication is accomplished by phase-locked oscillator multipliers (PLOMs) using low noise voltage controlled crystal oscillators (VCXOs) and phase-locked loop (PLL) integrated circuits. The error-multiplied 10.25 MHz PicoMult output is applied to the PicoPak signal input, and its user interface application performs the necessary scaling to present its measurements results with respect to the 10 MHz PicoMult signal input. The PicoMult and PicoPak both also require 10 MHz reference inputs. The only significant disadvantage of using the PicoMult to enhance the PicoPak resolution and lower its noise floor is that the nominal frequency of the signal under test is limited to near 10 MHz.

A photograph of the PicoMult hardware is shown in Figure 3 with its circuit board removed from its enclosure. At the left (rear) are the USB power and SMA 10.25 MHz RF output connectors. At the right (front panel) are the signal (upper) and reference 10 MHz RF input connectors. The unlock LED indicator is at center of the front panel, hidden by the enclosure trim. From left to right, the larger components are (a) the mixer, (b) the 106.25 MHz VCXO (top), (c) the 96.00 MHz VCXO (bottom), (d) the two PLL chips, and (e) the PIC and its in-circuit programming connector.

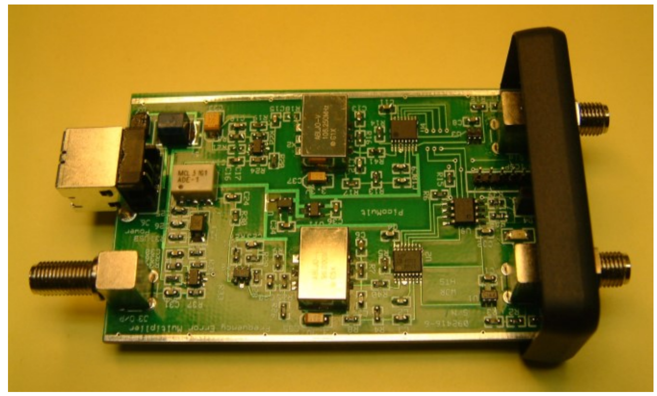

Figure 3. PicoMult Hardware

More details about the PicoMult design and its implementation can be found in a companion paper [3].

- **PicoMult/PicoPak System**

The PicoMult/PicoPak system setup is shown in Figure 4, where a passive RF power splitter is used to provide 10 MHz references for the two modules. The source being measured is applied to the PicoMult signal input and its output is connected to the PicoPak signal input. A PicoAmp distribution amplifier can also be used to provide the two 10 MHz references. The two modules are powered via their USB cables, and the PicoPak USB connection is used to communicate with its Windows® PC user interface application. The resulting phase data are stored to a file on the PC and optionally to a PicoPak PostgreSQL database where it can be monitored with the PicoMon program and accessed later with the PicoSQL program. This combination had a measured phase TC of +3.5 ps/°C.

Figure 4. PicoMult/PicoPak System Connections

• Noise Floor

The PicoMult/PicoPak coherent noise floor is an order-of-magnitude lower than that of the PicoPak by itself. Identical 10 MHz signals were applied to both PicoMult inputs and the PicoPak reference input, and the 10.25 MHz PicoMult output was applied to the PicoPak signal input. The resulting 1 second ADEV was about 2.0×10^{-12} instead of the normal 1.4×10^{-11} for the PicoPak alone, as shown in Figure 5. There is no significant interference visible on the All Tau stability plot, which shows pure white PM noise that integrates down as τ^{-1}.

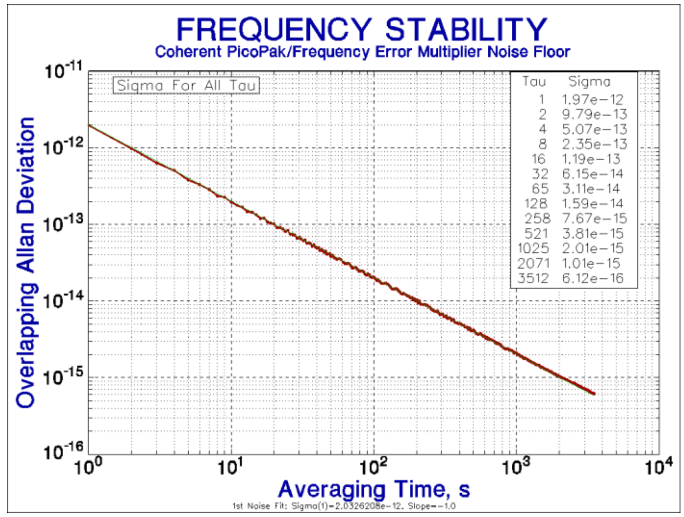

Figure 5. PicoMult/PicoPak Coherent Noise Floor

• User Interface

A new version of the PicoPak user interface supports its operation with the PicoMult frequency error multiplier by applying the FEM 10.625 error multiplication factor and 10.25 MHz FEM measurement frequency to the phase data.

The revised PicoPak Windows® user interface adds a Use Frequency Error Multiplier checkbox to the PicoPak Module group in the Configure dialog box where FEM error multiplication can be selected as an option as shown in Figure 6, using parameters stored in the PicoPak configuration file.

The PicoPak phase resolution and scale factor depend on the signal RF carrier period, the 14-bit DDS phase offset word size and the FEM frequency error multiplication factor (1 without a FEM).

For FEM-enhanced PicoPak measurements, the Nominal Frequency on the main screen is automatically set to 10.25 MHz so that its DDS is set to the FEM output frequency. However the frequency display and phase/frequency data are scaled to the 10 MHz signal frequency.

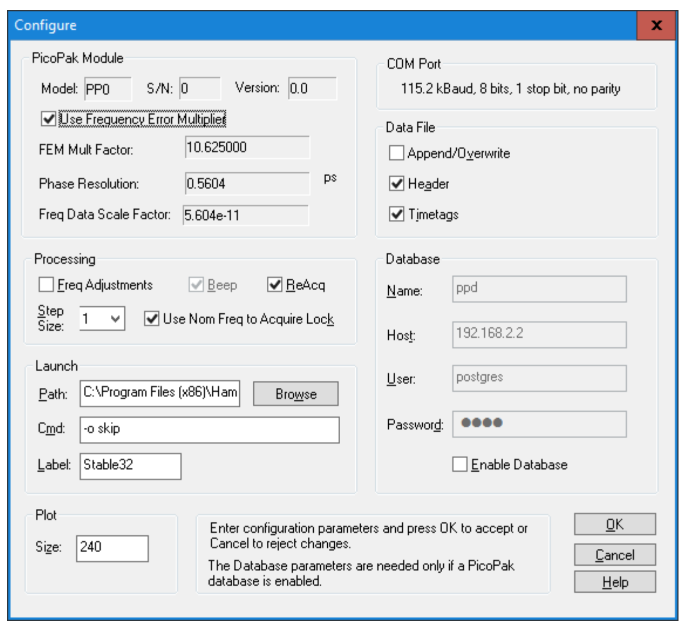

Figure 6. PicoPak User Interface Configure Screen

• Applications

Besides its obvious use for making precision clock phase and frequency measurements, especially in the short term where the instrumental white PM noise dominates, the PicoPak/PicoMult can serve as a very high resolution phasemeter. For example, it can measure the phase TC of a device such as a filter or distribution amplifier (or itself) at the picosecond level.

• Specifications

Preliminary specifications for the PicoMult frequency error multiplier are shown in Table I.

Table I. PicoPak Frequency Error Multiplier Preliminary Specifications

Parameter		Specification
Multiplication Factor	Frequency Error Expansion	x10.625
Signal RF Input	Frequency	10 MHz +ε, $\varepsilon \leq \pm 2\text{x}10^{-10}$ Δf/f
	Waveform	Sinusoidal (No DC)
	Level	0 to +10 dBm (+7 dBm nominal)
	Impedance	50 Ω nominal
	VSWR	≤ 1.5:1
Reference RF Input	Frequency	10 MHz
	Waveform	Sinusoidal (No DC)
	Level	0 to +10 dBm (+7 dBm nominal)
	Impedance	50 Ω nominal
	VSWR	≤ 1.5:1
RF Output	Frequency	10.25 MHz +10.625ε
	Waveform	Sinusoidal
	Level	+4 dBm nominal (PicoPak signal input)
	Impedance	50 Ω nominal
Noise	ADEV (white PM noise)	$\leq 3\text{x}10^{-12}\tau^{-1}$ ($2\text{x}10^{-12}\tau^{-1}$ typical)
Temperature Coefficient	Phase versus Temperature	≤ 5 ps / °C (±2 ps / °C typical)
Power	Voltage	+5 VDC from USB port
	Current	110 mA typical
Connectors	RF (all)	SMA Female
	Power	USB Type B Male
Physical	Size (LxWxH)	3.28"x2.25"x1.03" (excluding connectors, cables & feet)
	Weight	5 oz
Software	Windows® User Interface	Revised PicoPak user interface application

• References

1. W.J. Riley, "The PicoPak Clock Measurement Module", Hamilton Technical Services, Beaufort SC 29907, August 2016.
2. G. Kamas, Ed., "Time and Frequency Users' Manual", Section 4.7.2, *NBS Technical Note 695*, National Bureau of Standards, Boulder, CO 80302, May 1977.
3. W.J. Riley, "A Frequency Error Multiplier for the PicoPak", Hamilton Technical Services, Beaufort, SC 29907, October 2016.

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