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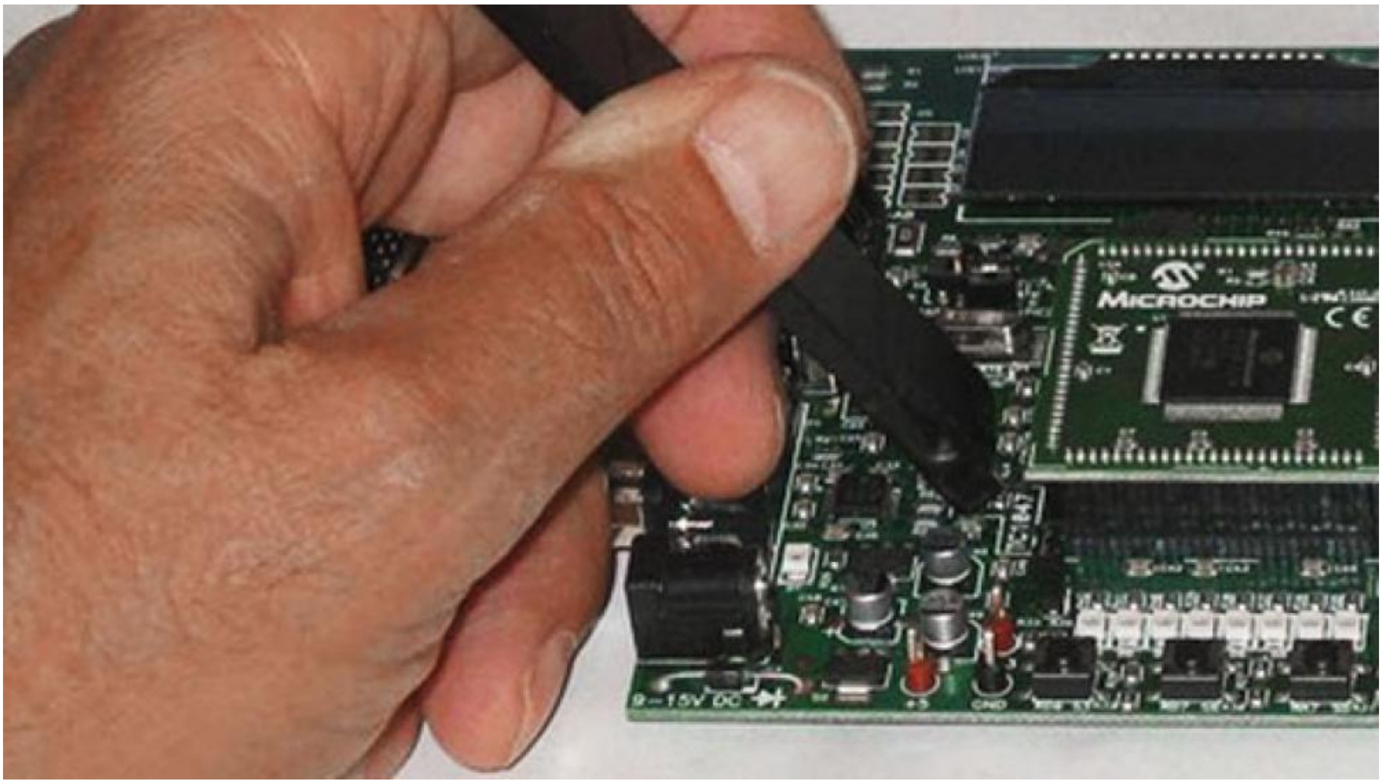

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Software Enables Accurate Stability Test, Improves Non-Invasive Phase Margin Measurement Accuracy

Many articles and application notes have come out in recent years discussing the assessment of stability without access to the control loop, since the method was introduced 2011. The method has proven to be a popular and simple technique to determine the phase margin of voltage references, linear and switching regulators, op-amps, class D switching amplifiers, and input filters.

Steve Sandler, Picotest | Apr 23, 2014

The mathematics behind the non-invasive measurement was incorporated into the OMICRON Lab Bode 100 VNA software, sold by Picotest.com, starting in late 2011. The solution was included as a single cursor based measurement utilizing a piecewise linear approximated solution. The approximate solution is most accurate below 40 degrees, while the method is capable of accurately determining phase margins up to nearly 70 degrees.

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Thanks to the completion of a license agreement with OMICRON Lab, the Bode Analyzer Suite V2.43 now includes the exact solution, improving the accuracy for measurements at higher phase margin values. While there are small measurement errors due to interpolation, measurement noise, and even the accuracy of the Bode plot measurement, the Bode and non-invasive results are generally within 1 degree accuracy.

As noted in [1] , the phase margin can be determined from an output impedance measurement on a VNA, which is then converted to group delay. This is because the phase margin is related to the Q factor and through the group delay information a conversion can be made to phase margin.

One Cursor or Two

The new implementation now includes a two-cursor (newer, more accurate) measurement in addition to the one cursor (current method). This may present some confusion, but the measurement is still easy to perform and non-invasive. The determination as to whether to use one cursor or two is simple.

The new exact 2 cursor math is more precise and most accurate above approximately 40 degrees. At higher phase margins, the impedance peak and group delay Q peak tend to separate, and the separation is used to improve the accuracy of the result for higher phase margin conditions. Therefore, using one cursor still results in a very reasonable approximation, the second cursor simply improves the accuracy, especially at higher phase margin.

Example 1

In this first example, a voltage regulator is paired with a ceramic capacitor resulting in a phase margin of approximately 25 degrees as shown in ***Fig. 1***.

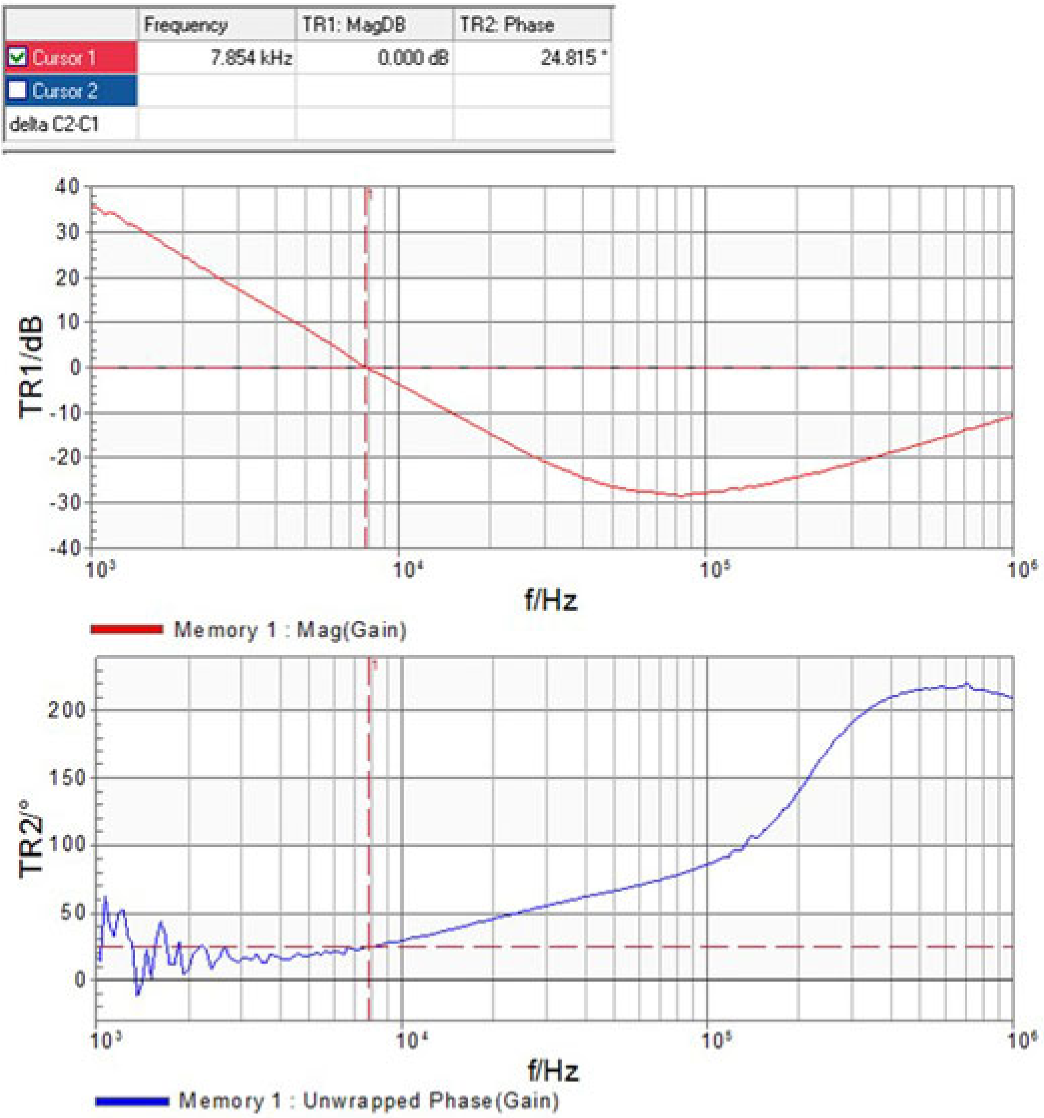

Fig. 1. LM317 voltage regulator at 25mA with a ceramic output capacitor resulting in a 24.8 degree phase margin. (Simulation courtesy AEi Systems.com).

The output impedance and Q of the group delay for the same regulator operating in the same conditions is shown in ***Fig. 2***. Note that since the phase margin is very low and the Q and impedance peaks occur at the same frequency. In this case, a single cursor measurement provides an accurate result and the two cursor measurement provides the exact same result.

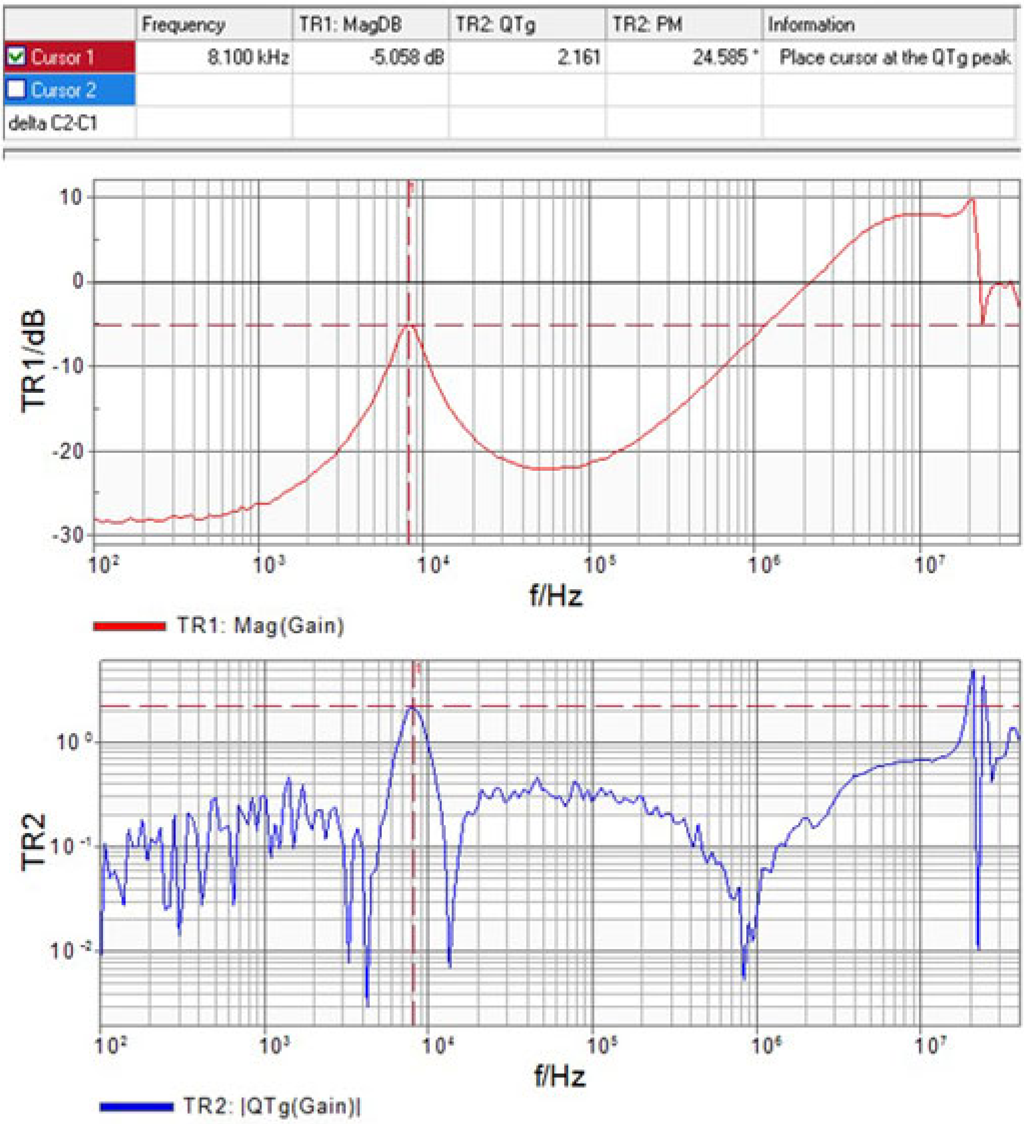

Fig. 2. Output impedance (top) and group delay Q (bottom) for the same regulator as in Fig. 1. The signal cursor measurement result is shown at the top. (Simulation courtesy AEi Systems.com).

Example 2

In this second example, the same voltage regulator is paired with a tantalum capacitor resulting in a phase margin of approximately 53 degrees as shown in ***Fig. 3***.

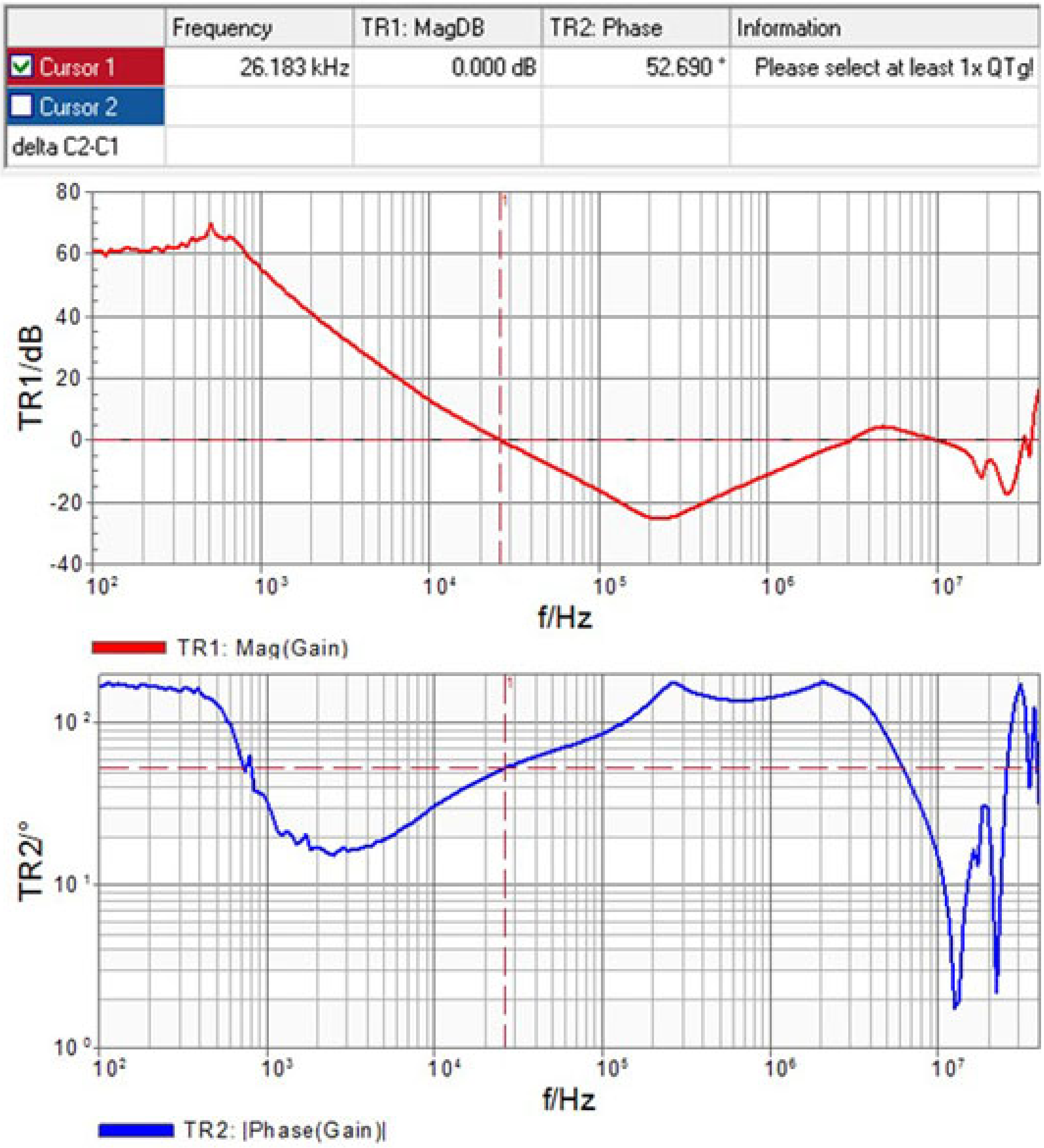

Fig. 3. The same LM317 operating at 25mA is paired with a tantalum capacitor resulting in a phase margin of approximately 53 degrees. (Simulation courtesy AEi Systems.com).

	Frequency	TR1: MagDB	TR2: QTg	TR2: PM	Information
Cursor 1	19.157 kHz	-2.824 dB	696.206 m	60.689 °	Place cursor at the QTg peak
Cursor 2					
delta C2-C1					

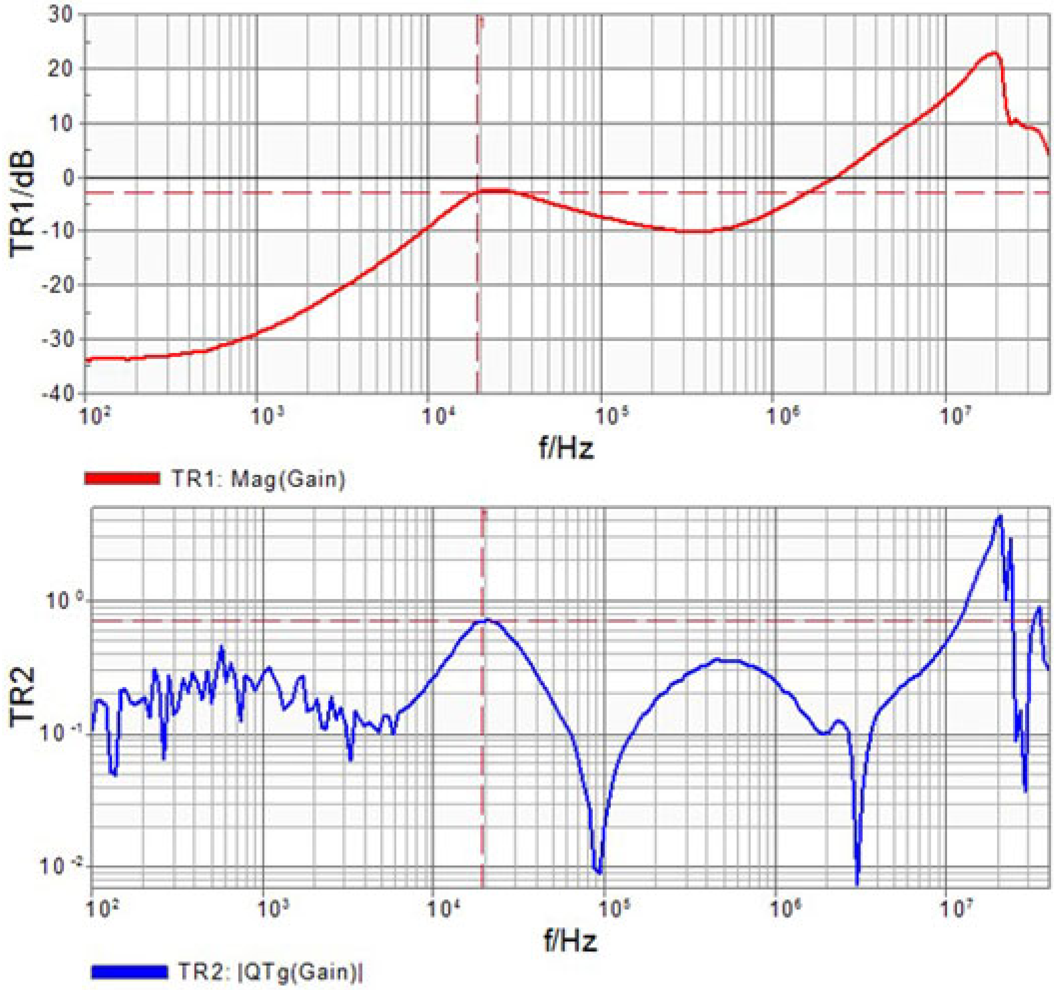

Fig. 4. The single cursor measurement places the cursor at the peak of the Q(Tg) curve and displays the phase margin as 60.7 degrees, which is slightly greater than 10% error. (Simulation courtesy AEi Systems.com).

The output impedance and Q of the group delay for this condition is shown in **Fig. 4**. Since the phase margin is much higher the Q and impedance peaks occur at different frequencies. The result from a single cursor measurement is shown in ***Fig.*** *4*. The non-invasive phase margin error is more than 10% in this case. The two cursor measurement result is shown in ***Fig. 5***. Note that using two cursors the 2 cursor result is within approximately 1 degree of the Bode plot derived phase margin or better than 2 percent.

	Frequency	TR1: MagDB	TR2: QTg	PM:	Information
Cursor 1	24.085 kHz	-2.235 dB	662.649 m	53.403 °	Place Cursor 1 at the MagDB peak
Cursor 2	19.157 kHz	-2.824 dB	696.204 m		Place Cursor 2 at the QTg peak
delta C2-C1	-4.928 kHz	-0.589 dB	33.555 m		

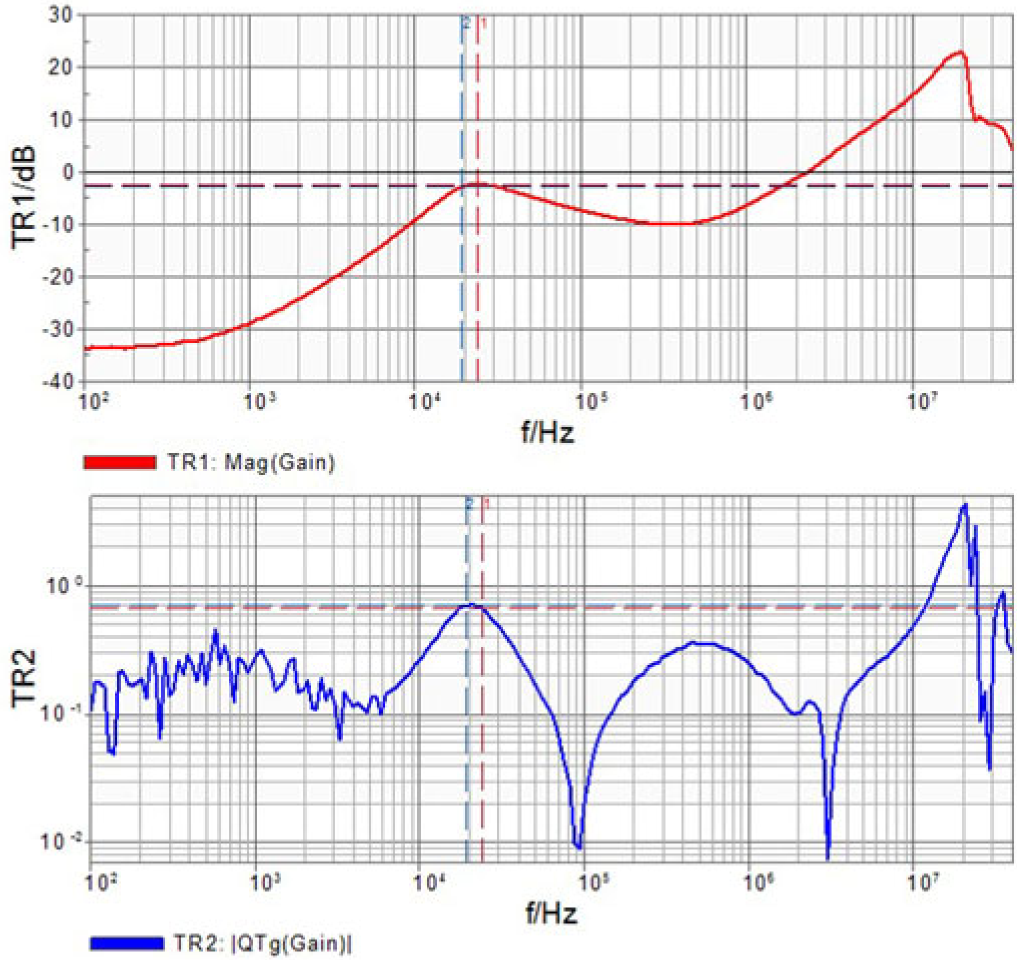

Fig. 5. Using the two cursor method improves the result, with a phase margin result of 53.4 degrees, within approximately 1 degree of the Bode plot result, or less than 2%.

Error Terms

The errors between the Bode plot measurement and the non-invasive phase margin measurement are largely due to measurement tolerance errors, and, noise, as well as nonlinearities resulting from the introduction of the injection signals. Another source of error is the limitation of the number of data points used in the measurement. This error can be reduced by increasing the number of data points or by using the ZOOM mode to reduce the frequency range of the measurement so as to only include the two trace peaks.

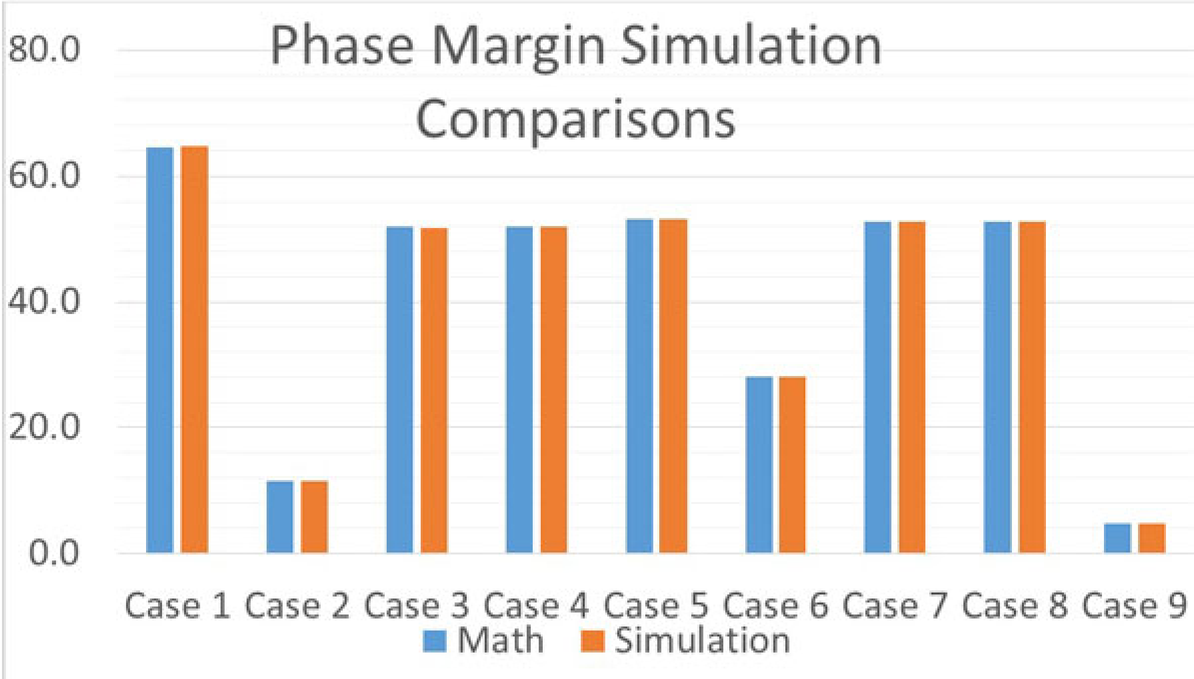

Fig. 6. Graphical comparison of simulated Bode plot and simulated noninvasive measurements. Simulation removes the test related errors.

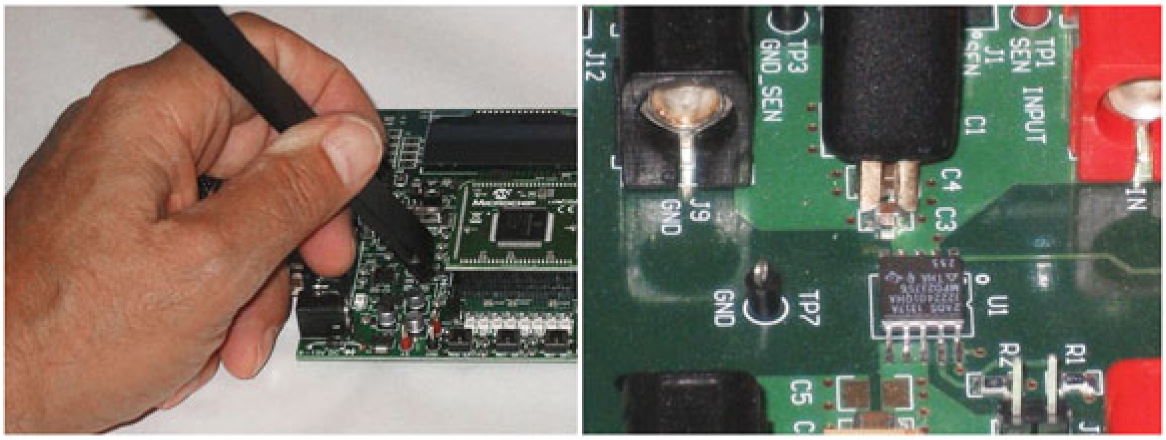

Fig. 7. Picotest's new 50-ohm 1 port and 2 port PDN probes simplify a variety of measurements to today's compact circuitry including PDN impedance, PCB resonances, stability, step load, clock jitter, TDT/TDR, ripple and noise.

We can remove nearly all of these real life error terms by using a simulation model that allows the measurement of both the Bode plot and the non-invasive phase margin measurement. The only errors that exist in the simulation model are related to the number of data points assessed and the interpolation of data between data points. The results of nine simulation cases, spanning phase margins from 5 degrees to 65 degrees, are shown in ***Fig. 6***. They clearly indicate that the basic methodology of deriving the phase margin from the output impedance yields the same result as the direct control loop assessment. The results of ***Fig. 6*** are shown numerically in *Table 1*.

Table 1. Numerical comparison of simulated Bode plot and simulated non-invasive measurements.

Case	Math	Simulation	Abs Error	% Error
1	64.6	64.7	-0.090	0.14%
2	11.5	11.4	0.020	0.17%
3	51.9	51.8	0.052	0.10%
4	51.9	51.9	0.000	0.00%
5	53.2	53.2	-0.020	0.04%
6	28.1	28.1	0.000	0.00%
7	52.8	52.8	-0.010	0.02%
8	53.8	52.8	0.000	0.00%
9	4.8	4.8	0.010	0.21%

With the measurement tolerances, noise and any non-linearity related to the injection signal removed, the average error is reduced to an average of 0.07% or 0.1 degrees. This remaining error is the result of the limited number of data points in the simulation and the interpolation between data points.

Conclusion

The non-invasive phase margin measurement has proven itself to be an invaluable tool using the approximation technique. This improved version now provides an exact solution over a wide range of phase margins from less than 5 degrees to more than 65 degrees. The method does not require access to the control loop, which is often not even available. The noninvasive method works for voltage references, linear and switching regulators, opamps, input filters, and class D switching amplifiers. The only access required is to the device's output pin and ground, which are generally available. In the case of the regulators and voltage references, the output capacitor is a convenient location for the measurement.

The upcoming release of the Picotest 1-port and 2-port PDN probes will further simplify the noninvasive assessment, including all of the necessary connections within a handheld probe.

References

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3. Non-Invasively Assess Your Multiple-Loop LDO's Stability, Steve Sandler , Electronic Design, Jan 7, 2014

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