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Optimizing Frequency Settling Time Measurements

TECHNICAL BRIEF

Introduction

The measurement of the frequency settling time is a common task when designing and evaluating the performance of programmable oscillators, phase locked loop circuits, RF synthesizers and more. Making such a measurement can be tricky. The Settling Time option for Tektronix Real-time Spectrum Analyzers and SignalVu-PC software (for analyzers and oscilloscopes) makes this task much easier. This technical brief describes how you can optimize these measurements to achieve greater accuracy and precision.

Example Case: Frequency Settling of an RF Synthesizer

In our example, we have an RF synthesizer that is hopping between three distinct frequencies. The spectrum and real-time spectrum (DPX) of this signal can be seen in **Figure 1**.

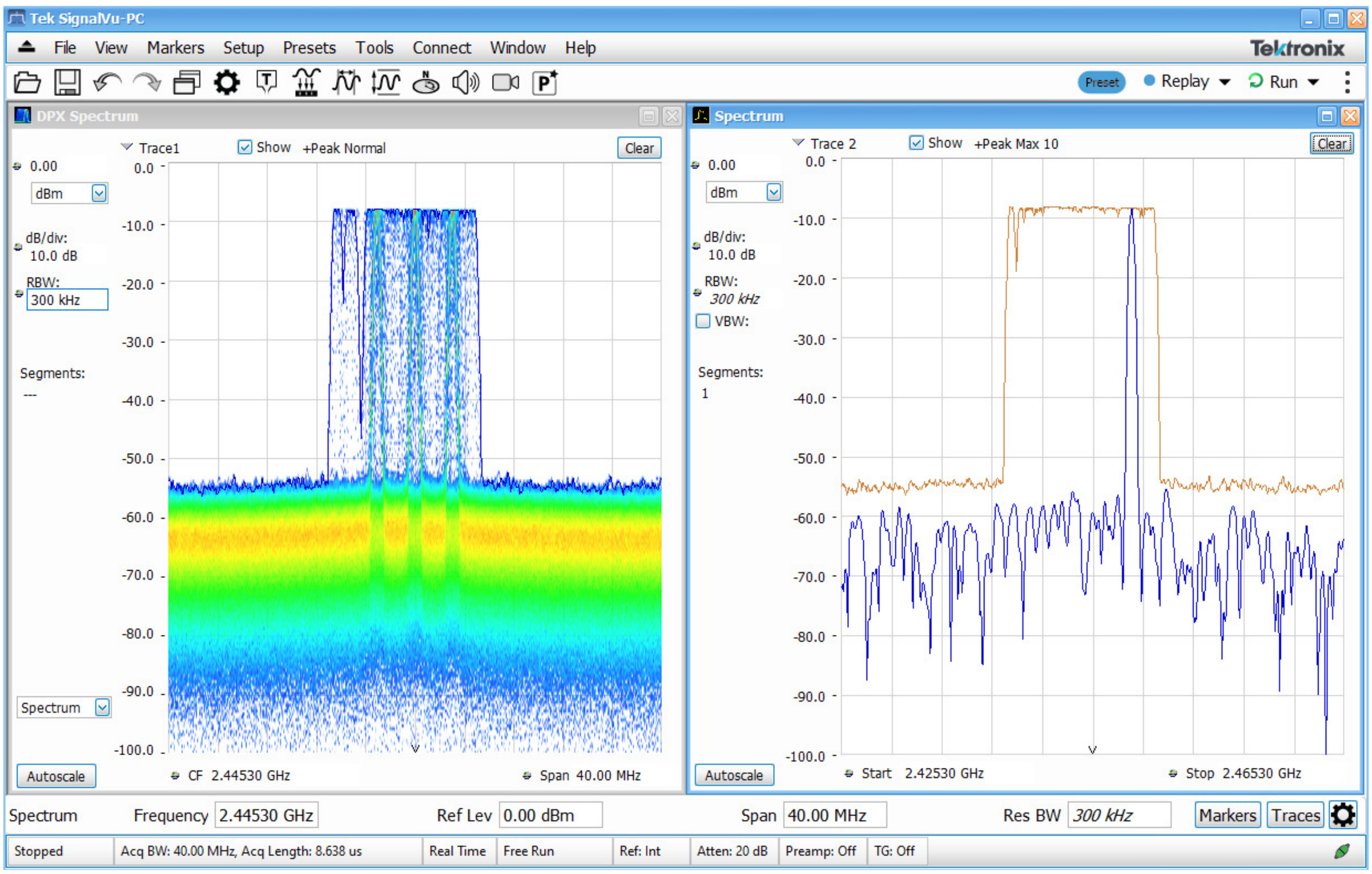

Figure 1. Spectral content of the frequency hopping signal.

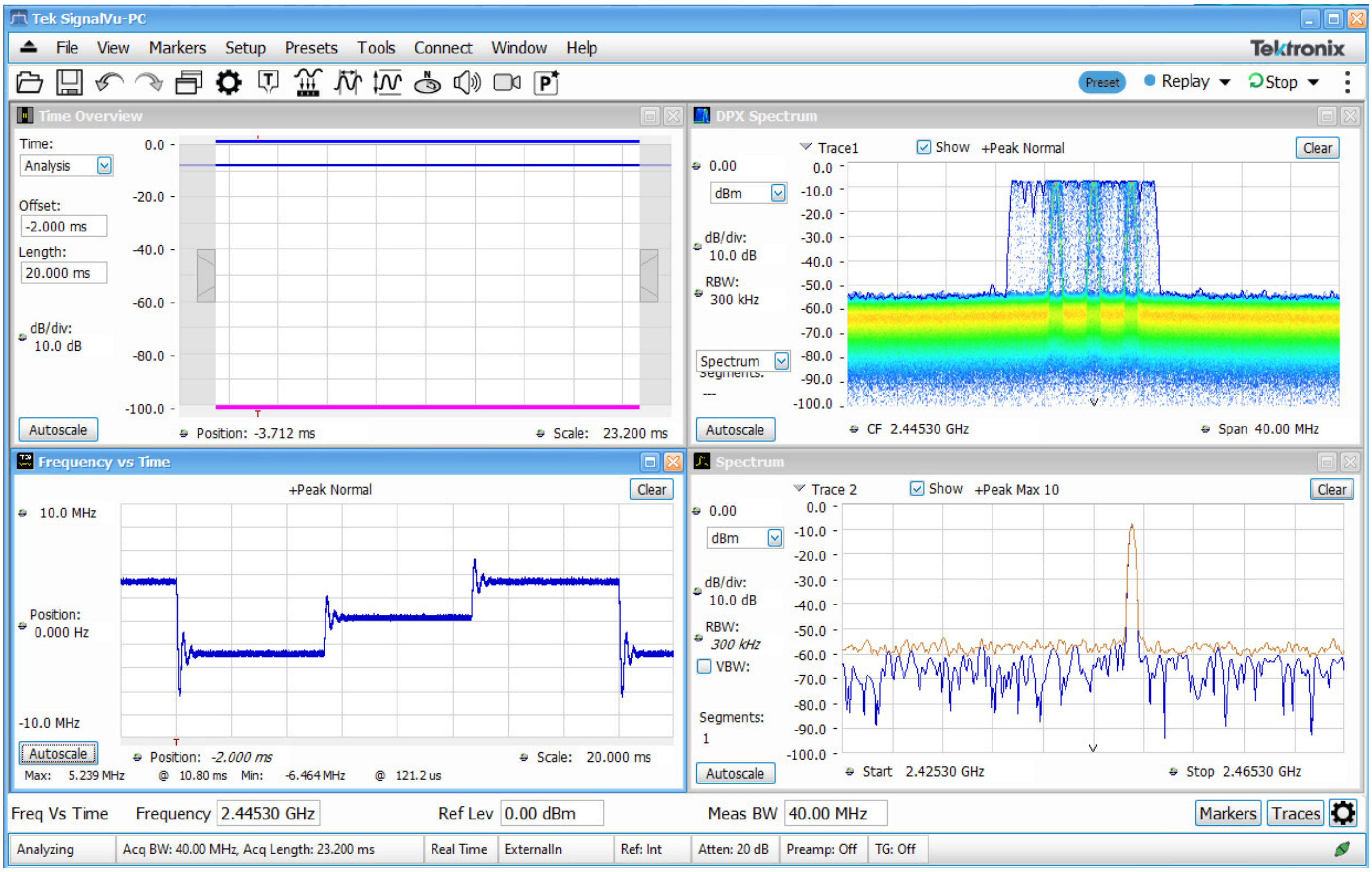

Figure 2. Time domain view of the complete frequency hopping pattern.

The RF synthesizer being used here gives us a trigger signal that is synchronous to transition from the highest frequency to the lowest frequency. By triggering the analyzer on this signal, we can setup an acquisition to observe the time domain behavior of each of the hops. In **Figure 2**, we have added the Time Overview display and the Frequency vs. Time display. The Time Overview display is used to setup the time-domain acquisition and analysis region. As shown, the analysis region is setup to measure a 20 ms long acquisition (Analysis Length) that begins 2 ms prior to the trigger event (Analysis Offset). This ensures that we acquire and measure the starting frequency prior to the transition to the lowest frequency. The Frequency vs. Time display shows the frequency deviation of the input signal with respect to the Center Frequency that is setup on the analyzer (2.4453 GHz). You can think of this display as an "FM demodulation" view of the input signal.

We will focus our attention on the initial falling frequency transition that is coincident with the trigger. To do so, the Analysis Length is shortened from 20 ms down to 6 ms as shown in **Figure 3**. We are now focused only on the single frequency transition coincident with our trigger input.

The frequency settling behavior can easily be observed in the Frequency vs Time display. The under-damped response of the PLL in the synthesizer can be seen in the "ringing" behavior of the signal's frequency following the main transition. Markers can be used to make measurements along the displayed trace. It would be a tedious task to record marker values at different locations to determine when the frequency has settled to within a given precision of the final resting frequency. This is where the Frequency Settling Time display becomes especially useful.

We can add the Frequency Settling Time display to analyzer (see **Figure 4**). The default settings for the Frequency Settling Time will likely not match your exact measurement scenario. You would typically start by hitting the Auto Scale button in the lower left corner of the Freq Setting display. This results in the display shown in **Figure 4**.

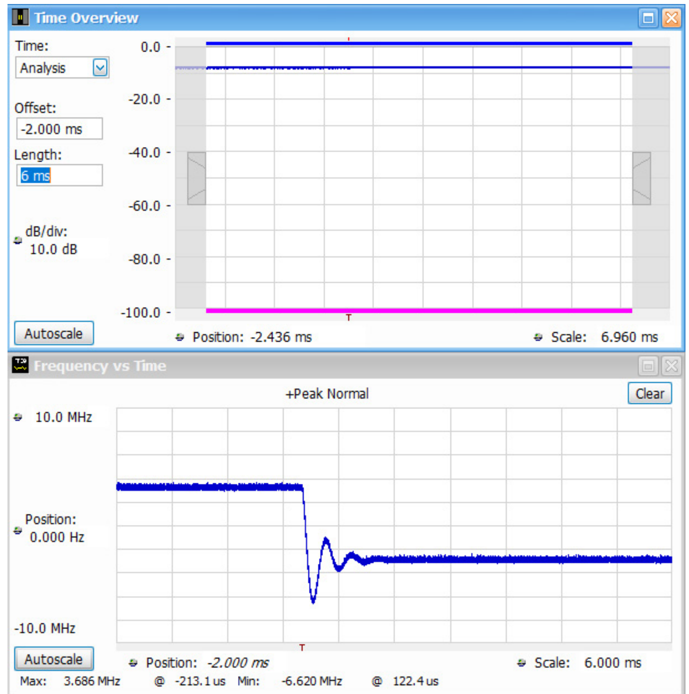

Figure 3. Focusing on the first frequency transition.

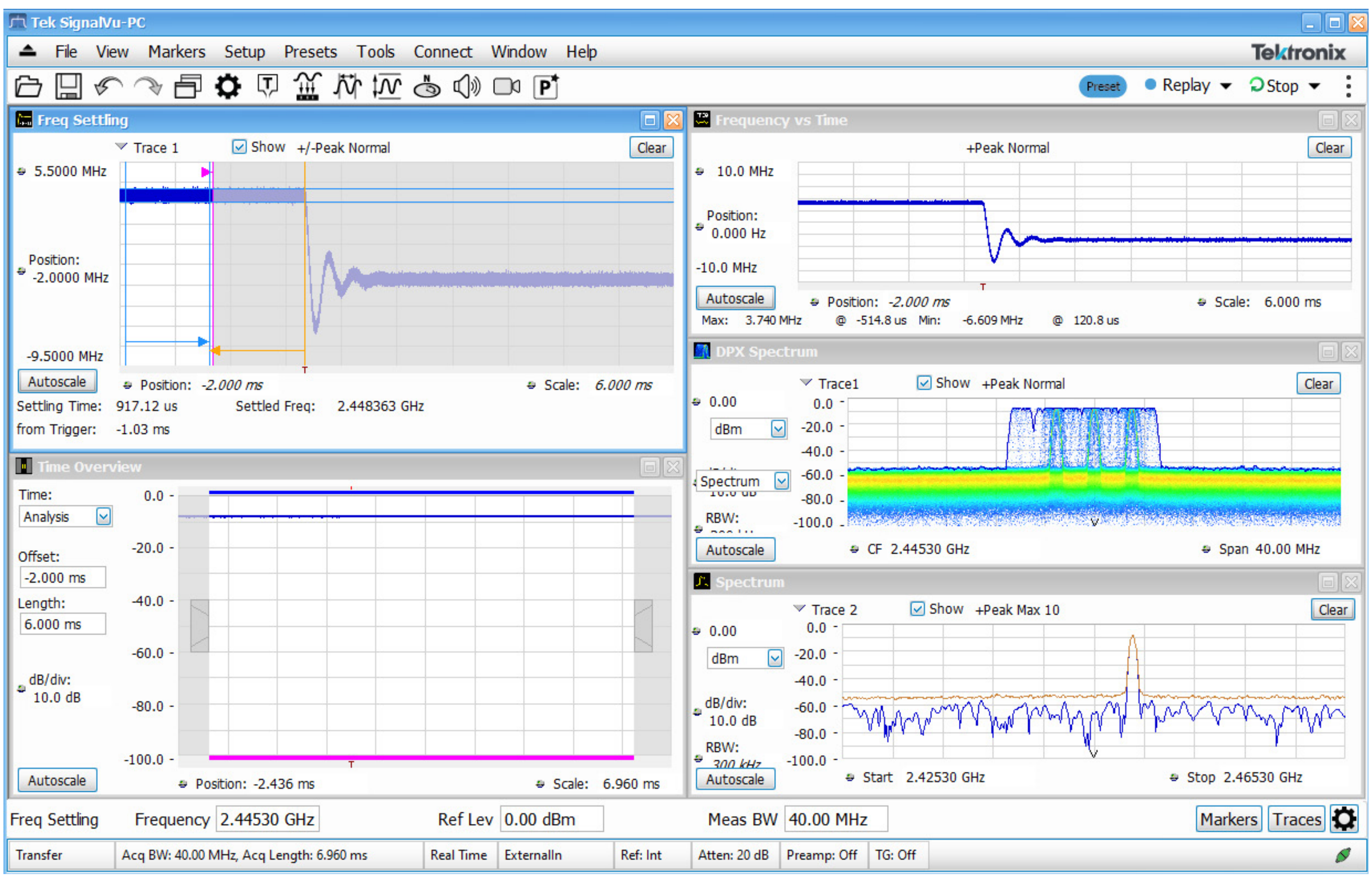

Figure 4. Adding the frequency settling display.

The pink vertical line that separates the shaded and unshaded areas in the Frequency Settling display (**Figure 4**) is called the "Measurement Length". The "settled" frequency is determined by the frequency deviation that exists where the trace crosses this line, thus it is necessary to adjust this length to where we expect the frequency to be fully settled.

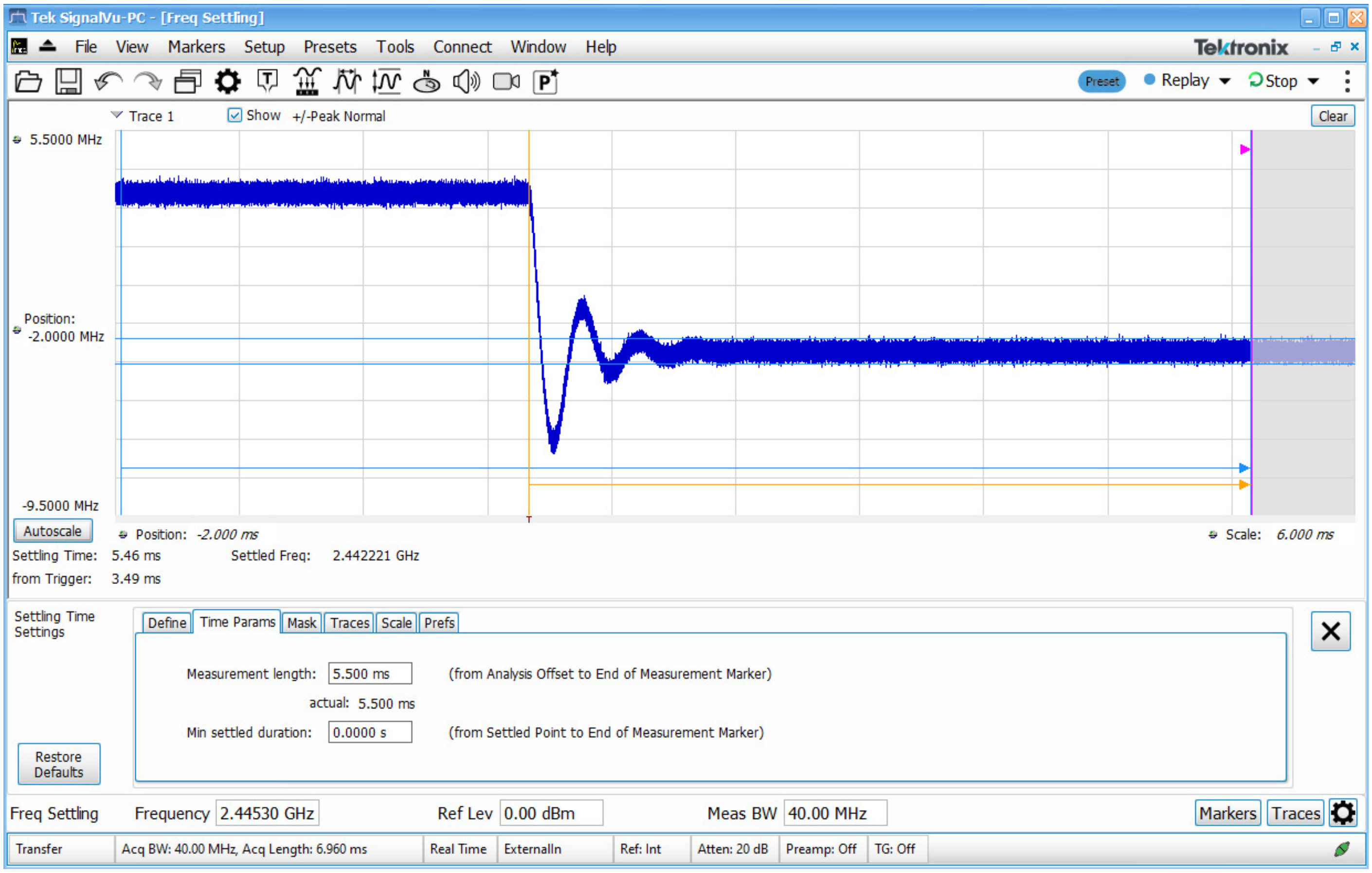

Figure 5. Adjustment of the frequency settling measurement length.

The frequency can be considered "settled" at about the ~5.5 ms point in this acquisition, so we will move the Measurement Length to this value. This can be done via the Settings>Time Params panel, or by simply dragging the pink line to the right with the mouse. The result is shown in **Figure 5**, with the Frequency Settling display maximized.

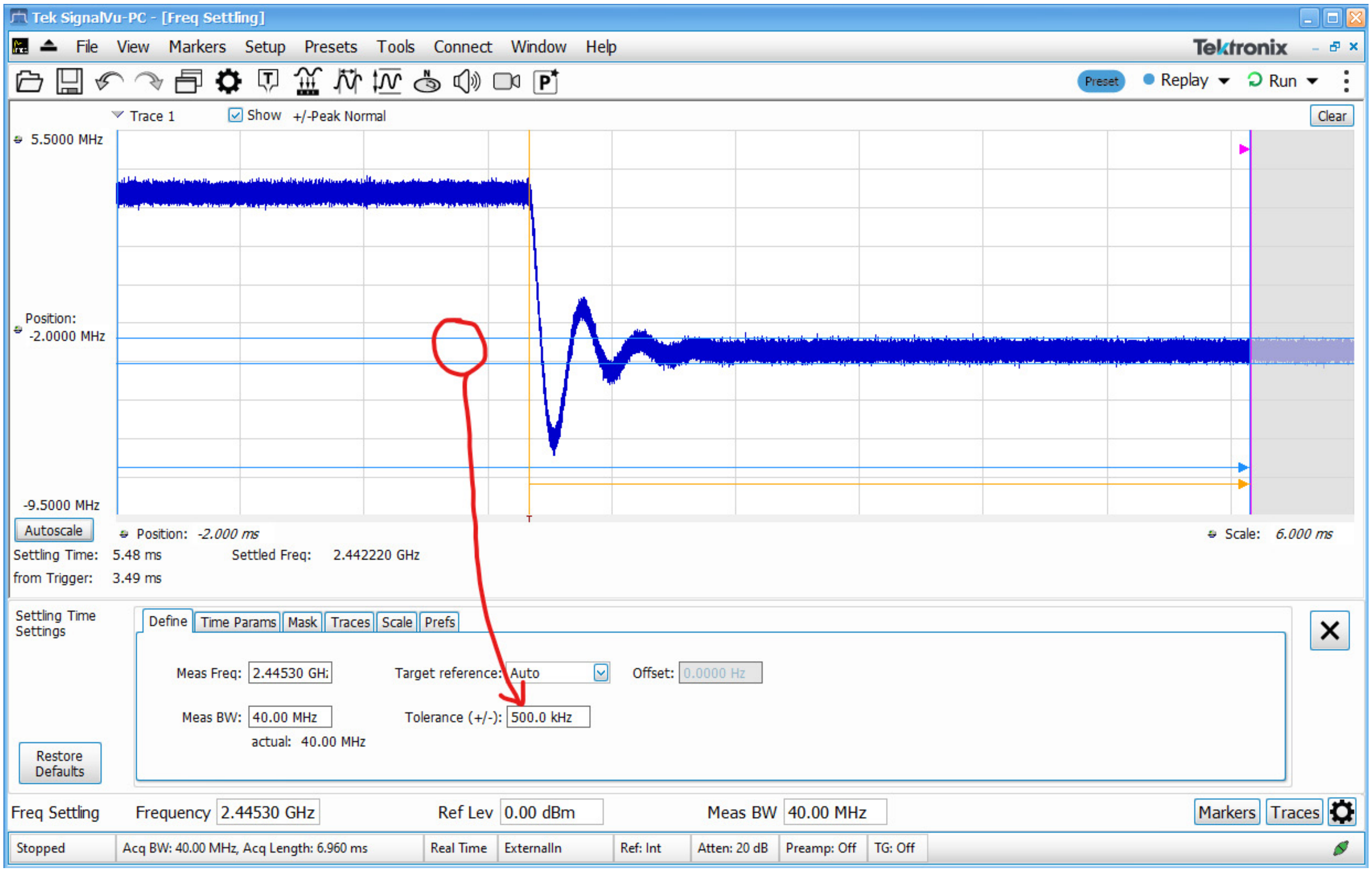

Figure 6. Frequency settling tolerance band adjustment.

The thin light blue horizontal bars highlighted in **Figure 6** show the Frequency Tolerance setting in the measurement. They are currently set for a ±500 kHz tolerance window. The "settled" time is determined by examining the trace from the Measurement Time (pink bar), right to left until the trace crosses one of the two tolerance lines. We can see that the "noise" on the trace fills this entire tolerance band, which makes it impossible to measure the settled frequency to anything less than ±500 kHz. This is where our optimization process begins.

The goal of the optimization process is to reduce the noise/variation on demodulated freq vs time trace. The noise is proportional to the RF measure bandwidth. As seen in the settings in the Settings>Define panel (**Figure 6**), the Meas BW is 40 MHz.

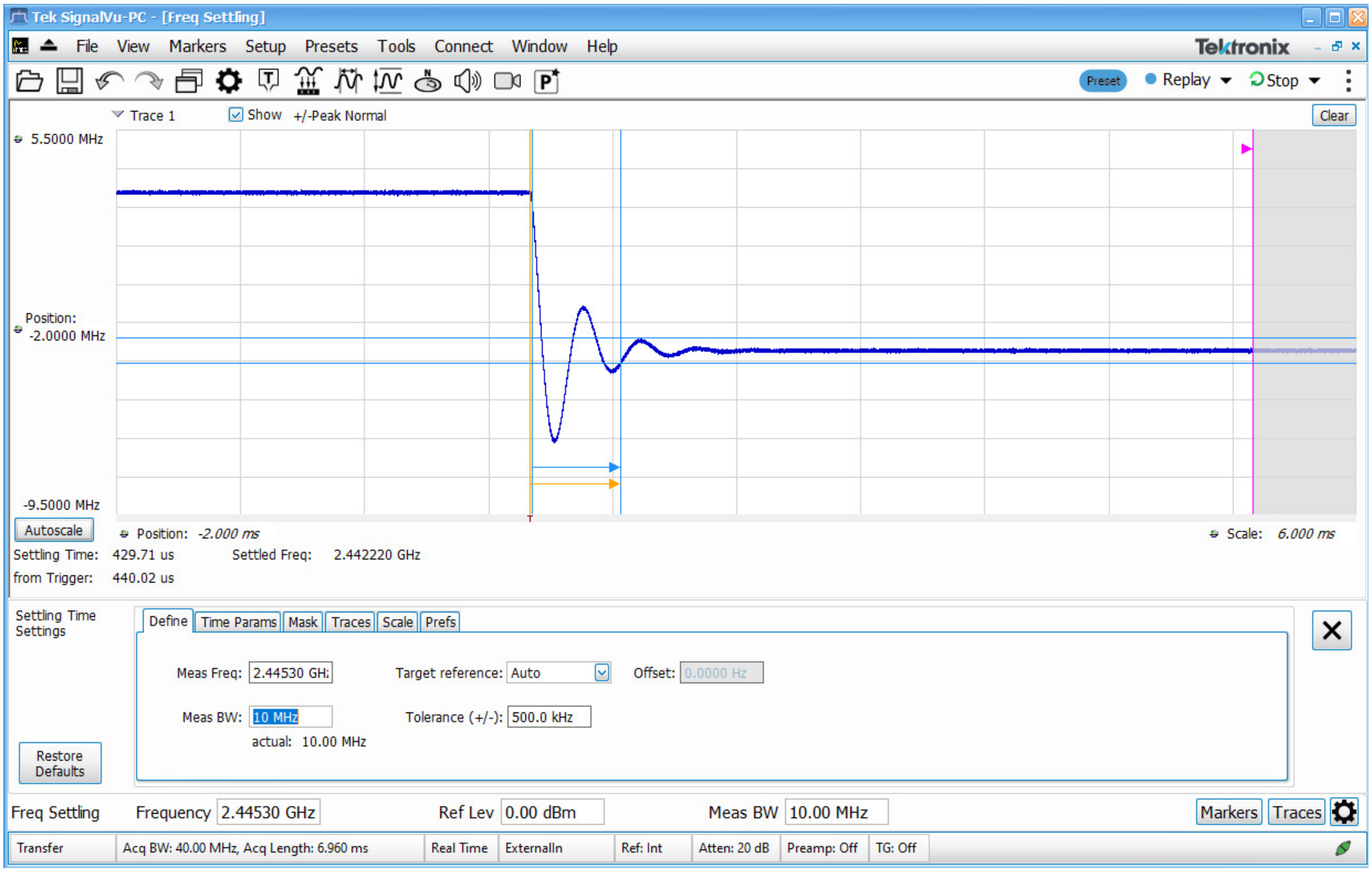

Figure 7. Reducing the measurement bandwidth to reduce noise on the trace.

From observation from our initial Spectrum plots, the entire frequency hopping signal occupies less than 10MHz of bandwidth. Thus, we can lower our Meas BW to 10 MHz. This significantly reduces the noise on the trace as shown in **Figure 7**.

The lower Meas BW results in a cleaner trace, and the ±500 kHz tolerance value can easily be used to measure when the device's frequency settles to within this tolerance of the final settled value. Two measurements are shown in **Figure 7**. The Settling Time (blue arrow) shows the time between when the frequency exited the ±500 kHz tolerance band at the beginning of the transition, to the time where the frequency enters and remains in the tolerance band. The "from Trigger" measurement (orange arrow) uses the Trigger event as the starting point.

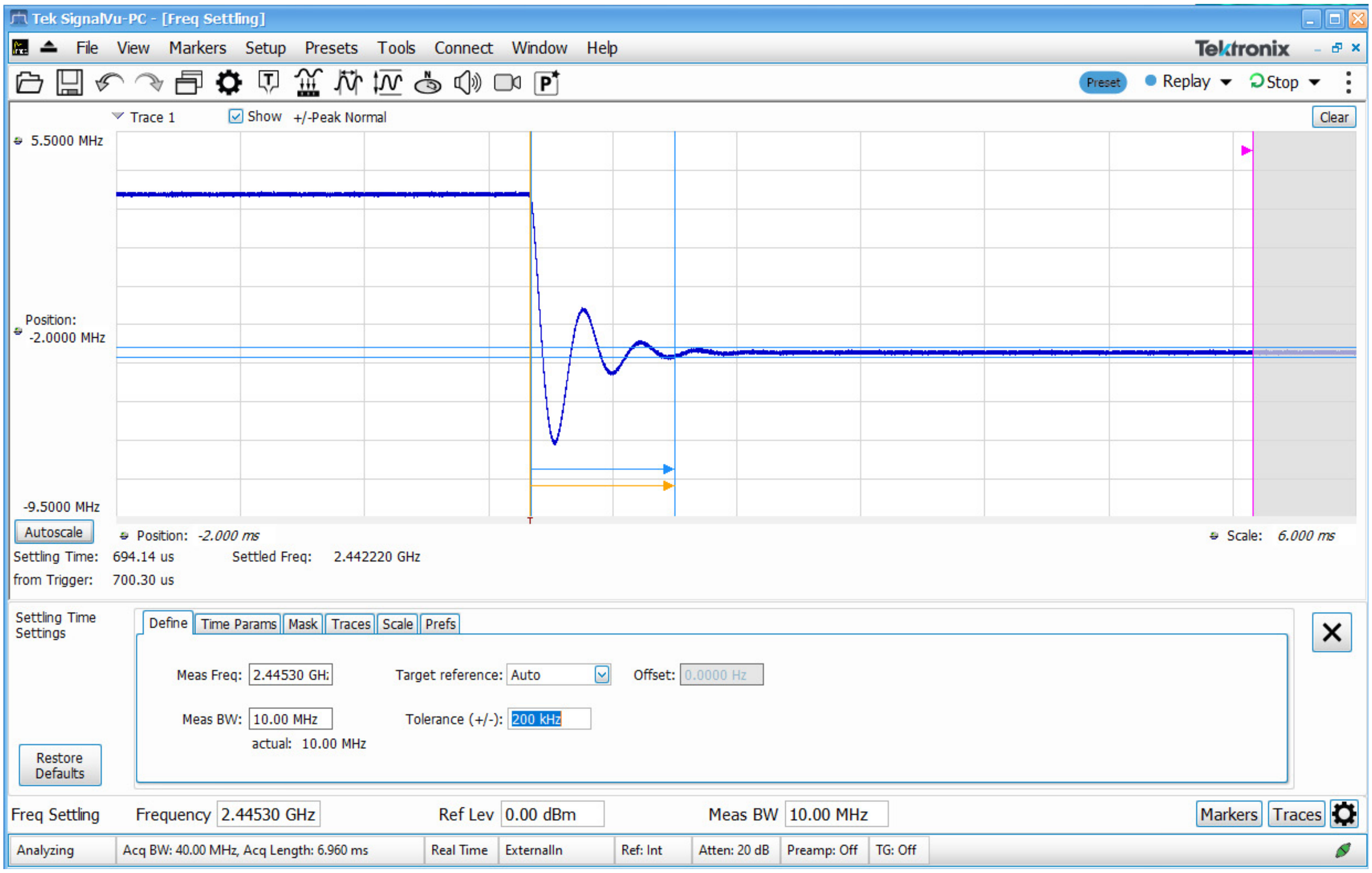

Figure 8. Tightening up the tolerance band.

The reduced noise on the trace allows us to tighten up the Tolerance window, giving us a more precise definition of the frequency settling. **Figure 8** shows the tolerance reduced from 500 kHz to 200 kHz.

Noise on the trace prevents us from setting the tolerance much lower than 200 kHz at this point. However, there are a few more optimizations we can do to further reduce the trace noise which will allow a tighter tolerance band.

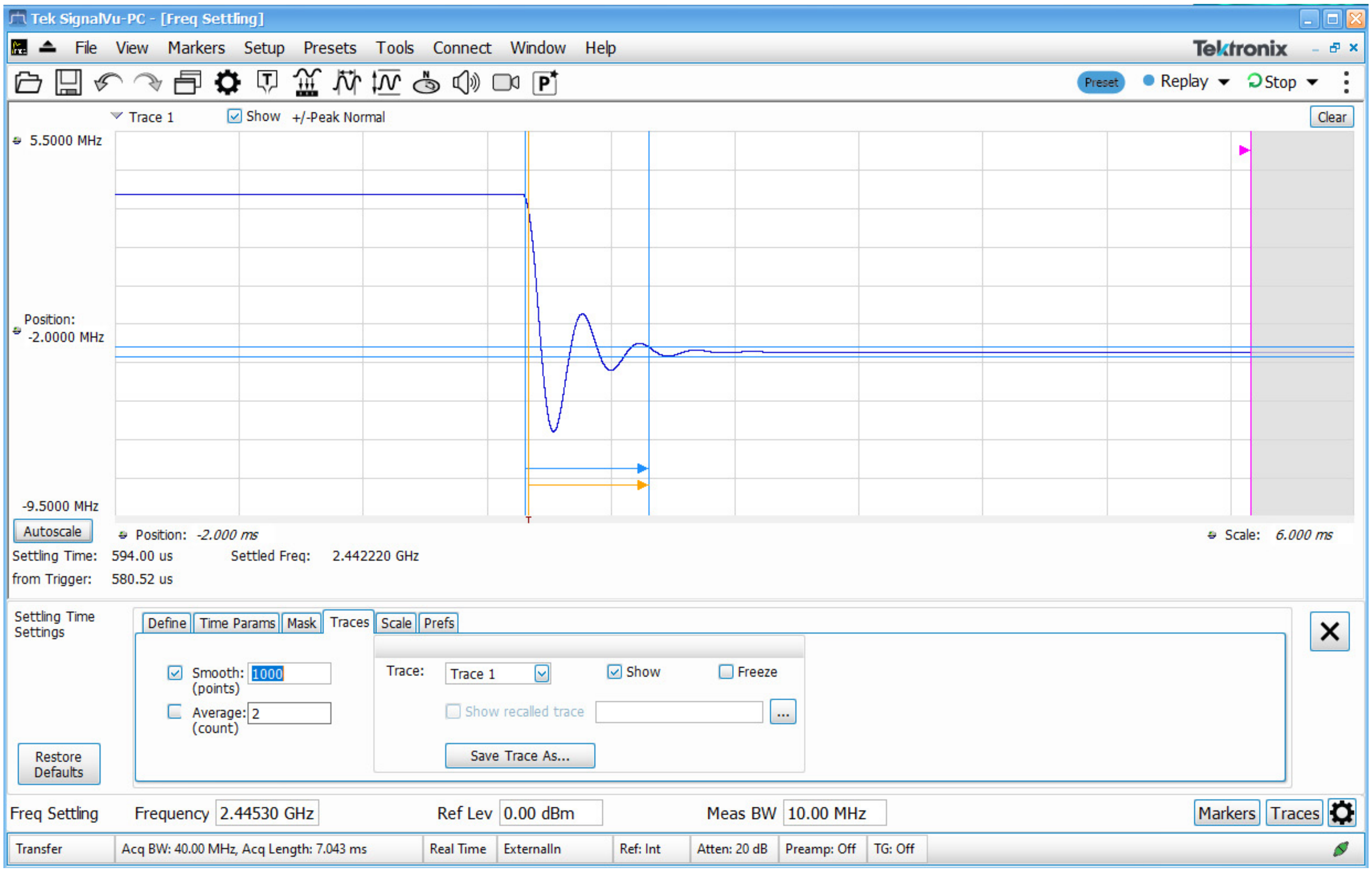

Figure 9. Adding trace smoothing to reduce the uncertainty on the trace.

Under the Settings>Traces panel, there are two features that will further reduce the trace noise: Smoothing and Averaging. The trace Smoothing function is a moving boxcar average filter that is applied to the trace to filter the rapid variations in the trace. This is a form of lowpass filtering of the trace result. You can enable this function and observe the effects on your trace as you increase the number of points in the smoothing. You can keep increasing the number of points included in the smoothing as long as you do not see a change in the overall transient behavior (rise/fall time, degree of overshoot or ringing, etc.). The smoothing can be adjusted up to 1,000 points as shown in **Figure 9**.

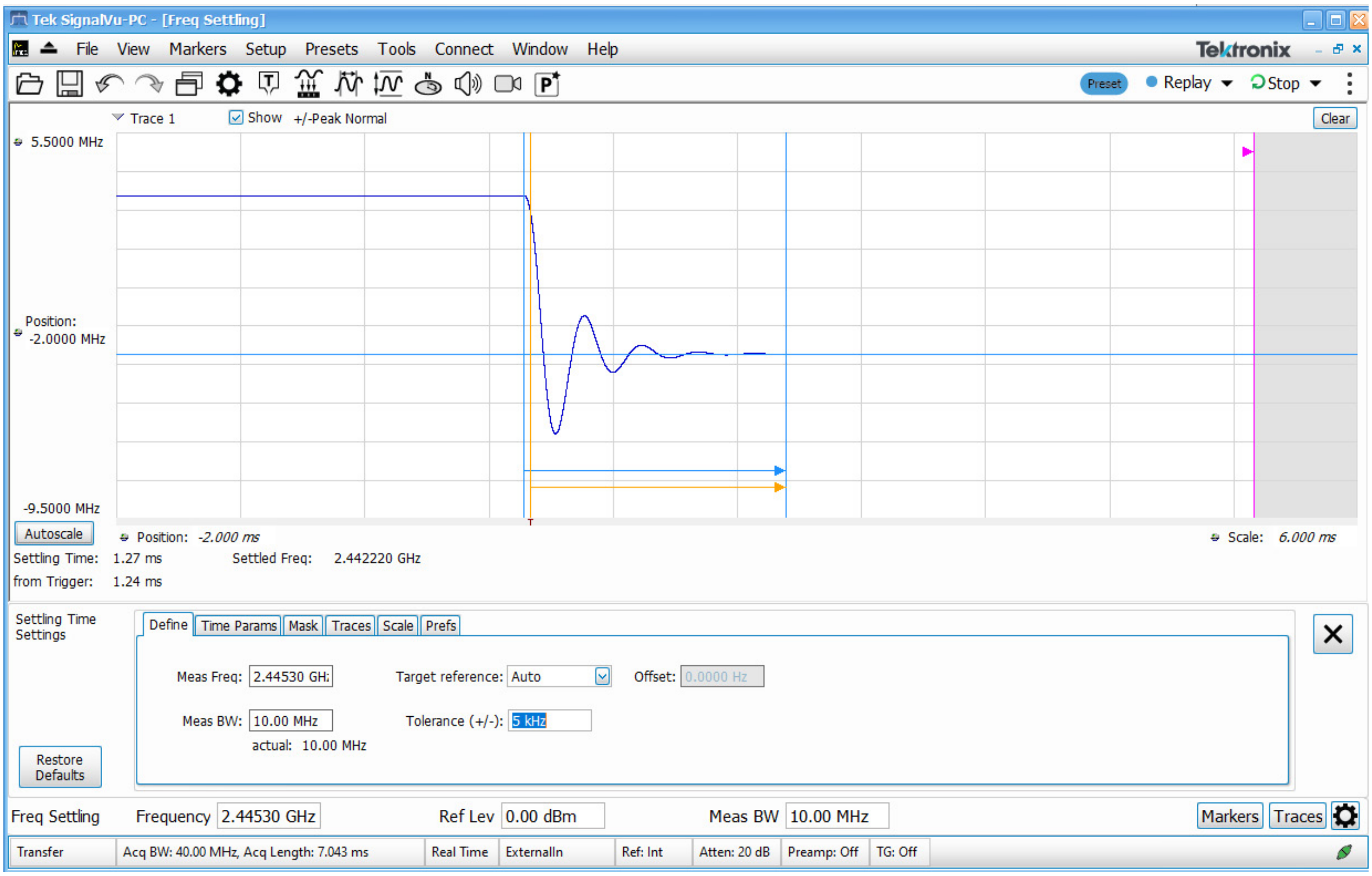

Figure 10. Tightening the tolerance on the smoothed trace.

The noise on the trace is now imperceptible and the tolerance used for the settling measurement can be further reduced. **Figure 10** shows the tolerance being reduced from 200 kHz down to just 5 kHz.

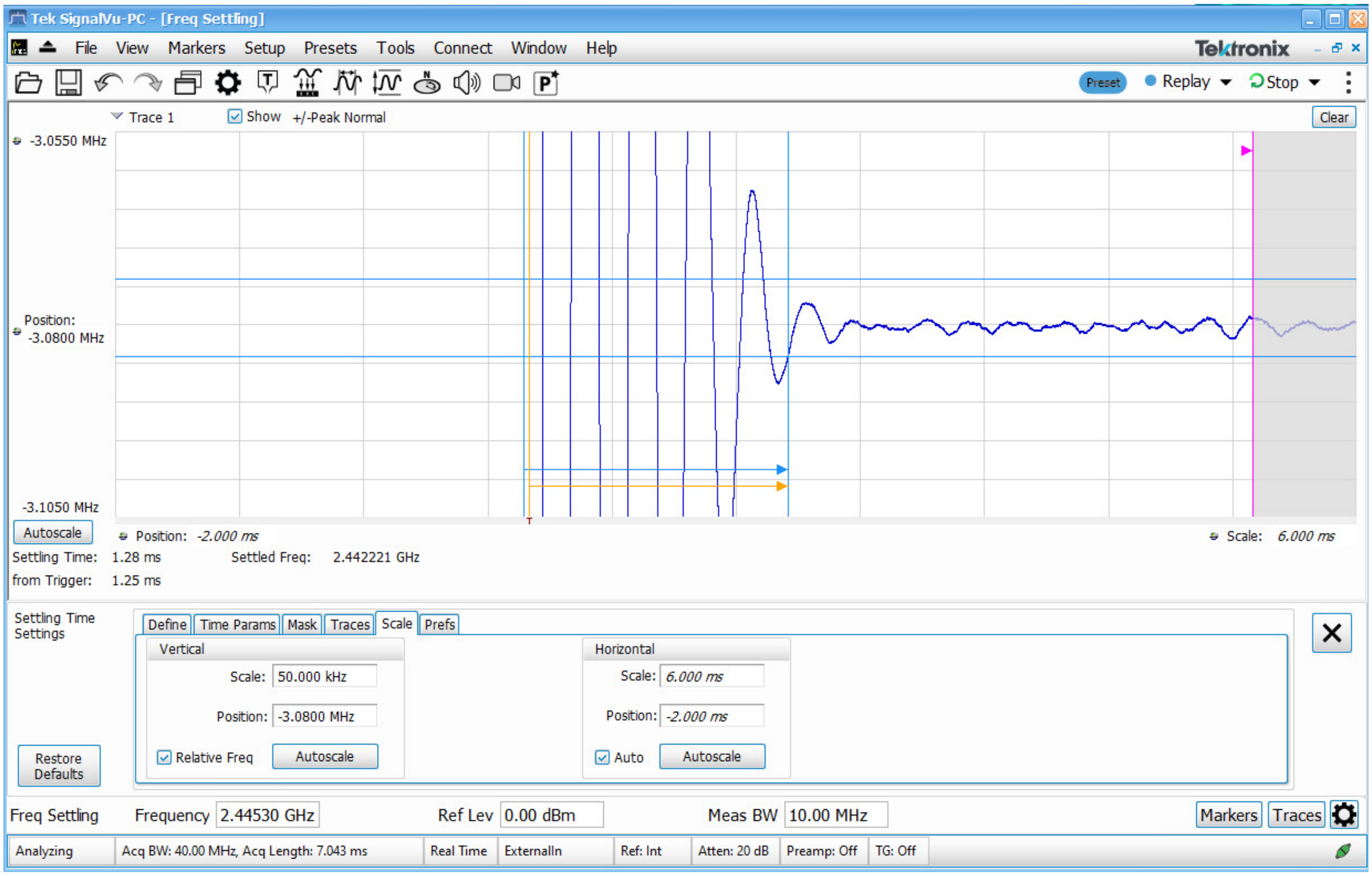

Figure 11. Zooming in vertically to observe tighter tolerance band.

The display resolution is not sufficient to allow us to see the width of the tolerance bands and the trace sitting between them. So, we will adjust the vertical scale to zoom in on this portion of the display. **Figure 11** shows the overall vertical scale adjusted to 5 kHz/div (50 kHz range). We can now see the tolerance band and the frequency vs. time trace within it.

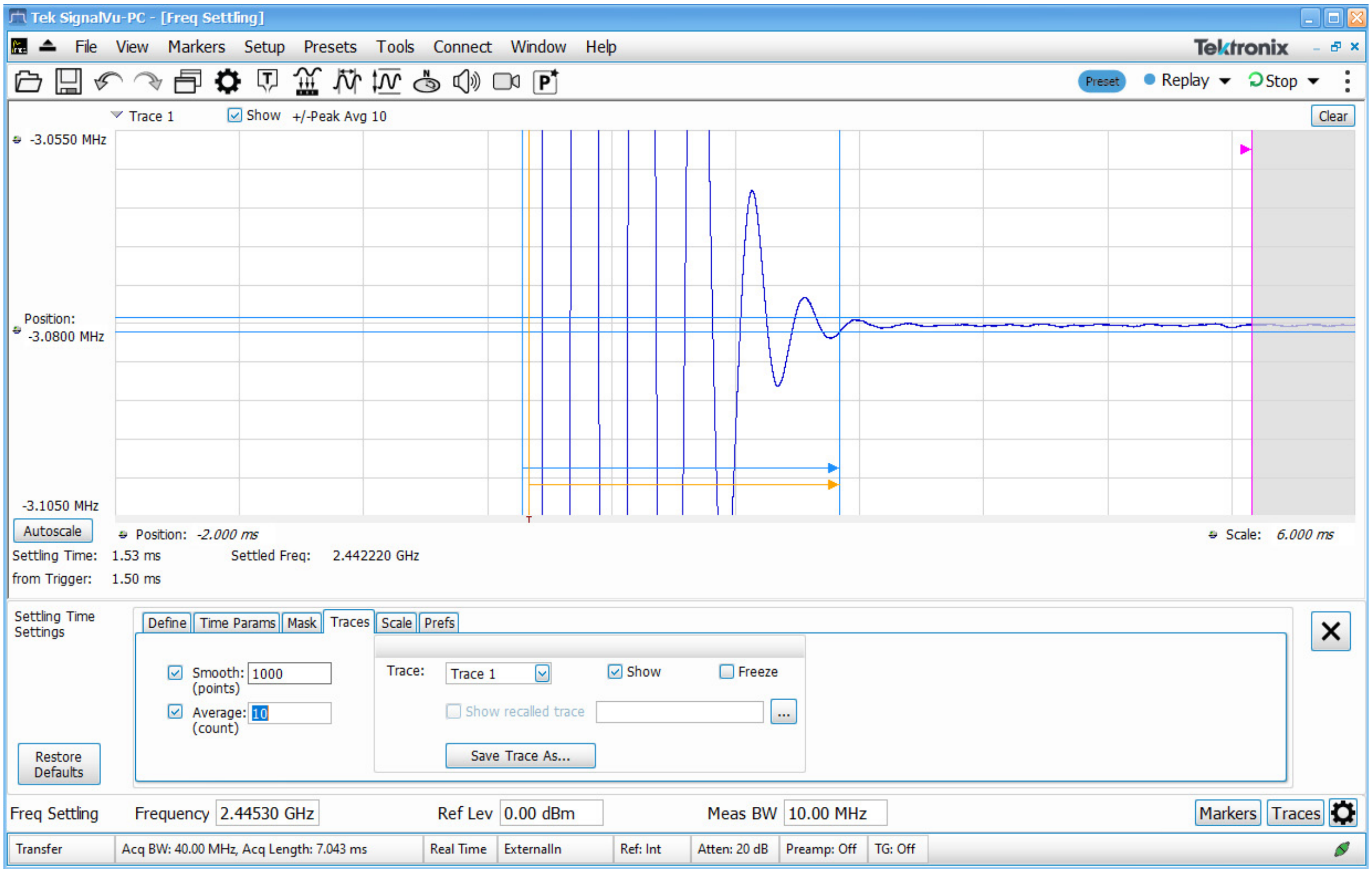

Figure 12. Adding trace averaging to further reduce uncorrelated noise on trace.

The live display is showing some noise/variation in the settled response. The random variation of this can be averaged away assuming that each triggered event is repeatable. **Figure 12** shows the result of adding ten time-domain averages to the result to reduce the random variation in the settled behavior. This allowed us to reduce the tolerance from ±5 kHz down to ±1 kHz.

The optimization techniques employed thus far have allowed us to improve the settled frequency measurement tolerance from ±500 kHz down to ±1 kHz, a 500× improvement!

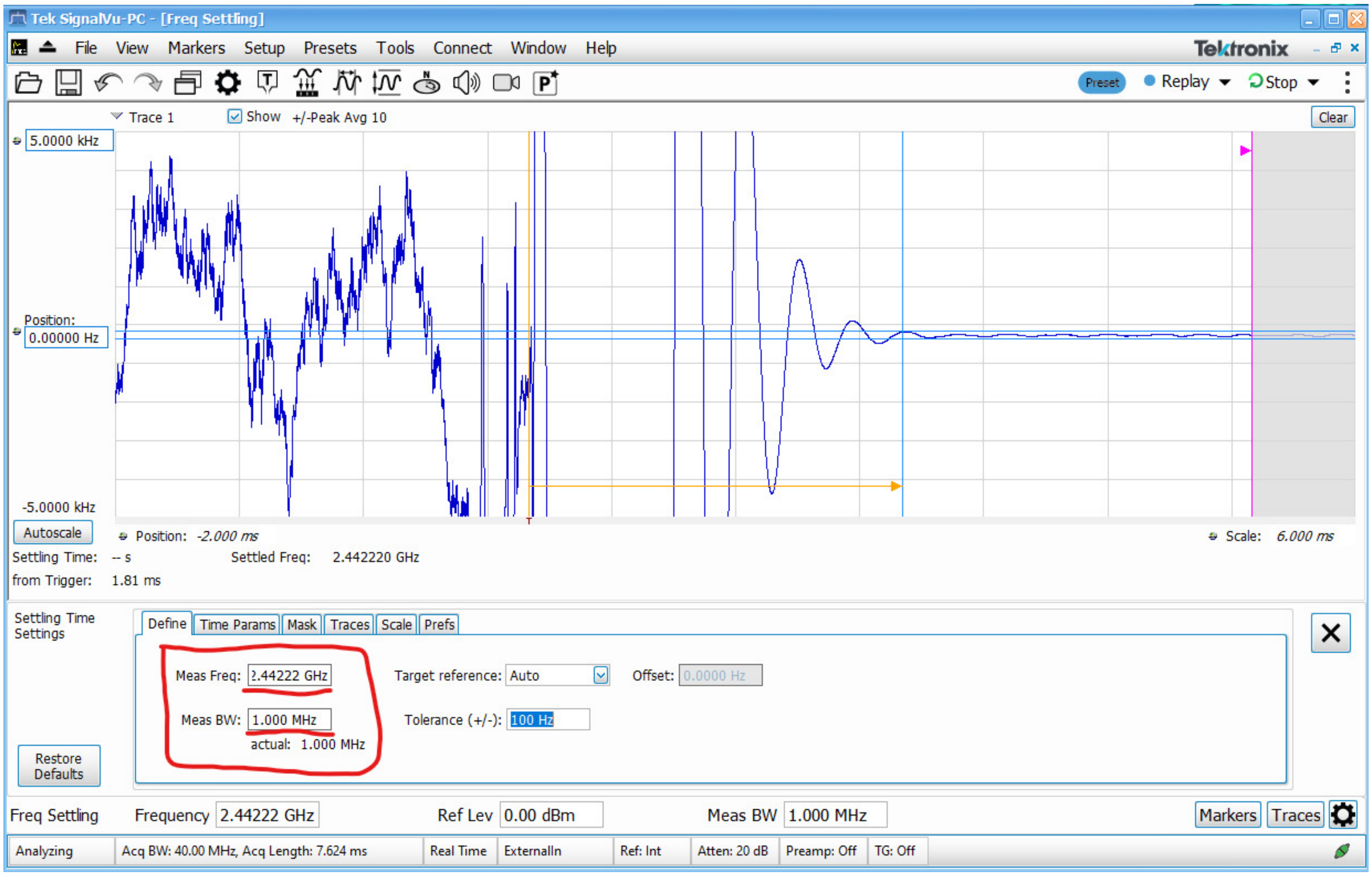

Figure 13. Adjustment of measurement frequency and bandwidth.

The measurement requirement in this case is to determine the settling time from the Trigger event (not from the starting frequency). This opens the possibility of further reducing the Measurement BW to lower the noise on the trace even further since the measurement BW does not need to include the starting frequency. Two adjustments are required. First, we adjust the Meas Freq. to be equal (or close to) our settled frequency, which is 2.44222 GHz in this case. This will then allow us to further reduce the measurement bandwidth around this re-adjusted measurement frequency. **Figure 13** shows the Meas Freq adjusted to 2.44222 GHz and the Meas BW reduced to 1MHz. This reduced the variation on the settled portion of the trace sufficiently to allow the measurement Tolerance to be reduced to ±100 Hz. The result shows that the signal takes 1.81ms from the trigger to settle to within ±100 Hz of the final frequency.

Optimization of the acquisition and measurement parameters of the Frequency Settling time measurement can yield tremendous improvements in the precision of the final settled tolerance. The example illustrated here shows a frequency transition of about 6 MHz on a 2.445 GHz signal, where the settling was measured to a tolerance of ±100Hz of the final frequency. This represents a 5,000× improvement over the achievable tolerance from the “default” starting settings.

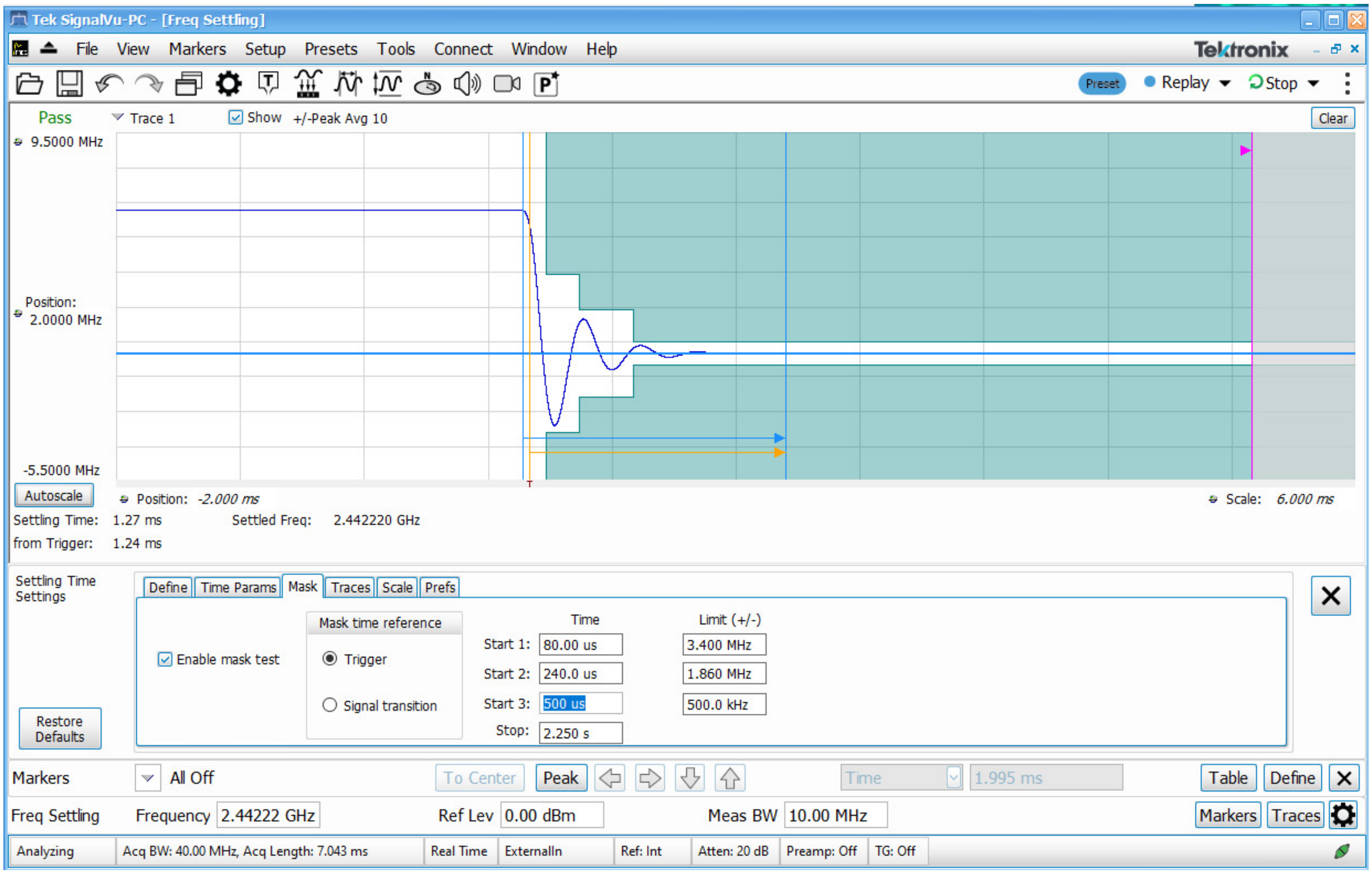

Figure 14. Mask testing adds additional pass/fail criteria.

Addition pass/fail test criteria can optionally be setup using the Mask Test functionality. You can setup up to three mask "corners" to be applied to the measured frequency vs time trace to limit test the transient behavior of the signal.

Conclusion

Frequency settling time is an essential measurement in the design and evaluation not only of RF synthesizers but also programmable oscillators, phase locked loop circuits, and more. Here the steps taken to reduce the noise/variation on a demodulated frequency vs time trace narrowed the tolerance band and made it possible to measure the settled frequency, a process made easier by taking advantage of the settling time option for Tektronix Real-Time Spectrum Analyzers and SignalVu-PC software (for analyzers and oscilloscopes).

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