Comparing the Traditional Oscilloscope FFT to Spectrum View Spectrum Analysis for Measuring Power Supply Control Loop Frequency Response

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New Tektronix oscilloscopes incorporate spectrum analysis using digital downconverters in each channel. The resulting displays and associated measurement data are called Spectrum View. Using Spectrum View to generate Bode plots for power supply control loop frequency response analysis results in improved frequency resolution compared to conventional FFTs.

Although frequency response analysis has often been performed using dedicated equipment, newer oscilloscopes may be used to measure the response of a power supply control loop. Often this analysis is referred to as Bode plotting after Hendrik Wade Bode. Traditionally, this analysis has used an FFT algorithm to measure the gain and phase of the system over a frequency range of interest. Several new oscilloscopes, for example the 4, 5 and 6 Series MSOs, employ dedicated digital downconverters on all channels that operate independently of time-domain sample rate and record length. This capability is called “Spectrum View” to distinguish it from the traditional FFT, and it can be applied for improved results in frequency response analysis. This white paper compares Bode plots (also known as control loop response) using both traditional FFTs and Spectrum View for two different devices under test (DUTs).

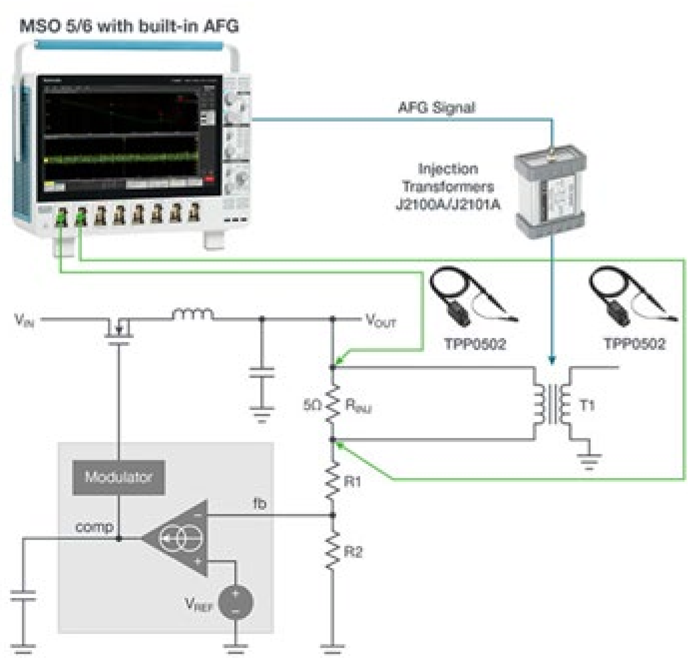

Figure 1. The test system used in this white paper uses a 6 Series MSO with built in function generator, a Picotest J2101A Injection Transformer, and TPP0502 low-attenuation passive probes.

Control Loop Response

An ideal power supply responds quickly to load changes and maintains a constant output, without excessive ringing or oscillation. An unstable power supply can oscillate, resulting in very large apparent ripple at the bandwidth of the control loop. Control loop measurements characterize how a power supply responds to changes in load conditions.

Measuring control loop response involves the injection of a stimulus over a range of frequencies into the feedback path of the control loop. Measurements of gain and phase are made at each frequency and presented in a Bode plot. The Bode plot maps the frequency response in two graphs – the Bode magnitude plot (expressing the magnitude in decibels) and the Bode phase plot (expressing the phase shift in degrees).

Using an oscilloscope, signal source and automation software as shown in Figure 1, Bode plots can be quickly generated making it easy to evaluate margins and compare circuit performance to models. By measuring the actual gain and phase of the circuit over a range of frequencies, one can gain confidence in the stability of the design – greater than relying on simulation alone.

FFT and Spectrum View on 4, 5 and 6 Series MSOs

Like most modern digital oscilloscopes, 4/5/6 Series MSOs provide a basic math FFT for visualizing the frequency-domain representation of analog inputs, as well as math and reference waveforms. This is a “traditional FFT” and is included in the 4/5/6 Series to maintain consistency with other oscilloscopes. However, the 4, 5 and 6 Series also add “Spectrum View” spectrum analysis which takes advantage of distinct digital signal paths and digital downconverters to deliver better results.

Traditional oscilloscope FFTs have shortcomings. They rely on time domain acquisition parameters such as sample rate and record length to make adjustments. Tradeoffs between sample rate and record length often make it impossible to achieve desired combinations of frequency resolution and span.

Spectrum View in the 4, 5 and 6 Series MSOs uses digital downconverters (DDCs) and an acquisition system independent of time domain sample rate and record length controls. This provides:

- Independent time and frequency domain controls
- Familiar center frequency, span, and resolution bandwidth (RBW) controls for spectrum analysis
- Time-correlated displays of any or all analog channels in both the time and frequency domains

Oscilloscope-based System for Measuring Control Loop Response

A system for measuring the loop response of a power supply consists of:

- Oscilloscope
- Power Measurement and Analysis Software
- Integrated Function Generator
- Injection Transformer
- Low attenuation probes

The Tektronix 4/5/6-PWR Power Measurement and Analysis application automates control loop response measurements. (It also automates impedance measurements and power supply rejection ratio measurements. Spectrum View spectrum analysis provides similar performance improvements to other frequency response analysis, but these are outside the scope of this white paper.)

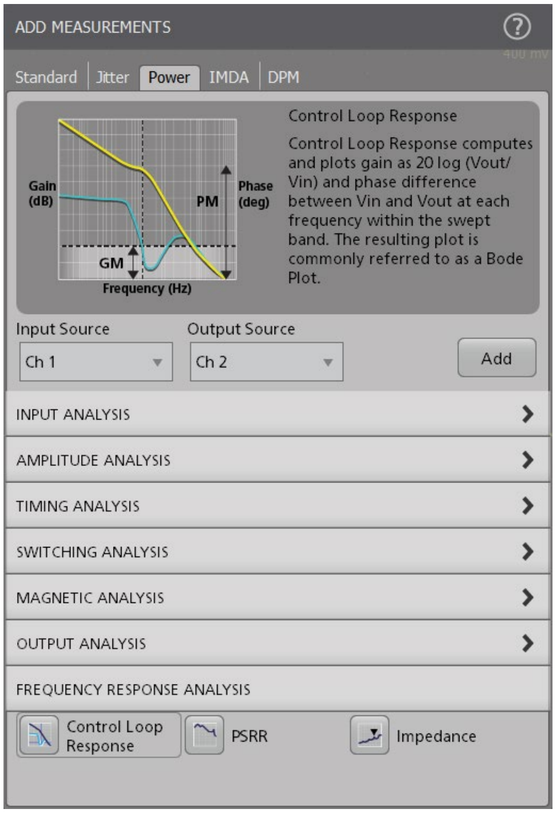

Figure 2. Selecting control loop response measurements from the Advanced Power Measurement and Analysis (4/5/6-PWR) option.

To stimulate the control loop, a function generator is used to inject a signal into the loop's feedback across a low-value injection resistor (5-10 Ω), as shown in Figure 1. An injection transformer with a flat response over a wide bandwidth is connected across the injection resistor and isolates the grounded signal source from the power supply. Two probes, applied across the injection resistor, provide all the information the analysis software needs. They measure the stimulus and response amplitudes to calculate gain and measure the phase delay between stimulus and response.

In this white paper the Arbitrary/Function Generator (AFG) option in the 4/5/6 Series is used to generate sinewaves over a specified range of frequencies. The injection transformer should be chosen based on the frequency of interest. The Picotest J2101A Injection Transformer has a range of 10 Hz–45 MHz which aligns well with the function generator option for the 4/5/6 Series MSO. Picotest also offers a J2100A injection transformer for use when frequencies are in 1 Hz to 5 MHz range. TPP0502 low capacitance, low attenuation passive probes are used for the voltage measurements. This enables measurements with vertical sensitivity of 500 µV/div on the 6 Series MSO, or 1 mV/div on 4 and 5 Series MSOs.

Configuring the Measurement

The measurements are configured in the power analysis package, as shown in Figure 3. Note the "Analysis Method" setting. This allows one to choose between a traditional FFT and Spectrum View. The comparison of these two methods forms the basis of this white paper.

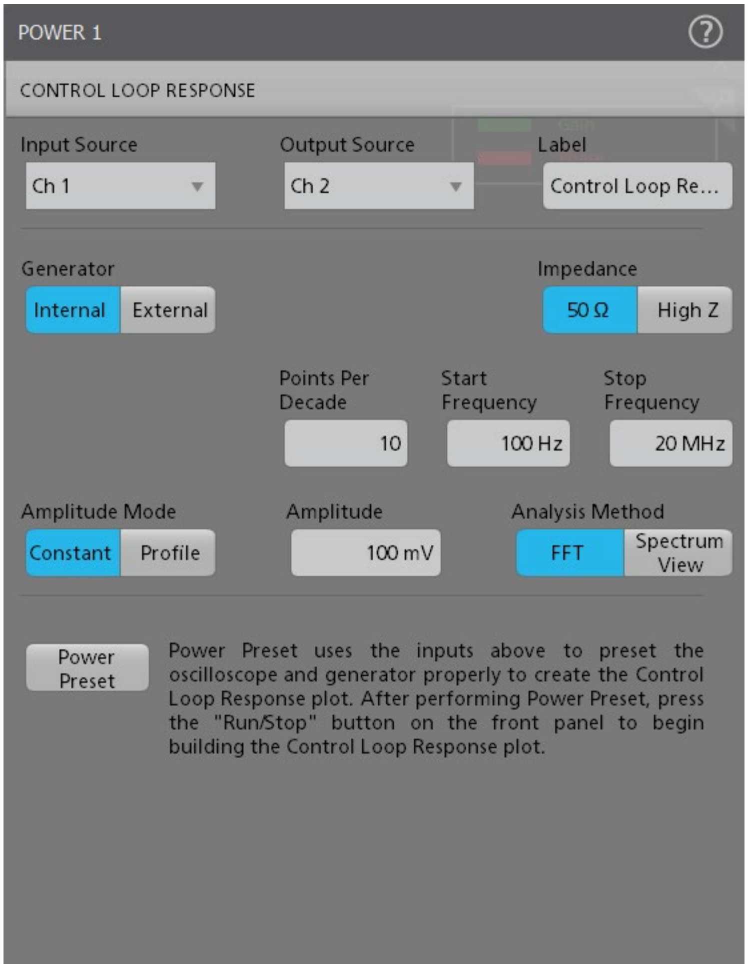

Figure 3. Settings for generating a Bode plot include start and stop frequencies, step size, and a number of other settings.

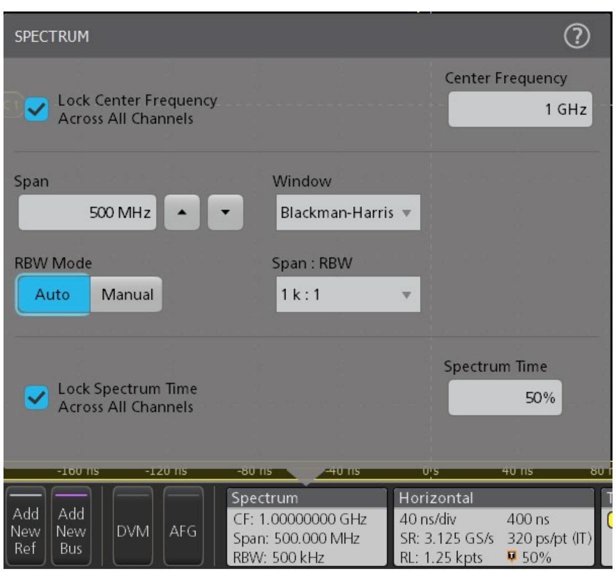

Figure 4. Setting Spectrum View spectrum analysis.

Case 1: ST Microelectronics STEVAL-ISA207V1 Buck Converter

In this first case study, an STEVAL-ISA207V1 step-down switching power supply evaluation board was used as a DUT. The probe connections are shown in the image below.

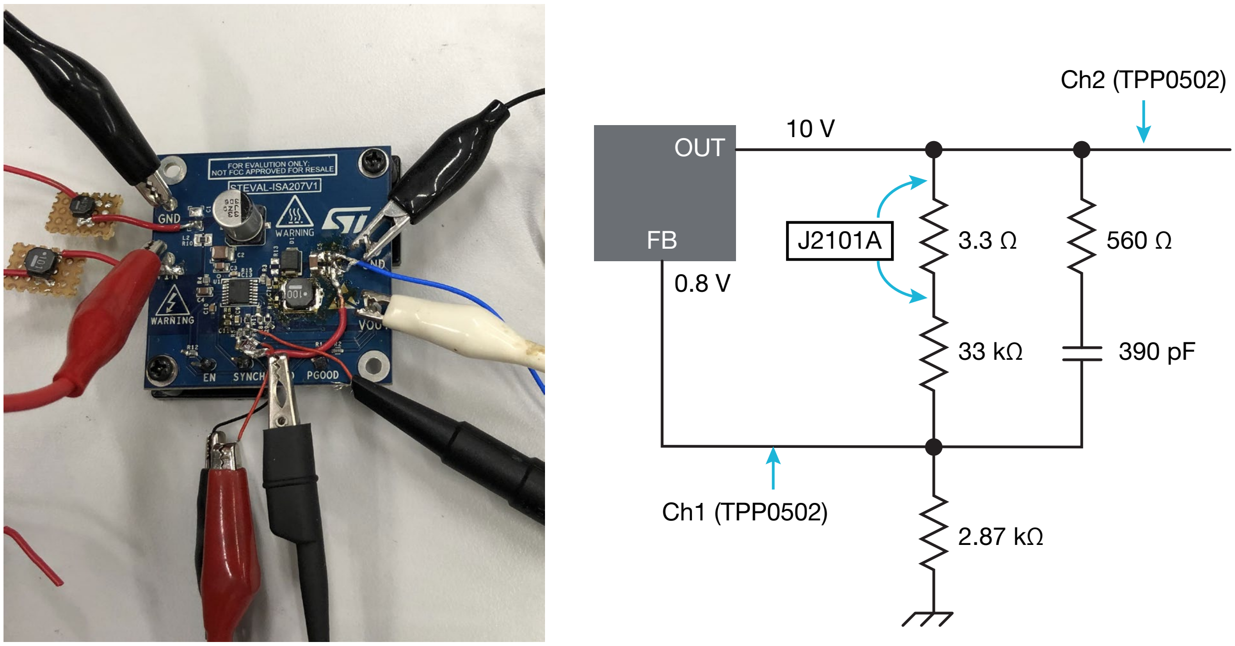

Figure 5. Test connections for measuring control loop response on an STEVAL-ISA207V1 Buck Converter.

Frequency Response Measurements using the Traditional FFT Method

Once the setup is ready, a Control Loop Response measurement was selected and configured to use the internal AFG to generate a stimulus. Key settings were:

- Start frequency: 10 Hz
- Stop frequency: 1 MHz
- Points per decade: 20
- Stimulus amplitude: Constant at 2.5 Vpp

The Power Preset button was clicked to clear the previous results and configure the oscilloscope. The measurement was run, and phase and gain curves were plotted on the oscilloscope display. Measurement results are shown in Figure 6. When the green trace crosses the 0dB line, the phase margin is displayed. When the red trace crosses the 0° threshold, the gain margin is displayed. Note that with the FFT approach, the phase plot has some irregularities in the trace. This is mainly due to limitations in the ability to resolve frequencies.

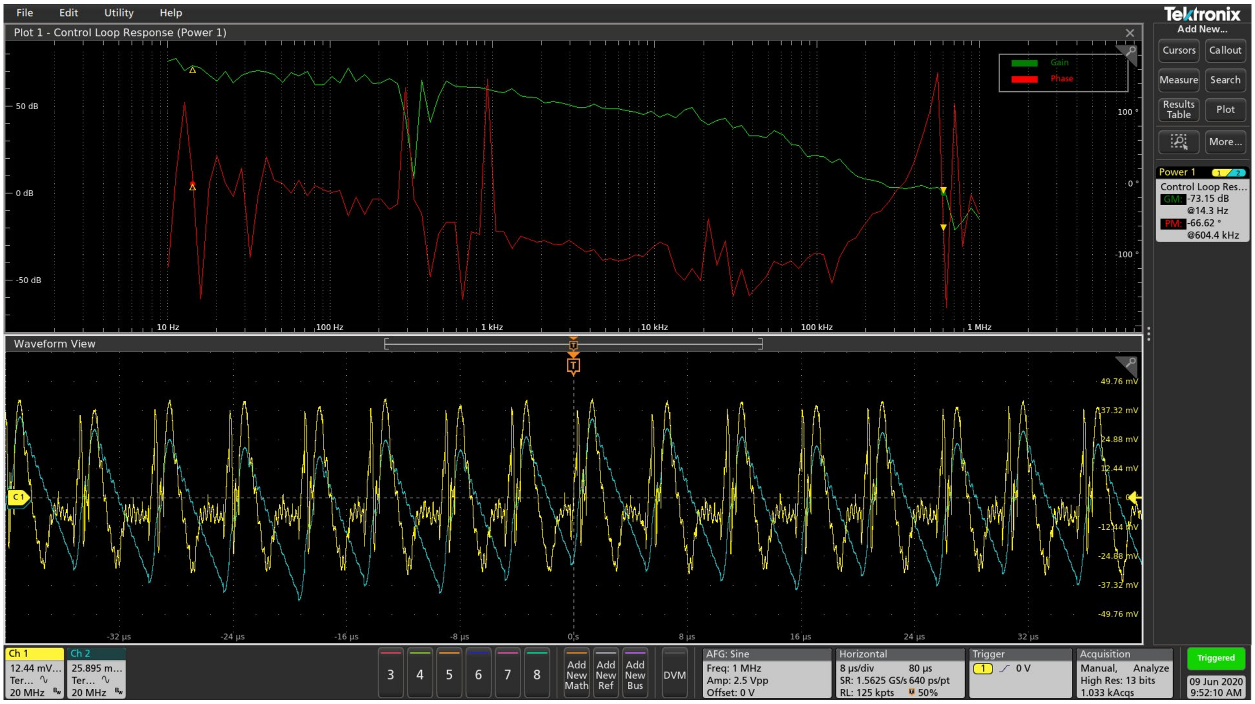

Figure 6. Control Loop Response using FFT Method. Irregularities in the phase trace are mainly due to limitations in the ability to resolve small frequency differences.

Frequency Response Measurements using Spectrum View

The test was re-run using Spectrum View spectrum analysis which uses digital downconverters built into the oscilloscopes. In the Control Loop Response configuration, the Analysis Method is set to Spectrum View. All other settings were retained from the FFT method and Power Preset was clicked. Spectrum View spectrum analysis was set as follows:

- RBW: 100 Hz
- Span: 10 MHz

The front-panel Run button was pressed to start the test and the phase and gain response curves were plotted as shown in Figure 7. In contrast to the traditional FFT the irregularities in the phase plot have been minimized to a large extent, with a relatively smooth plot from 100 kHz to 10 MHz. This is mainly due to the Spectrum View tool's ability to resolve and measure milli-hertz frequencies.

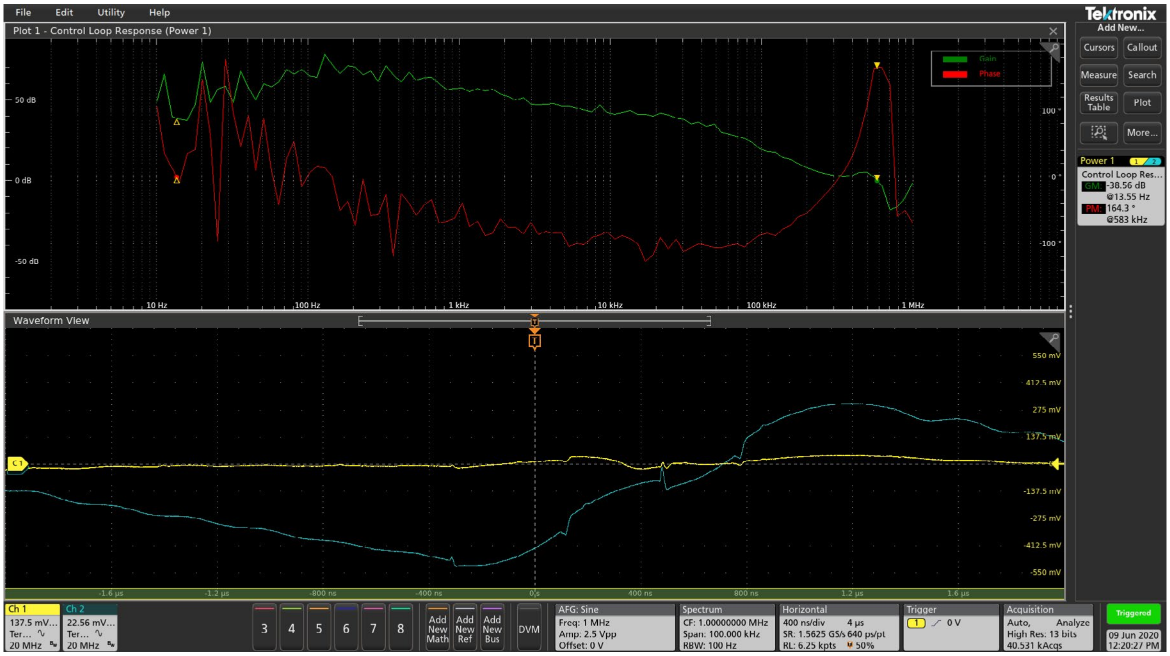

Figure 7. Control loop response using Spectrum View Method at RBW = 100 Hz setting.

By further lowering the Spectrum View RBW settings, the frequency resolution can be further refined, and the response curves can be smoothed. This is shown in Figure 8 where the response curves, with RBW reduced to 10 Hz, are relatively smooth from 1 kHz to 100 kHz.

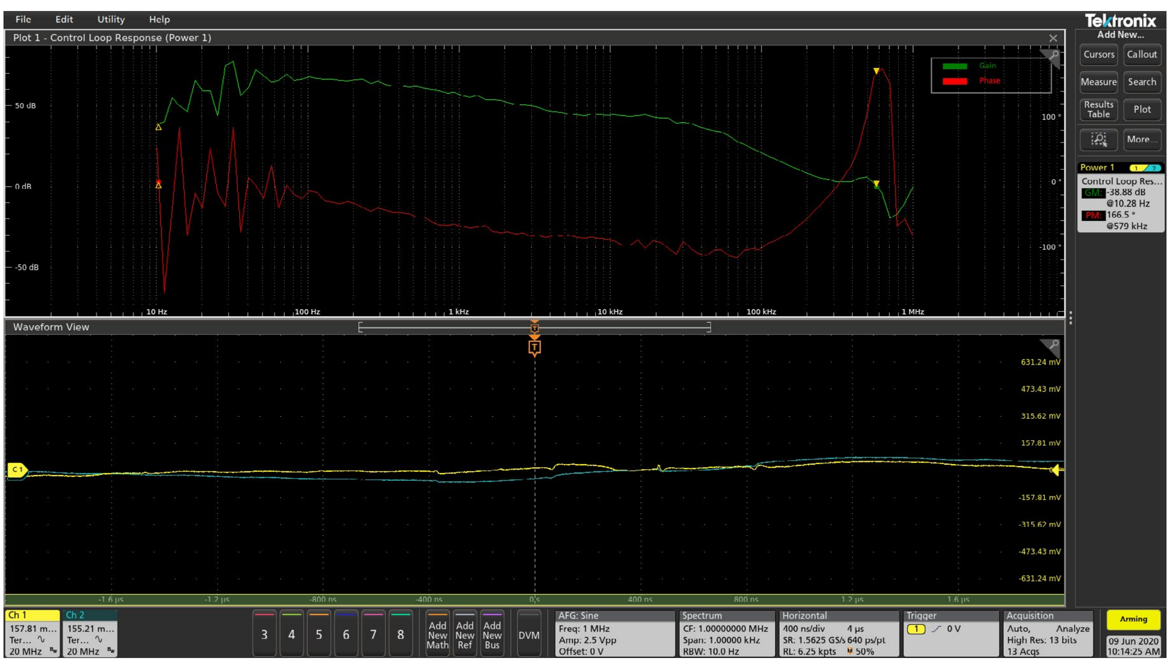

Figure 8. Control loop response using the Spectrum View method with RBW set to 10 Hz.

Case 2: Picotest VRTS3 demo board

For the second case, the loop response of a point-of-load voltage regulator on a Picotest VRTS3 demonstration board was measured.

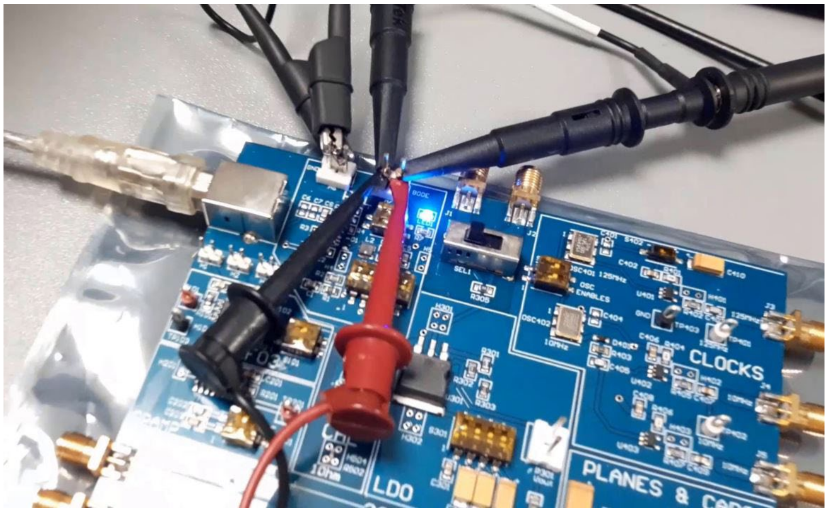

Figure 9. Probing for control loop response measurement on a Picotest VRTS3 demonstration board.

Frequency Response Measurements using the Traditional FFT Method

First, control loop response measurements were run using the traditional FFT method with the following settings:

- Start frequency: 100 Hz
- Stop frequency: 1 MHz
- Points per decade: 20
- Stimulus amplitude: Constant at 400 mVpp

As in the first case, using the traditional FFT results in variations in the gain and phase plots above 100 kHz (Figure 10).

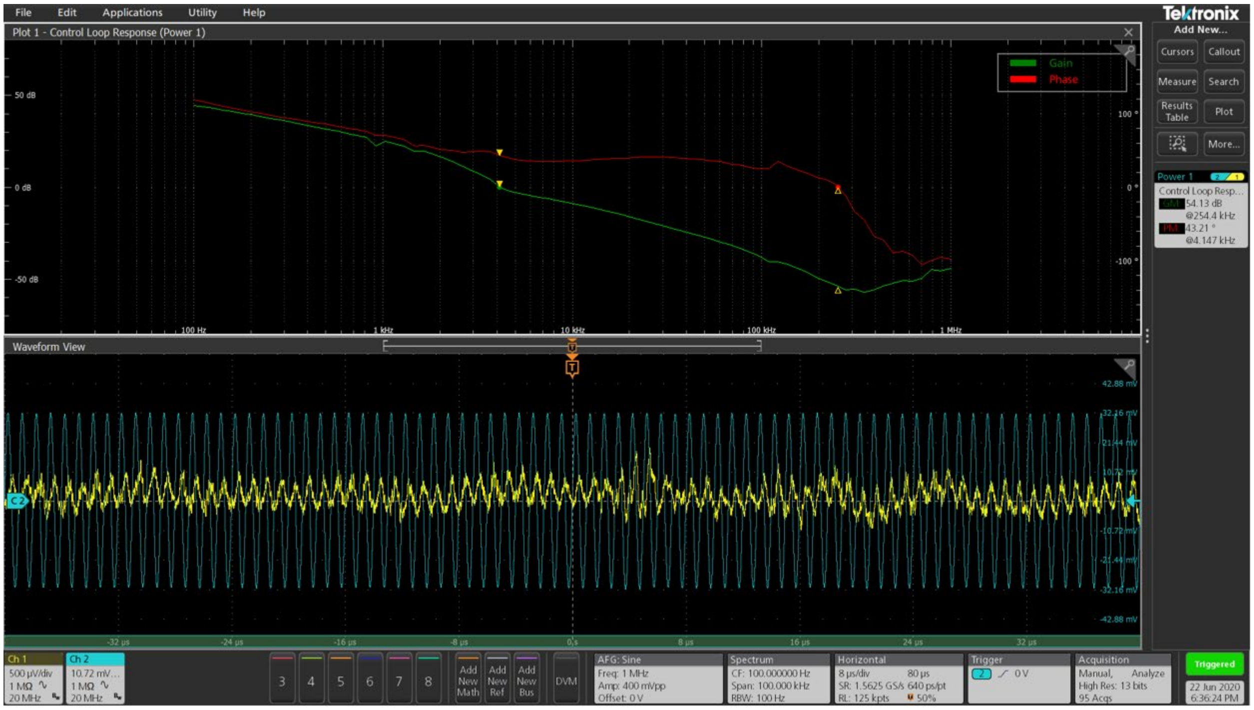

Figure 10. Control Loop Response measurements using the FFT Method with stimulus amplitude of 400 mVpp. Note the variation in the curves above 100 kHz.

Using the Spectrum View method with the RBW set to 100 Hz, these high frequency variations above 100 kHz are smoother and the reported phase margin at 4.1 kHz is much more accurate using the Spectrum View method due to reduced noise.

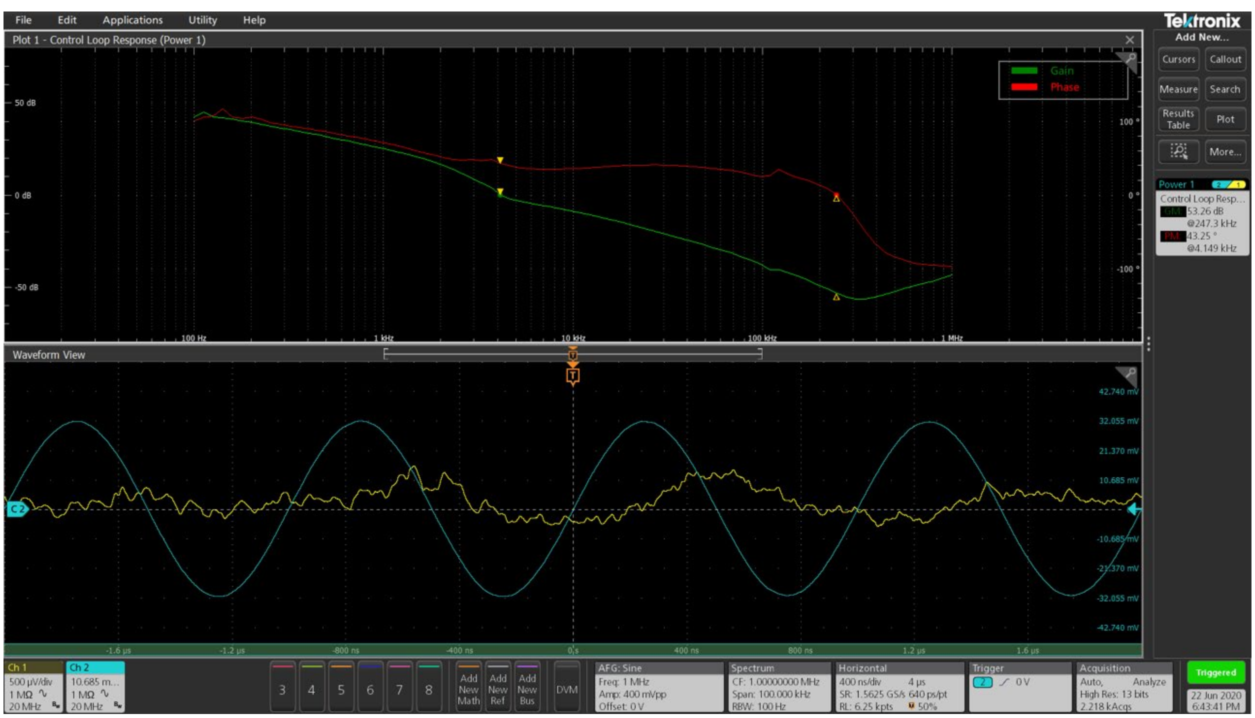

Figure 11. Running Control Loop Response measurement with Spectrum View Method at RBW = 100 Hz.

Frequency Response Measurements using Spectrum View

Next the measurement was run using different settings to confirm that results with Spectrum View are consistently improved. The signal voltage levels were reduced to 100 mVpp:

- Start frequency: 100 Hz
- Stop frequency: 1 MHz
- Points per decade: 20
- Stimulus amplitude: Constant at 100 mVpp

Figure 12 shows the results using the traditional FFT method. Again, the results show variations in the gain and phase margin plots above 100 kHz. Figure 13 shows the results using the built-in downconverters in the instrument (Spectrum View). The results from this run show smoother gain and phase plots at the higher end of the frequency sweep. Higher stimulus amplitude generally provides better results but will cause the DUT to saturate if it is too high. Experimenting with different amplitudes can provide insight into how much injected voltage a DUT can tolerate without saturating.

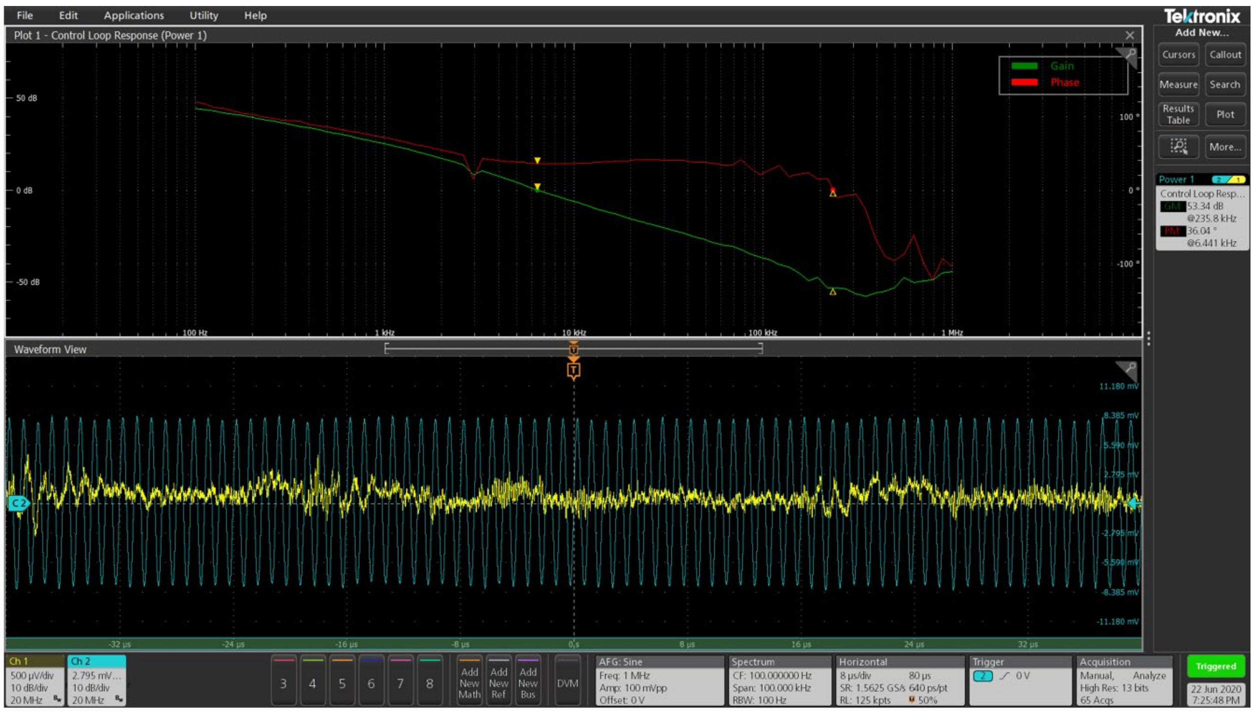

Figure 12. Control loop response measurement with FFT Method and stimulus amplitude set to 100 mVpp. Variations in the gain and phase plots occur above 100 kHz.

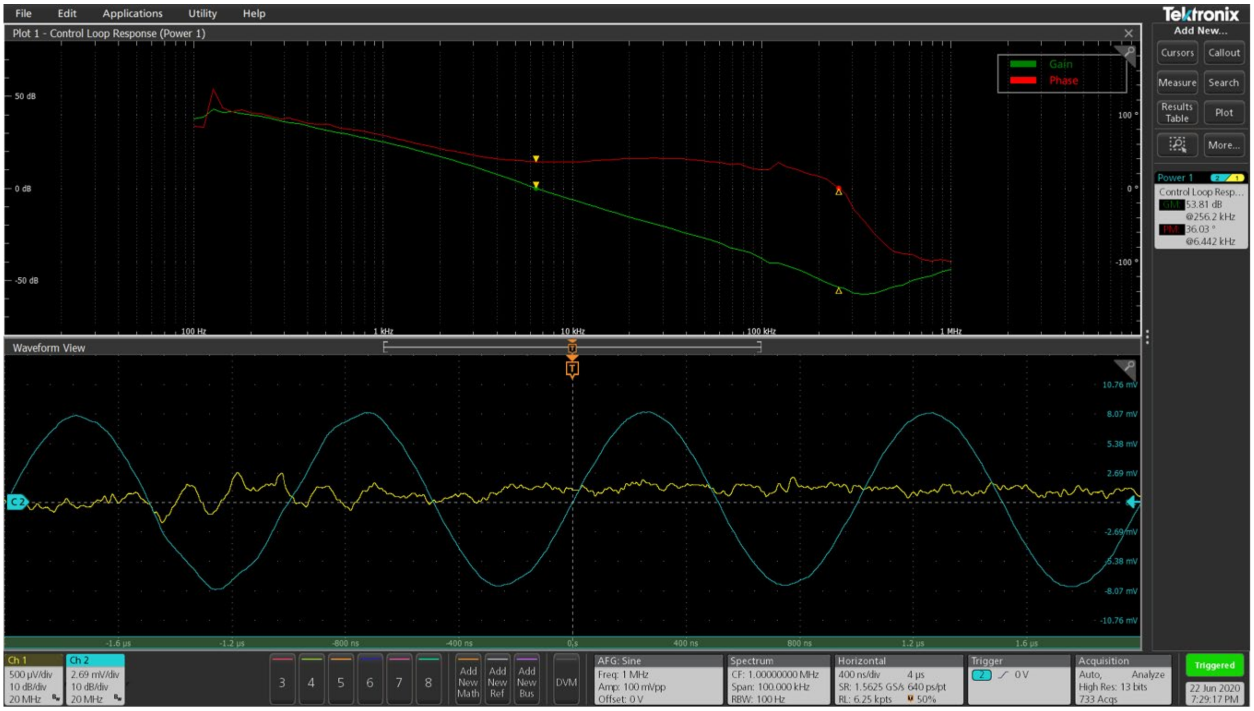

Figure 13. Control loop response measurement with Spectrum View Method at RBW = 100 Hz and stimulus amplitude of 100 mVpp.

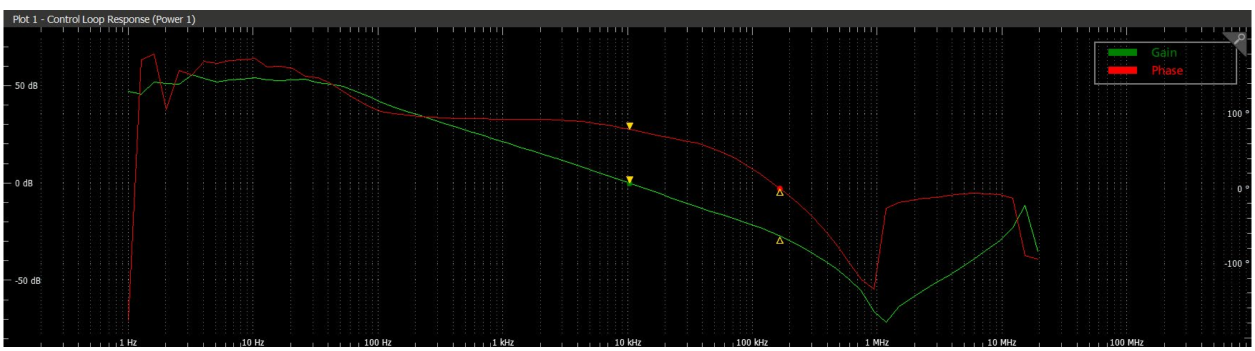

Figure 14. Control loop response measurement with Spectrum View method starting from 1 Hz. Note that the discontinuity at 1 Hz is due to phase wrapping at 180° = 0°.

In addition to providing better resolution, with the Spectrum View approach, we can start the analysis from as low as 1 Hz as shown in Figure 14. This is not practical with the traditional FFT.

Figure 15. Control loop response measurement with Spectrum View method starting from 10 Hz with the Spectral View window turned on during the execution.

The spectral window supported by the Spectrum View tool provides an insight into the dominant swept frequency for both input and output signals. This helps to observe if the swept frequency is stable or noisy.

Summary

Examples with two different DUTs, and at different signal settings have demonstrated that using the traditional oscilloscope FFT produces variation in the gain and phase curves due to constraints in frequency resolution. Using Spectrum View spectrum analysis, we have seen much lower variations at both higher and lower frequencies. The ability to use lower RBW settings, independent of time-domain sampling, enables finer frequency resolution for more precise gain margin and phase margin values. In short, the independence of Spectrum View spectrum analysis from time domain acquisition parameters and dedicated downconverters provide more stable, and repeatable results for control loop analysis and frequency response analysis in general. It enables 4/5/6 Series MSO oscilloscopes to achieve results comparable with vector network analyzers (VNAs) and frequency response analyzers in power supply control loop analysis.

References:

Spectrum View: A New Approach to Frequency Domain Analysis on Oscilloscopes; https://www.tek.com/document/application-note/spectrum-view-new-approach-frequency-domain-analysis-oscilloscopes