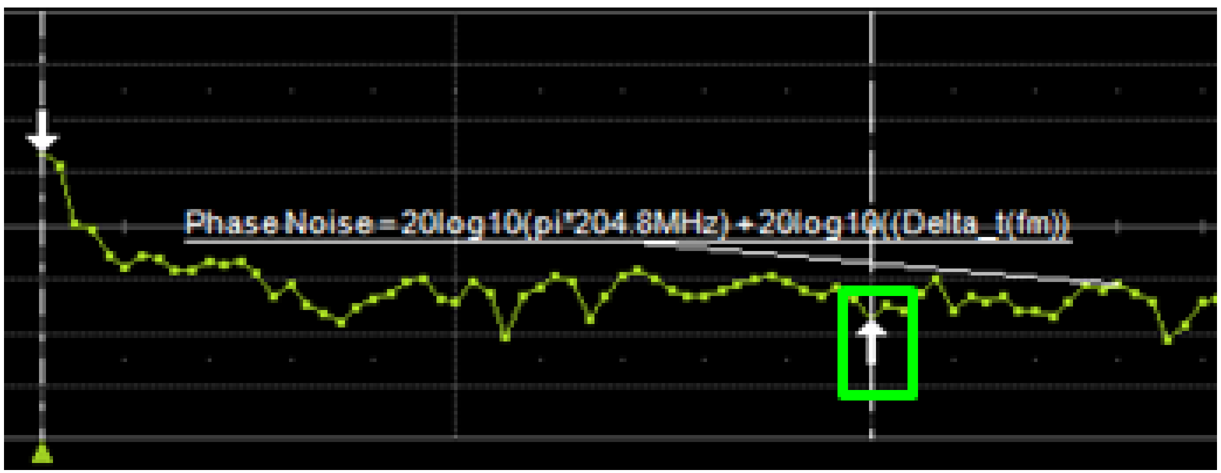
How to Measure Phase Noise

Using a LeCroy Oscilloscope



Test procedure written 2011-01-05-mh

Purpose:

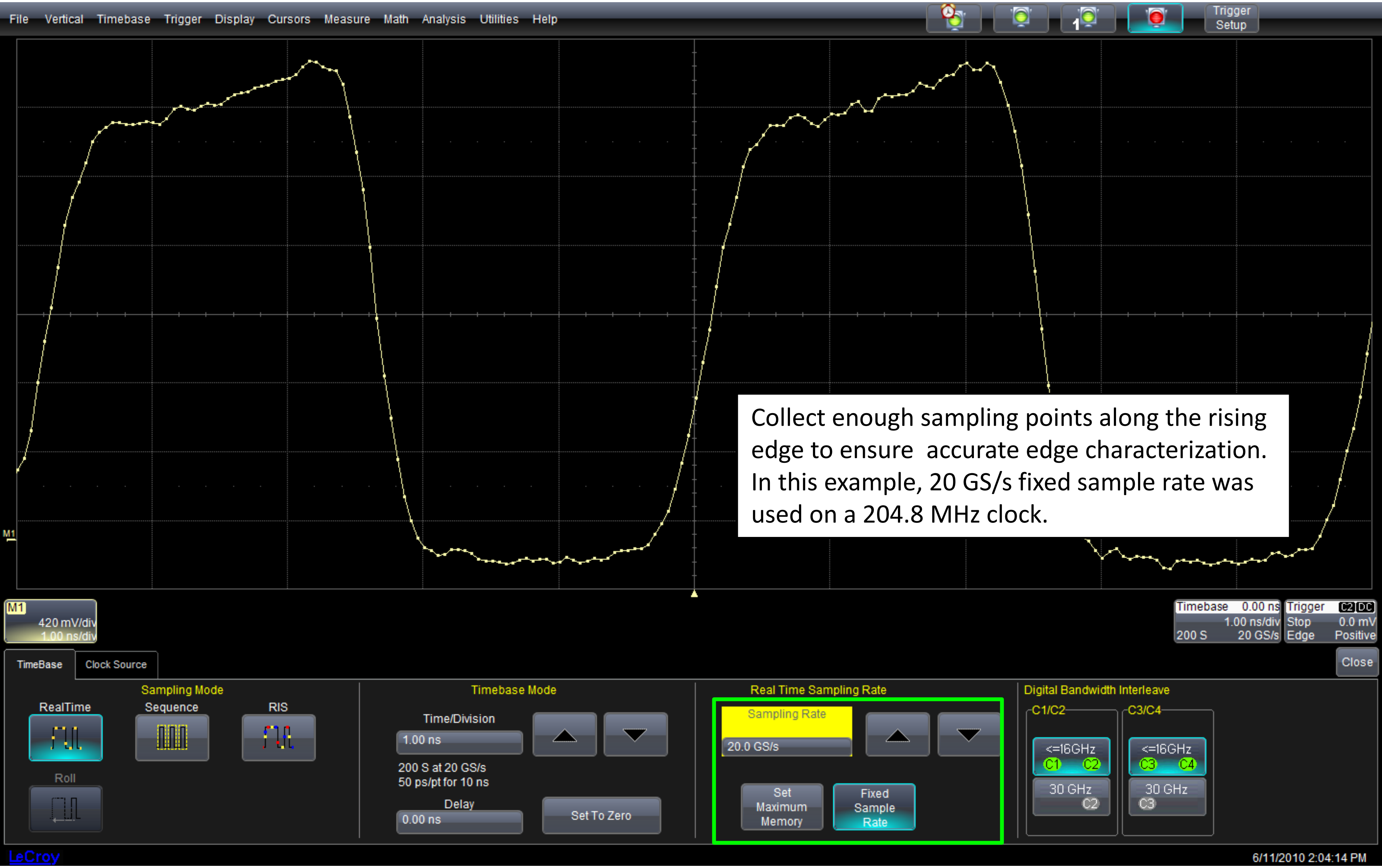
Phase noise is the power spectral density of a signal's random phase fluctuation, and is usually expressed as dBc/Hz in the frequency domain.

Signals with low phase noise are best measured using frequency domain equipment with a wide dynamic range, such as a spectrum analyzer and phase noise test set.

However, for signals with phase noise less than approximately -70 dBc (or -80 dBc with averaging), an oscilloscope may be used.

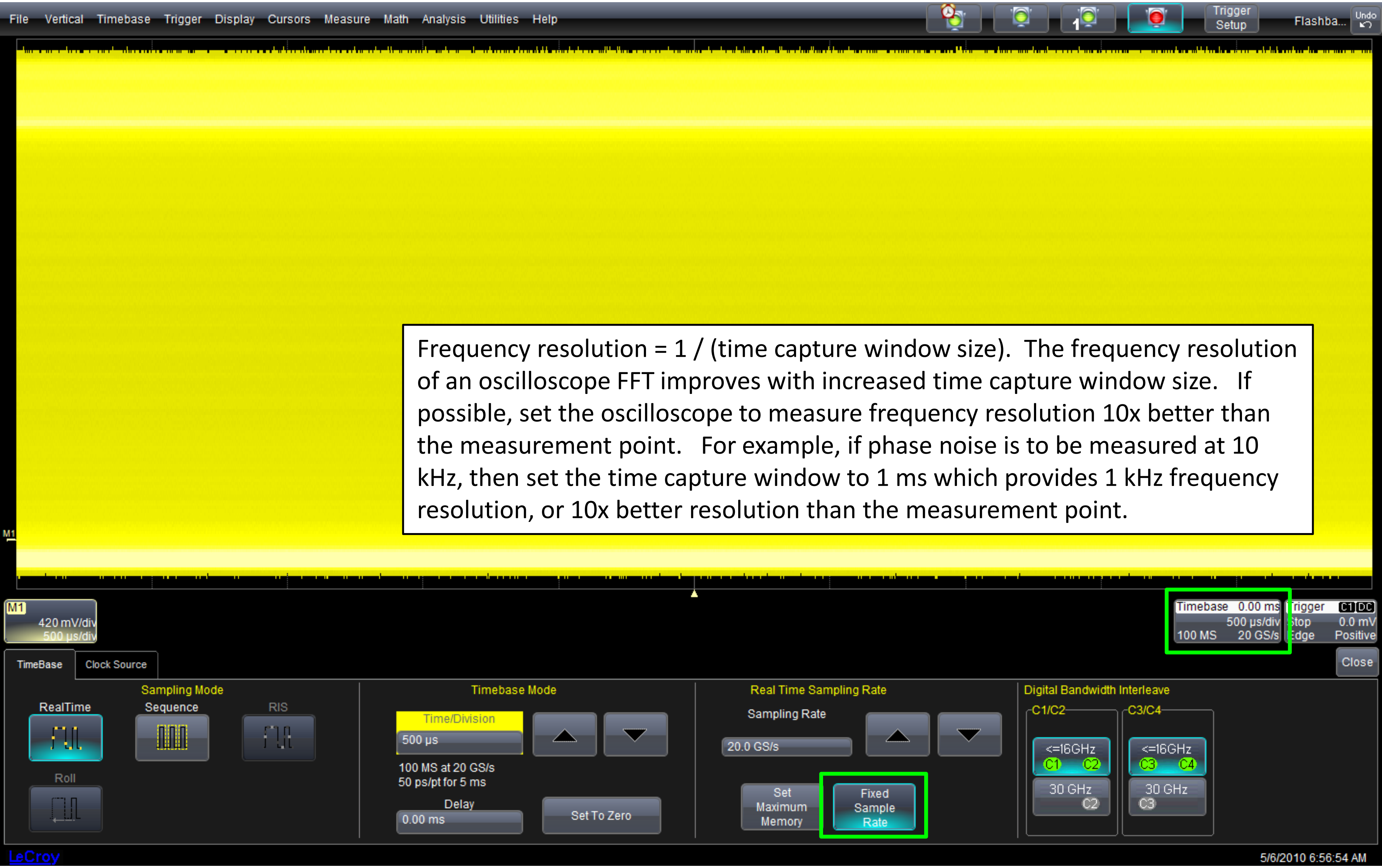
This document describes a test procedure for how to measure phase noise using an oscilloscope.

Select "Fixed Sample Rate" in the Timebase menu and choose a sample rate which provides adequate characterization of the edge shape (i.e., many points per rising edge).



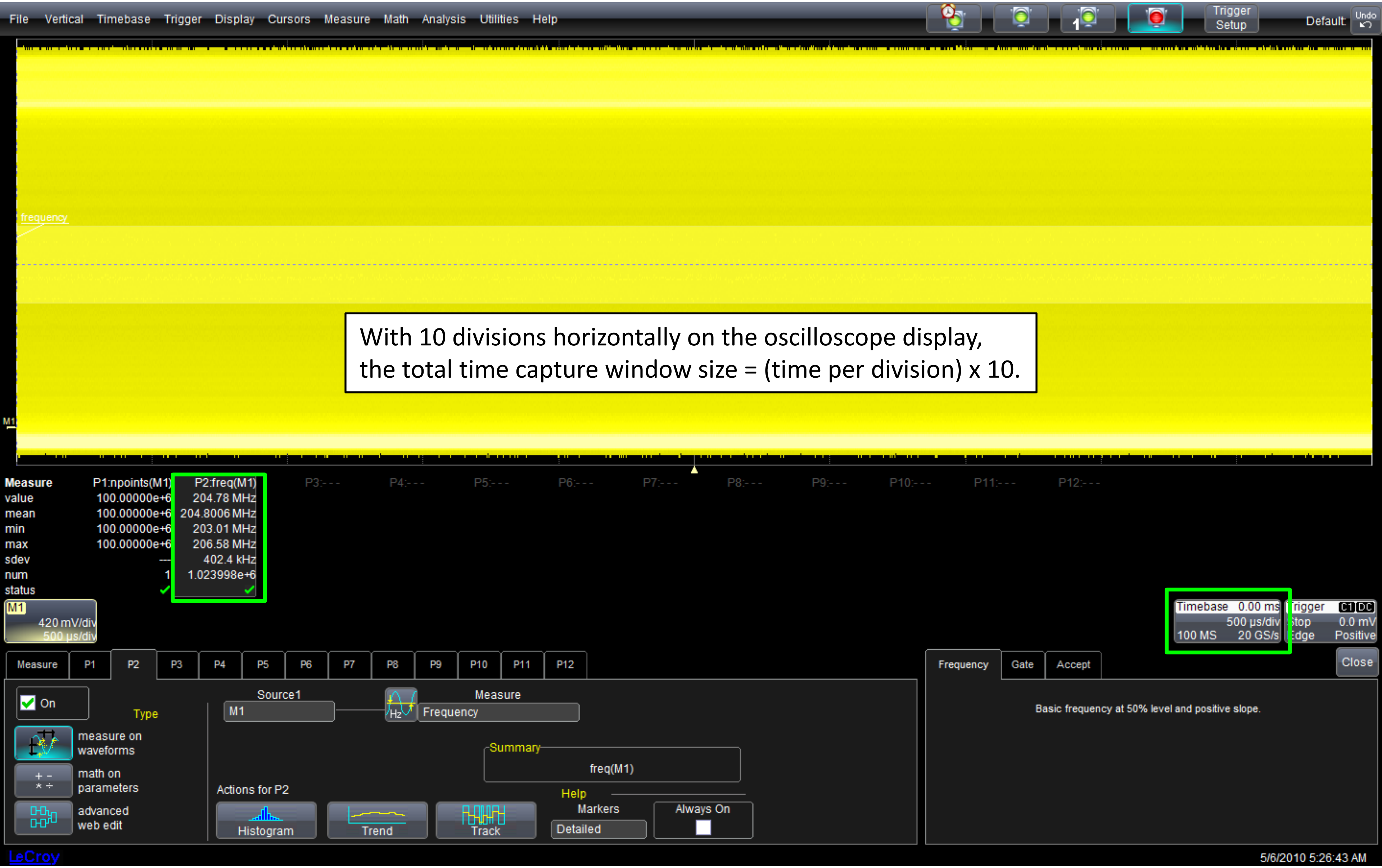
Collect enough sampling points along the rising edge to ensure accurate edge characterization. In this example, 20 GS/s fixed sample rate was used on a 204.8 MHz clock.

Acquire a minimum time capture window of 1 millisecond. This will provide 1 kHz frequency resolution in the FFT. A longer time capture window will provide greater frequency resolution (for example, the 5 millisecond time capture window shown below will provide 200 Hz resolution).



Frequency resolution = 1 / (time capture window size). The frequency resolution of an oscilloscope FFT improves with increased time capture window size. If possible, set the oscilloscope to measure frequency resolution 10x better than the measurement point. For example, if phase noise is to be measured at 10 kHz, then set the time capture window to 1 ms which provides 1 kHz frequency resolution, or 10x better resolution than the measurement point.

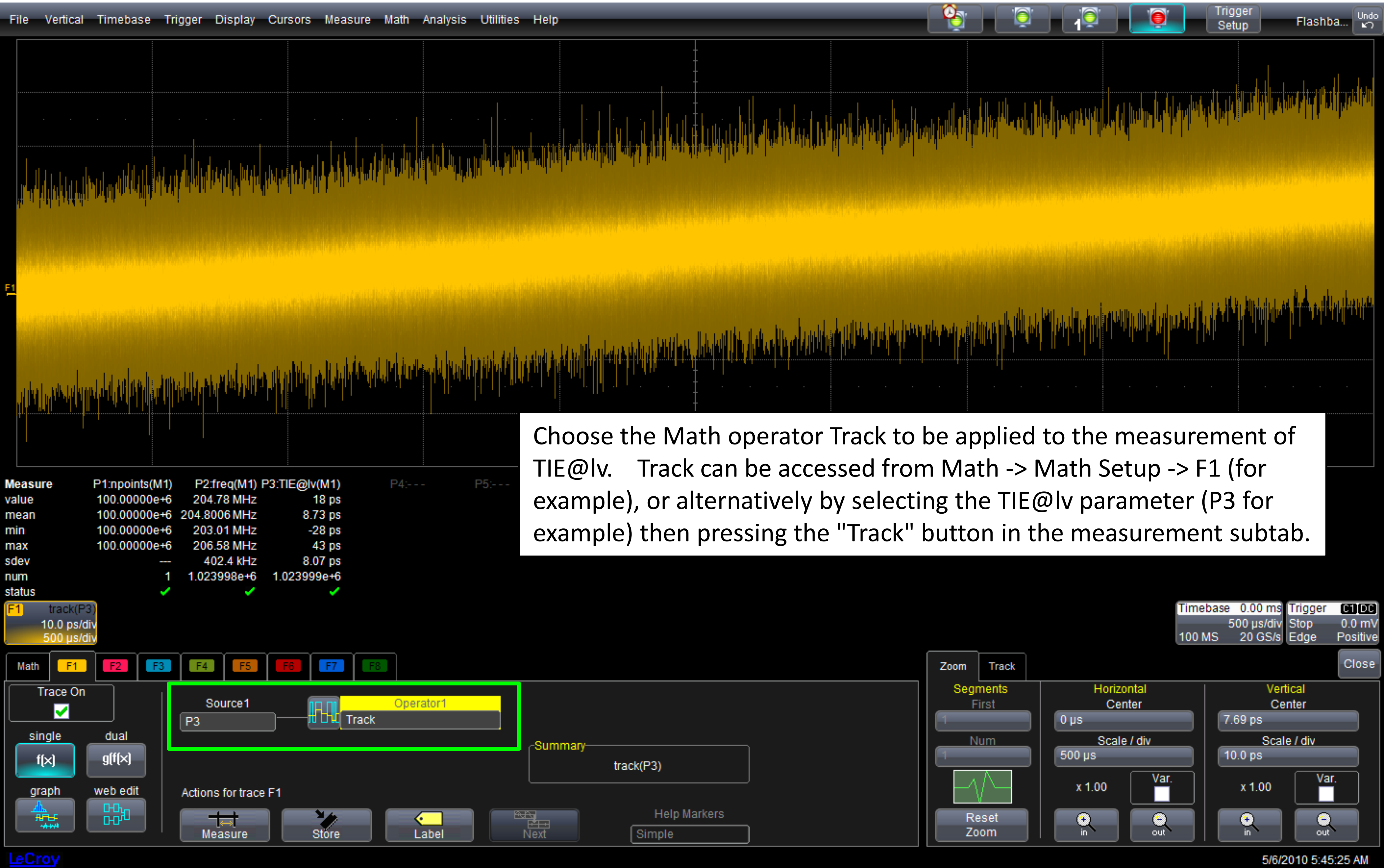
Shown below, 100 million sample points of this 204.8 MHz clock were acquired with a 5 millisecond time capture window, in order to obtain a large time capture window.



Measure TIE of the clock waveform. Set the input source to be Clock.

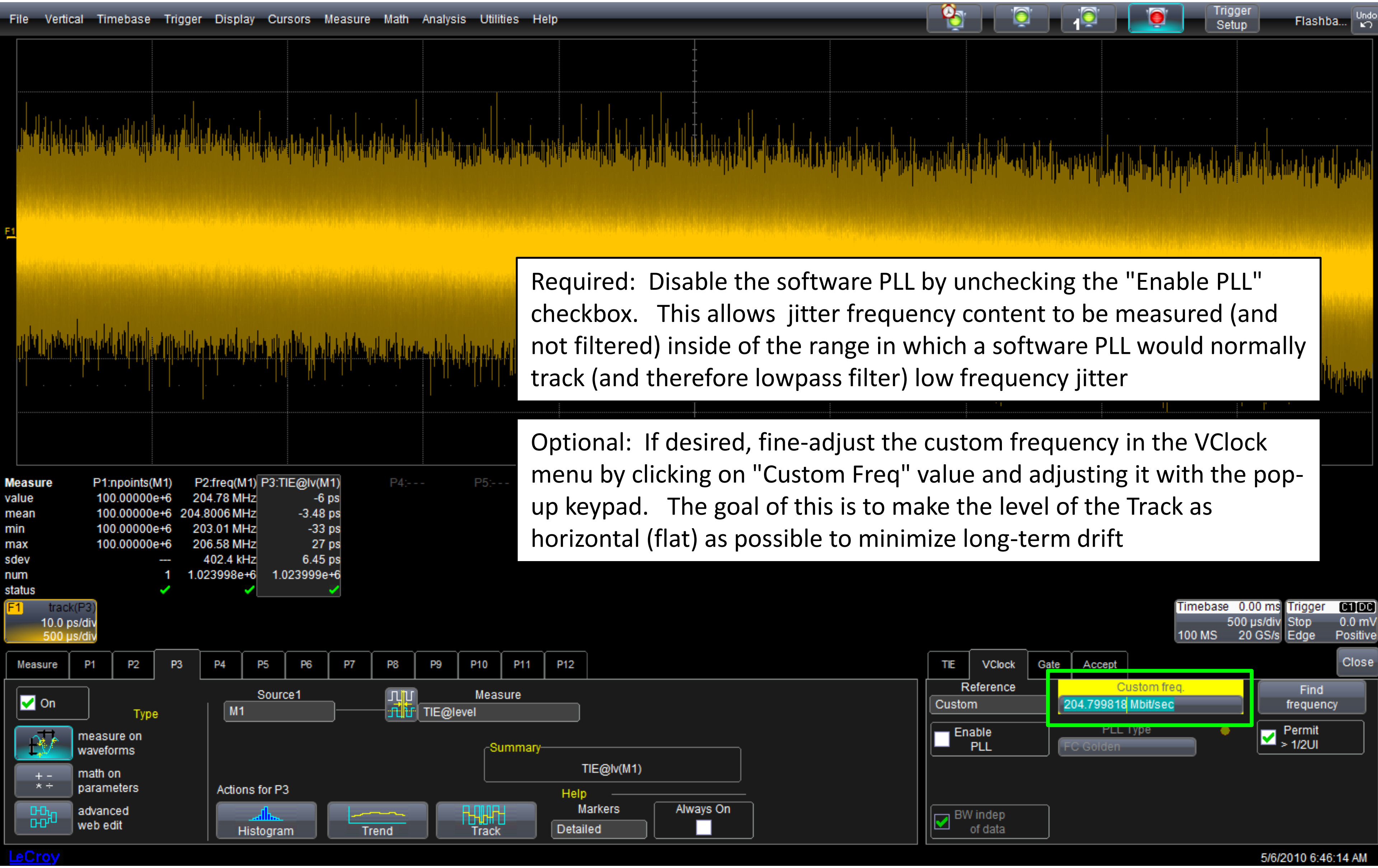
"Find Frequency" of the signal using the VClock of TIE parameter tab.

Apply the Track math operator to TIE.



Choose the Math operator Track to be applied to the measurement of TIE@lv. Track can be accessed from Math -> Math Setup -> F1 (for example), or alternatively by selecting the TIE@lv parameter (P3 for example) then pressing the "Track" button in the measurement subtab.

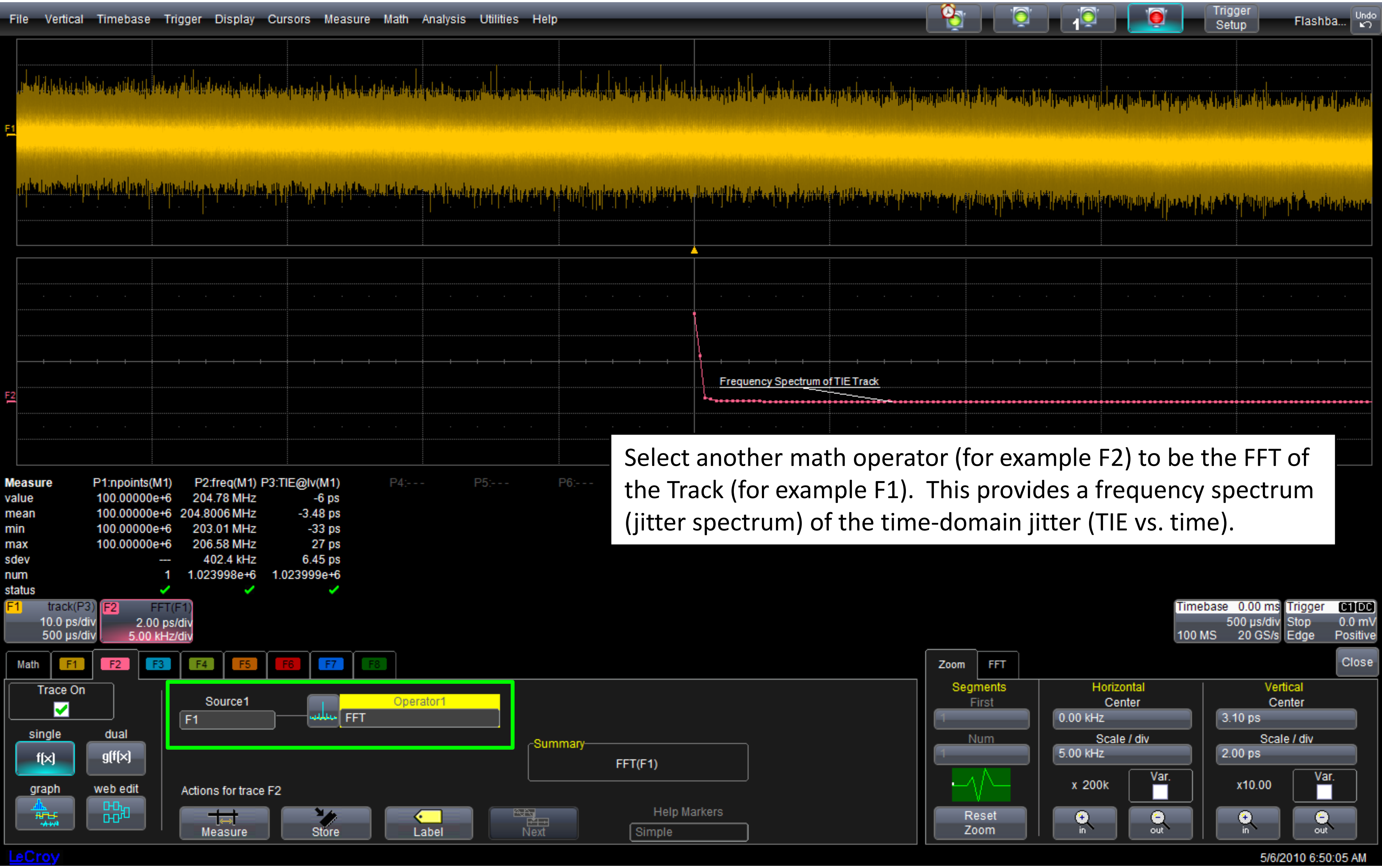
Disable the software PLL and fine-adjust the TIE custom frequency for maximum flatness of the Track.



Required: Disable the software PLL by unchecking the "Enable PLL" checkbox. This allows jitter frequency content to be measured (and not filtered) inside of the range in which a software PLL would normally track (and therefore lowpass filter) low frequency jitter

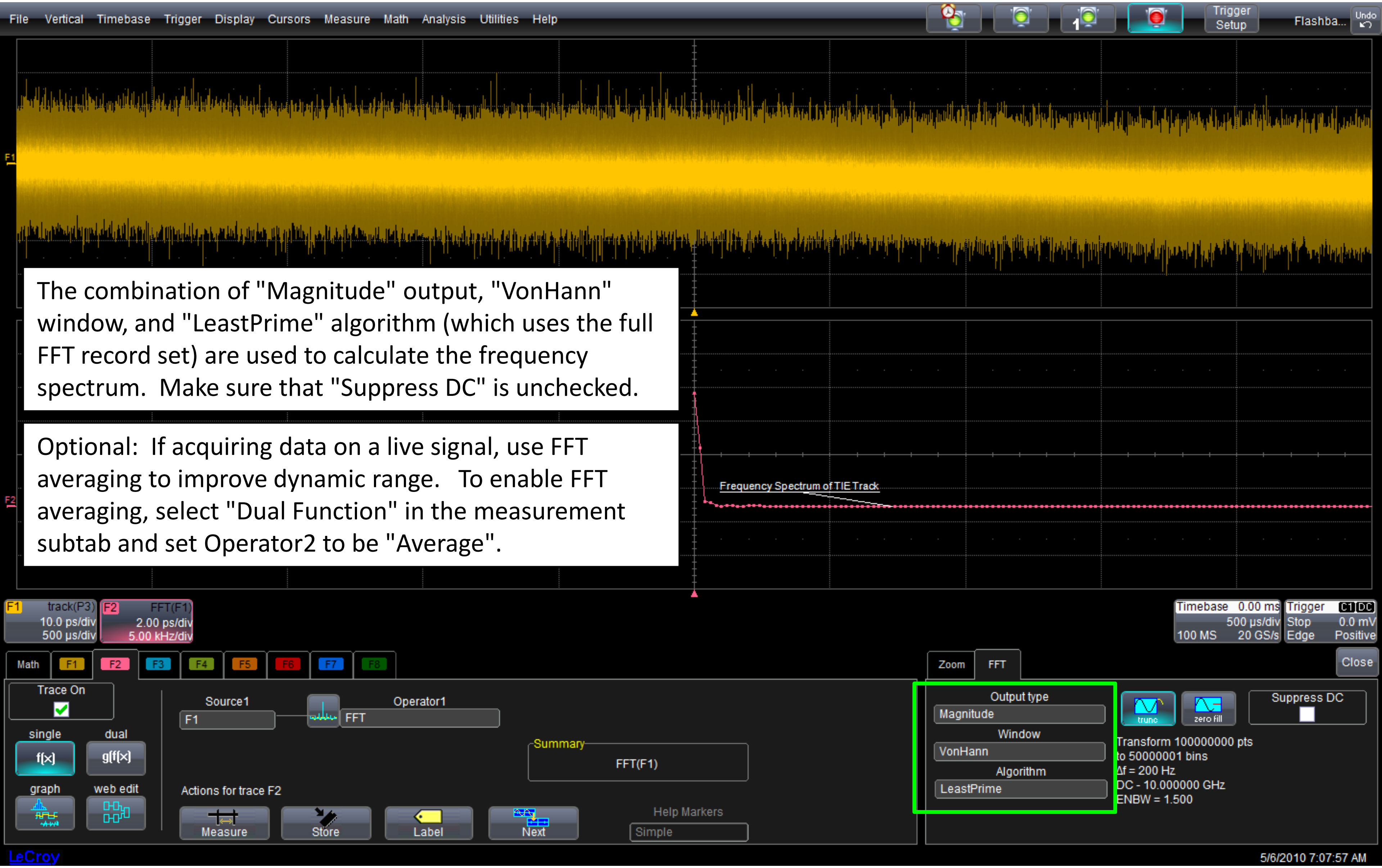
Optional: If desired, fine-adjust the custom frequency in the VClock menu by clicking on "Custom Freq" value and adjusting it with the pop-up keypad. The goal of this is to make the level of the Track as horizontal (flat) as possible to minimize long-term drift

Apply an FFT to the Track.



Select another math operator (for example F2) to be the FFT of the Track (for example F1). This provides a frequency spectrum (jitter spectrum) of the time-domain jitter (TIE vs. time).

Choose the FFT settings of "Magnitude", "VonHann", "LeastPrime", and uncheck "Suppress DC".



The combination of "Magnitude" output, "VonHann" window, and "LeastPrime" algorithm (which uses the full FFT record set) are used to calculate the frequency spectrum. Make sure that "Suppress DC" is unchecked.

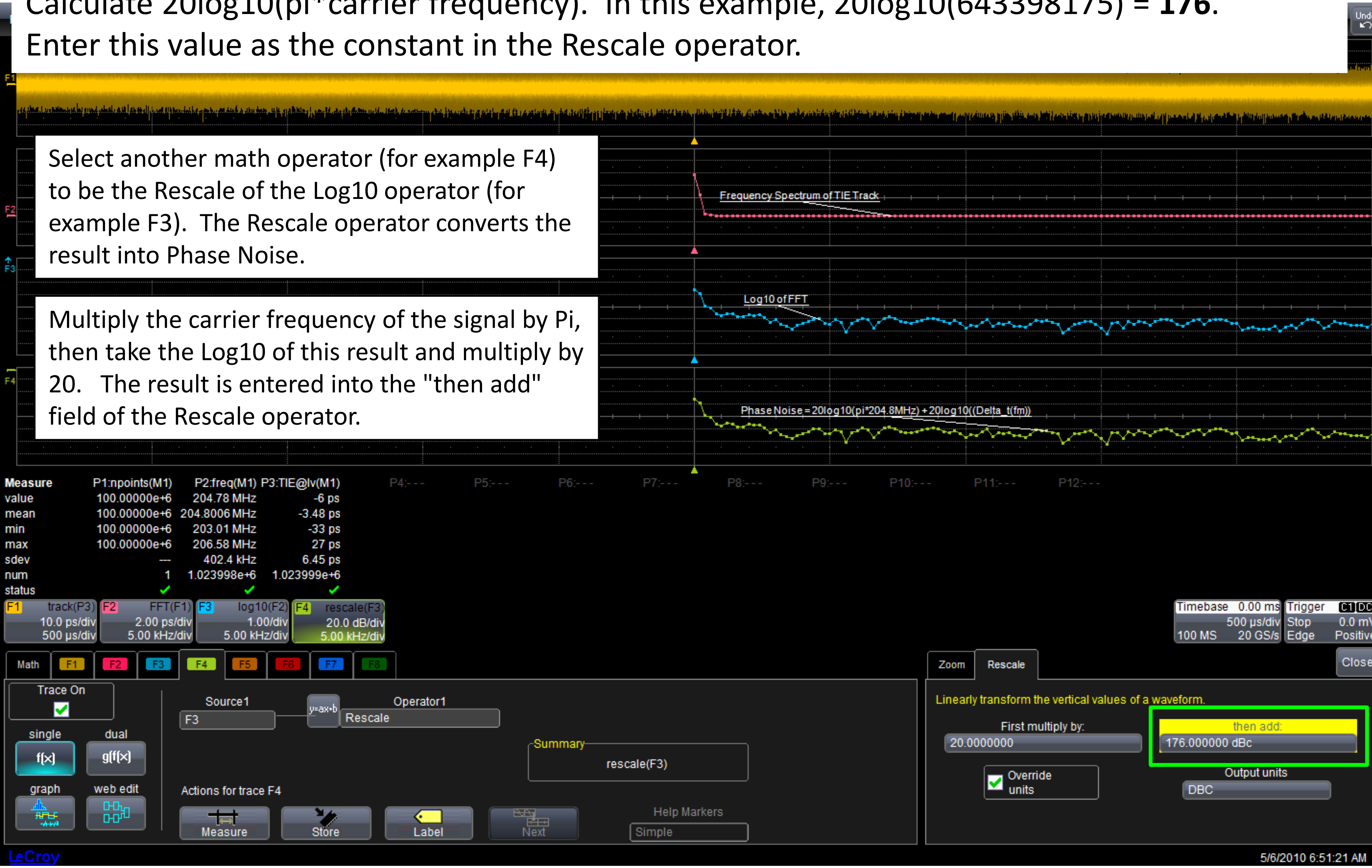
Optional: If acquiring data on a live signal, use FFT averaging to improve dynamic range. To enable FFT averaging, select "Dual Function" in the measurement subtab and set Operator2 to be "Average".

Apply Log10 to the FFT.

In the Rescale operator, multiply by 20, then determine the constant to add as follows: Calculate 20log10(pi*carrier frequency). In this example, 20log10(643398175) = **176**. Enter this value as the constant in the Rescale operator.

Select another math operator (for example F4) to be the Rescale of the Log10 operator (for example F3). The Rescale operator converts the result into Phase Noise.

Multiply the carrier frequency of the signal by Pi, then take the Log10 of this result and multiply by 20. The result is entered into the "then add" field of the Rescale operator.

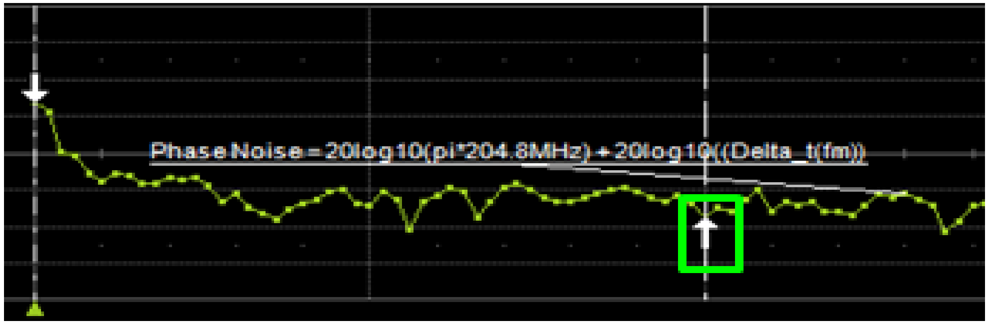


Place a cursor at the phase noise offset frequency (for example 10 kHz) and read out the cursor value in DBC from the F4 trace descriptor to determine phase noise.

Note about Dynamic Range

An oscilloscope provides accurate phase noise measurements to -70 dBc with approximately +/- 1 dB accuracy without averaging.   With averaging, an 8-bit oscilloscope dynamic range may be extended to approximately -80 dBc or greater.

Shown here, the left cursor is placed at DC, and the right cursor is placed at 10 kHz.   The right cursor value at 10 kHz shows a **10 KHz offset phase noise value of -109.63 dBc.**



The left cursor placed at 0 Hz shows a carrier level of -47.401 dBc.   However, since oscilloscope FFTs only display positive frequencies, the DC point needs to be adjusted by 6 dB.   Therefore, the **dynamic range** of this measurement is (109.63 - 47.401 - 6.0) = **56.229 dB**, which is well within the dynamic range of an oscilloscope.

Summary

By applying the TIE Track math operator to the input waveform, data is effectively sampled at the carrier frequency, translating the carrier down to zero frequency. By generating a scaled FFT of this result, phase noise can be determined at a fixed frequency displacement from the carrier frequency.

The absolute phase noise level measurement is not limited on an oscilloscope, but the dynamic range is. An oscilloscope with an 8 bit digitizer limits the maximum dynamic range of a phase noise measurement to approximately 80 dB, where the dynamic range is the ratio of the highest to lowest phase noise level. The scaling moves the phase noise graph up or down proportionally to the carrier frequency.

For low phase noise applications requiring wide dynamic range, a frequency domain instrument such as a spectrum analyzer or phase noise test set is recommended.