NISM using the P2102A Probe and E5061B VNA

By Benjamin Dannan and Steven Sandler, Picotest.com

Control loop stability is critical to the performance of all systems, as it influences all closed loop parameters, as well as system noise. Unfortunately, in many instances (particularly in the cases of voltage references, fixed voltage LDOs, and integrated POLs), a Bode plot assessment is not feasible because there is no feedback loop access to the part. In other cases, the feedback loop is difficult to access because the hardware is integrated or would require cutting a printed circuit board (PCB) trace. In yet other cases, the devices either contain multiple control loops (with only one of them being accessible) or the order of the control loop is higher than 2nd order, in which case the Bode plot is a poor predictor of relative stability. A further complication is that in many portable electronics such as cell phones and tablets, the circuitry is very small and densely populated, leaving little in the way of access to the control loop elements. In these cases, the non-invasive stability margin (NISM) assessment, which is derived from easily accessible output impedance measurements, is the only way to verify stability.

NISM computes stability from output impedance [1]. The 2-port shunt-through impedance measurement is the gold standard for measuring a VRM's output impedance in the microOhm and milliOhm region [2]; however, it is not always possible to make these measurements without direct SMA connections to the PCB or Device Under Test (DUT). Therefore, when a designer makes these types of measurements with a Vector Network Analyzer (VNA), the method of connecting the DUT requires attention to detail to ensure inductance and various error sources are minimized to allow an accurate measurement. To get the most out of your VNA, you need to use the right probes and accessories to ensure your measurement is successful. With a browser probe like the P2102A, you can quickly characterize multiple VRMs to ensure stability or even check if your model is accurate during your initial power delivery network (PDN) design.

The Picotest P2102A 2-port PDN transmission line probe is a browser probe that achieves a very low inductance at the tip to mitigate space constraints on a dense PCB, while eliminating the need to solder coax, add additional SMA connections, or other test points necessary for impedance measurements. It is especially useful when there are dozens of rails to assess and there isn't time, or PCB iterations available to provide test point implementations for each. Repeated measurements are simplified because connection is by simply touching the tip to an output capacitor. This browser probe comes with 4 probe tips to allow measurement across a variety of SMD packages on a PCB such as 1206, 0805, 0603, or 0402. The P2102A probe tips are available with 1X, 2X, 5X, and 10X attenuations as well as a DC Block option. This allows flexibility for users to measure across a wide range of voltages. For instance, the 2X probe can measure 6Vrms without DC blocks. The tradeoff is the attenuation increases the impedance floor. In short, this 2-port P2102A probe is best suited to assess power supply's stability at the same time as you assess the PDN. An added benefit is that you can also use the P2102A probe to make VRM, power plane and decoupling measurements at the same time you assess a power supply's stability.

The goal of this document is to show design and test engineers how to accurately capture the control stability of a VRM or power rail efficiently and quickly, using Picotest's proprietary, Non-Invasive Stability Margin (NISM) software. This application note is for the Keysight E5061B and Picotes's P2102A 2-port probe. It will also show how to use this browser probe as a quick GO/NO-GO tester. In this application note, two DUTs will be measured as detailed by the process shown in Figure 1.

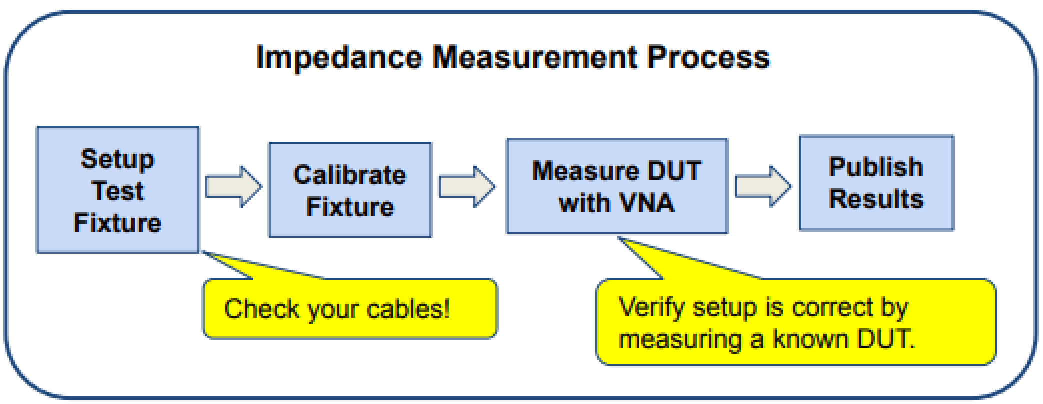

Fig. 1 - Impedance Measurement Process.

1.0 Test Equipment List

Description	Model	QTY
Vector Network Analyzer	Keysight E5061B [3]	1
2-port PDN Transmission Line Probe Kit	Picotest P2102A-1X [4]	1
Common Mode Transformer	Picotest J2102B-N [5]	1
2-Port Probe Adapter Panel	Picotest J2160A [6]	1
Picotest PDN Cable®, BNC-BNC, 0.25 meter	BNCJ/BNCJ-250 [7]	1
N Male to BNC Female Adapter	Pasternack PE9002 [8]	2
3D Probe Positioner	Keysight N2787A [9]	1
VRM Demo Boards (Flat and Varying Impedance)	LM20143B [10]	1
VRM - Infineon PS5401 Eval (DUT)	EVAL_PS5401-INT [11]	1
Calibration Board/Substrate	Included in Picotest P2102A kit	1

Fig. 2 - Picotest P2102A probe, P2102A probe tips, Picotest PDN Cable, J2102B ground isolator, adapters, calibration substrate, and probe holder for measurement (for use with the Port 1-Port-2, N-connector S-parameter ports).

Fig. 3 - Picotest P2102A probe, P2102A probe tips, J2160A, calibration substrate, and probe holder for measurement (for use with the low frequency-RF(T/R) BNC-connector ports).

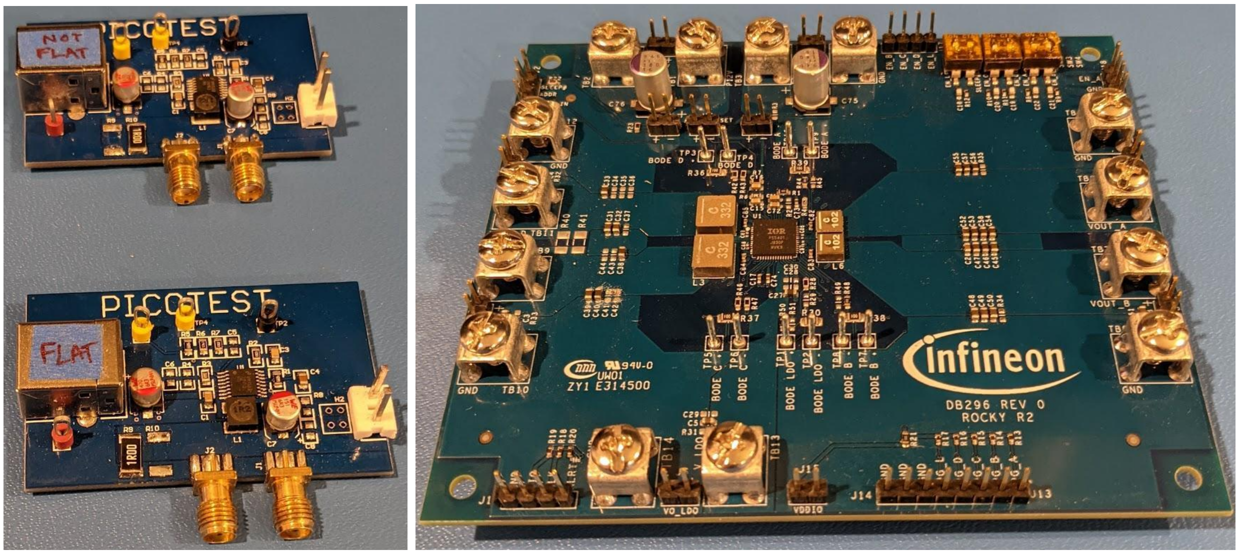

Fig. 4 - Picotest LM20143 DUTs* (left) and Infineon PS5401 Eval DUT (right).

***Note:The Picotest LM20143 test board may be referred to as Flat DUT and Not Flat (NF) DUT throughout this document.**

2.0 Measurement Setup

The P2102A-2X probe tips include 50 Ω series resistors (Rs), which can be set up/accounted for in the E5061B calibration menu. Figures 5 and 6 provide a depiction of how the DUT is connected to the 2-port P2102A probe with the E5061B S-parameter ports.

For the other P2102A-#X probe tip models, set Rs as defined below in the E5061B VNAs:
P2102A-1X - Rs = 0Ω
P2102A-2X - Rs = 50Ω
P2102A-5X - Rs = 200Ω
P2102A-10X - Rs = 450Ω

With the Keysight E5061B VNA, there are two possible 2-Port Shunt-Through measurement setups with the P2102A to use with NISM.

One setup includes the Picotest J2102B common mode transformer, connected to ports 1 and 2 on the E5061B S-parameter ports as shown in Figure 5. The necessary test equipment for this setup is shown in Figure 2.

The shunt-thru configuration inherently suffers a ground loop error at low frequencies. The current flowing through the cable shield of the connection to channel 2 ground introduces a measurement error that can become significant at frequencies between 10 kHz to 100 MHz when measuring very low impedance values. To reduce the ground loop error at low frequencies, use a ground isolator or common mode transformer (e.g., J2102B) or an active isolation device such as the J2113A [12].

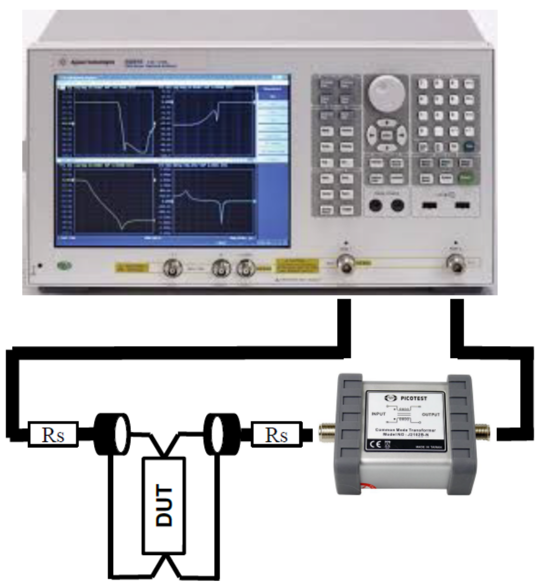

Fig. 5 - 2-port Shunt-Thru with series resistance impedance measurement setup using E5061B and Picotest ground isolator J2102B.

The other measurement setup includes the Picotest J2160A 2-port probe adapter, connected to the T/R ports low frequency VNA BNC ports on the E5061B, as shown in Figure 6. The necessary test equipment for this setup is shown in Figure 3.

The Picotest J2160A Probe Adapter provides a low noise, compact solution when using the E5061B T/R ports in a 2-port shunt-through measurement. It converts the instruments's three GP ports to the 2 ports necessary to perform a 2-port shunt-through measurement. The T/R ports are desirable for low frequency 2-port measurements, since the receiver port is semi-floating, allowing low impedance measurements **without** the use of a coaxial common mode transformer such as the J2102B. The floating ports allow milliohm measurements even at very low frequency and up to the 30 MHz range of the T/R ports.

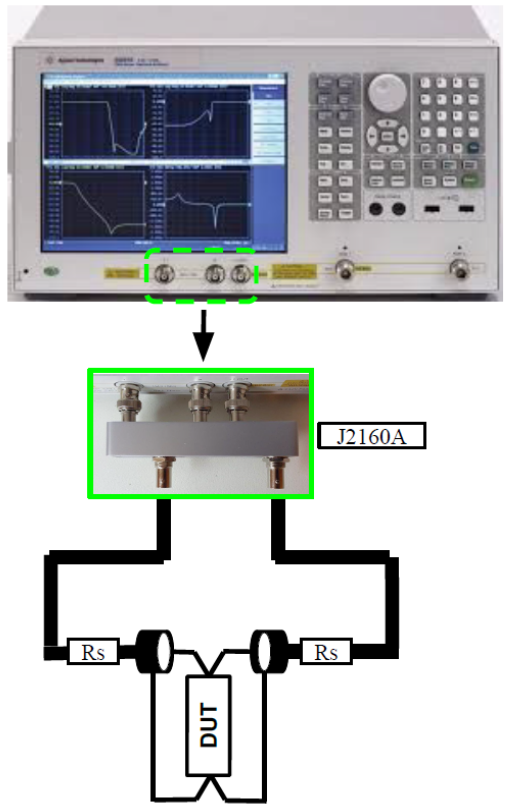

Fig. 6- 2-Port Shunt-Thru with series resistance impedance measurement setup using E5061B and Picotest J2160A 2-port probe adapter.

2-port probe users generally own a probe station; however, the commitment to setting up the camera, microscope, calibration, etc., is a much bigger commitment than sometimes necessary for simple VRM stability or even impedance measurements. This is where the P2102A browser probe provides a great option on-the-go, as depicted by Figures 7 and 8.

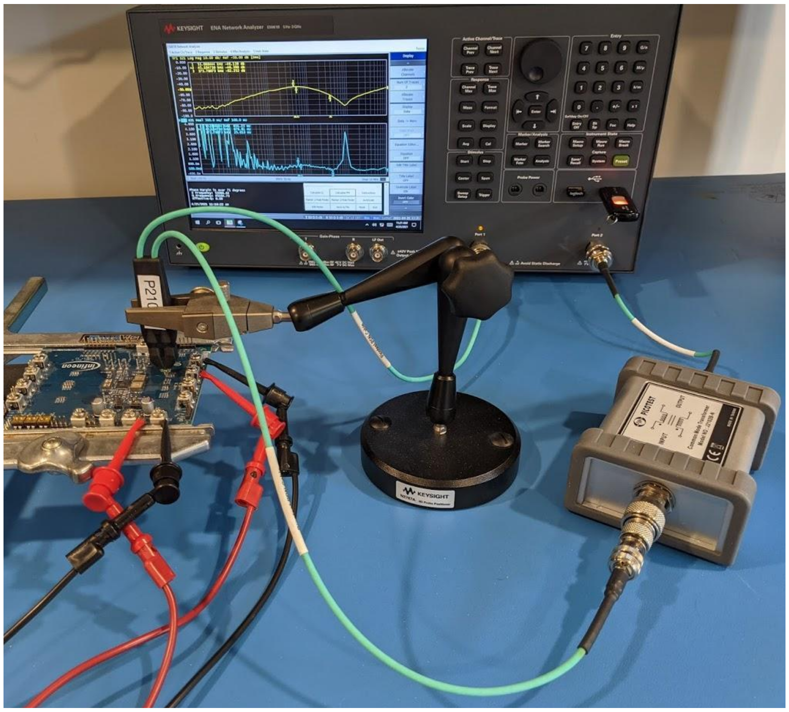

Fig. 7 - Measurement Setup after calibration with DUTs, the P2102A probe and the J2102B Common Mode Transformer.

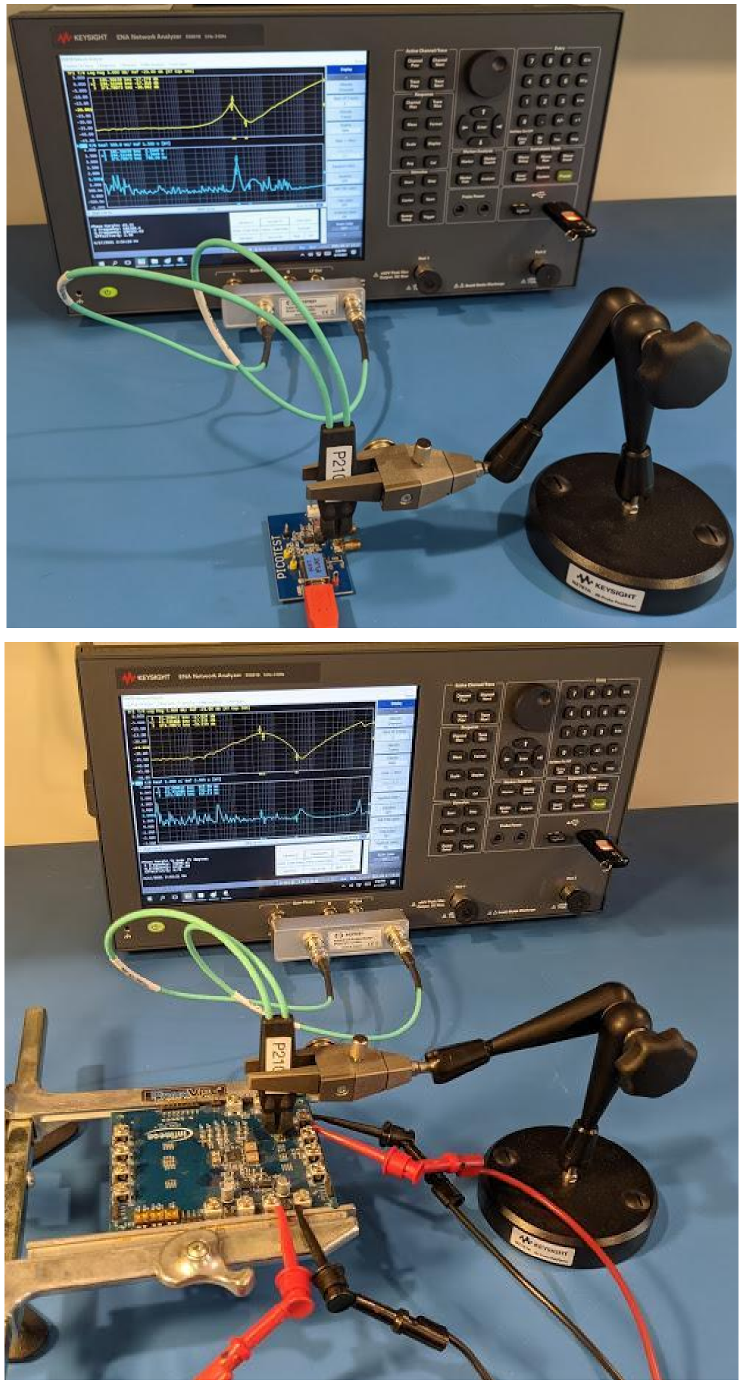

Fig. 8 - Measurement Setup after calibration with DUTs, the P2102A probe and the J2160A 2-Port Probe Adapter.

Prior to making any measurements, you should ensure calibration of the setup is performed by using the proper calibration method. The E5061B VNA has multiple calibration options shown in Table 4-1 of the E5061B user manual. Proper calibration is critical since it corrects for contact resistance, tip inductance, and coupling. Since the NISM method is only looking at the phase margin of the power supply to access stability, Picotest's recommendation to achieve accurate NISM results is to use the THRU calibration method.

Figures 9 and 10 provide a depiction of the probe tip location on each DUT. For Figure 9, an 0603 capacitor (C42) was removed prior to measurement and the 0603 probe tip is then used as shown; however, it is not necessary to remove the capacitor to make this measurement. For identification purposes the probe head has an indent in the housing for the tip side while the ground side is flat and smooth, so as not to confuse them.

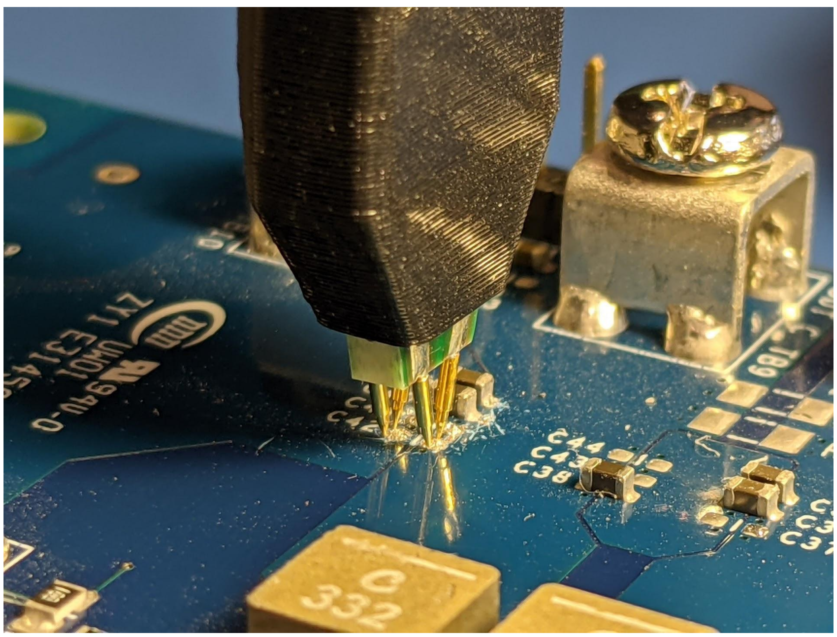

Fig. 9 - Probe location on DUT - Infineon PS5401 Eval at C42.

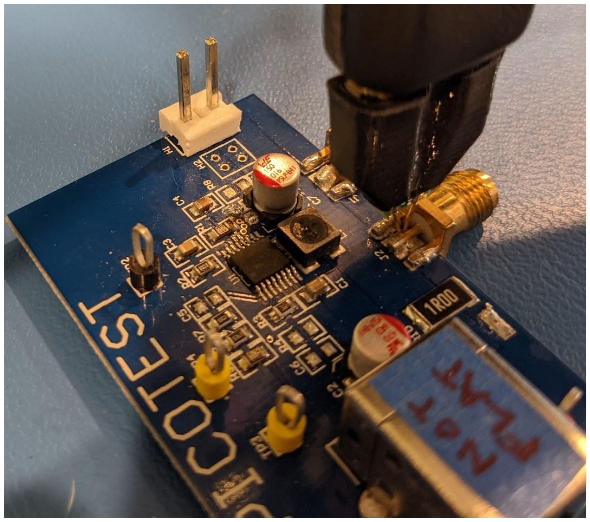

Fig. 10 - Probe location on DUT - LM20143 at J2.

3.0 Measurement Results

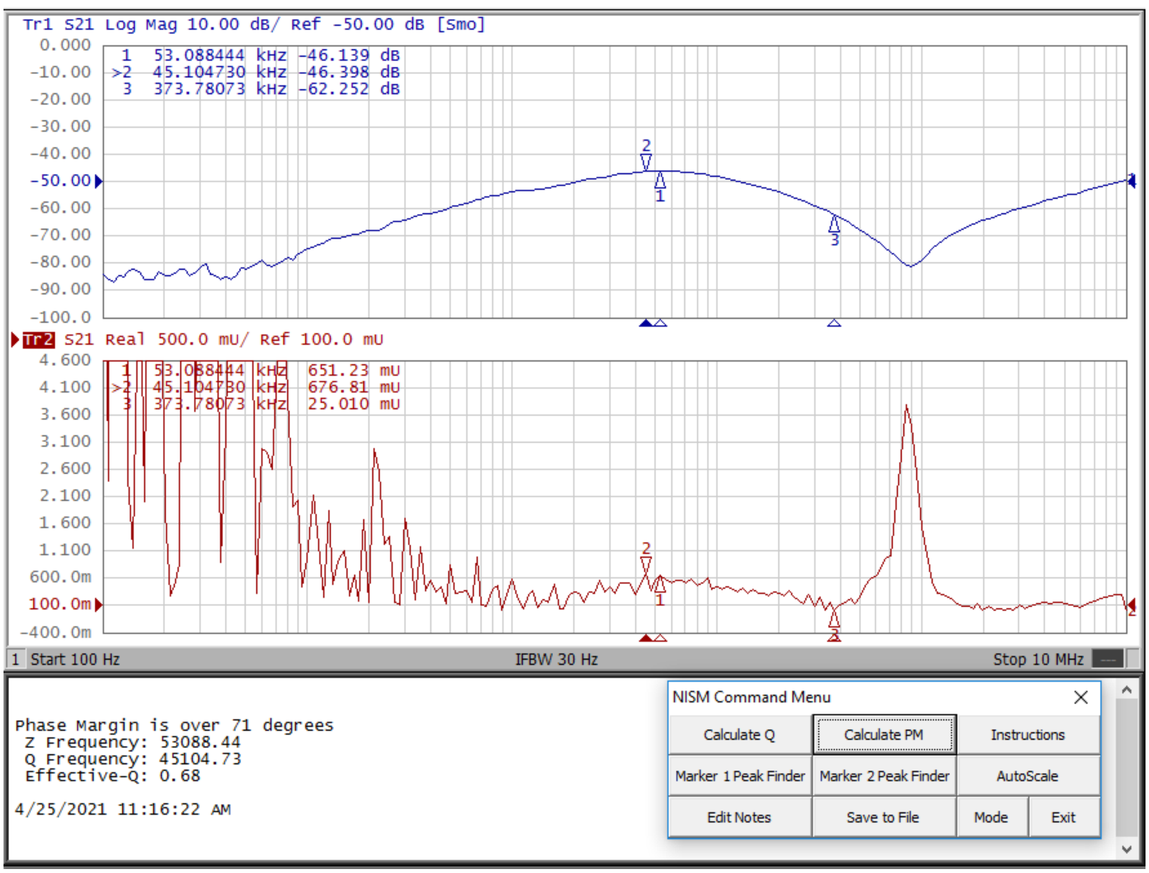

Fig. 11 - NISM Output Impedance results with J2102B on PS5401 VRM.

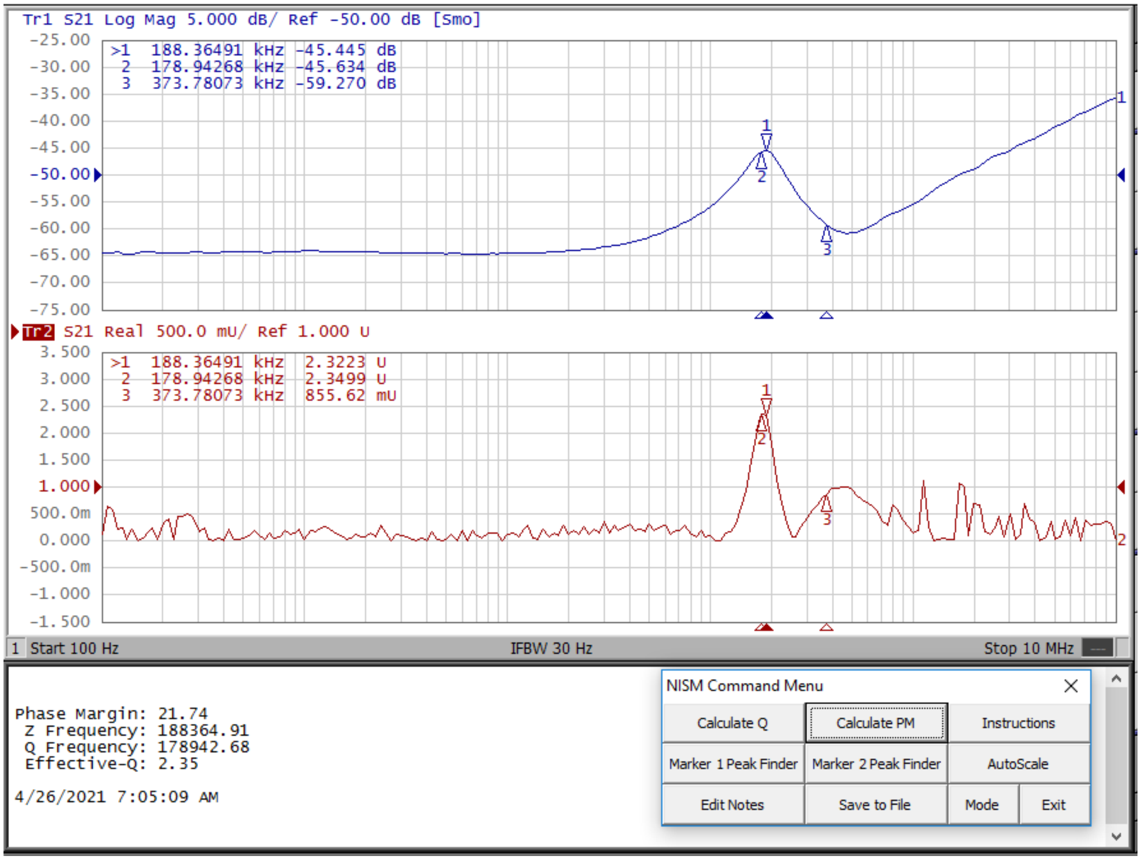

Fig. 12 - NISM Output Impedance results with J2102B on LM20143 NF VRM.

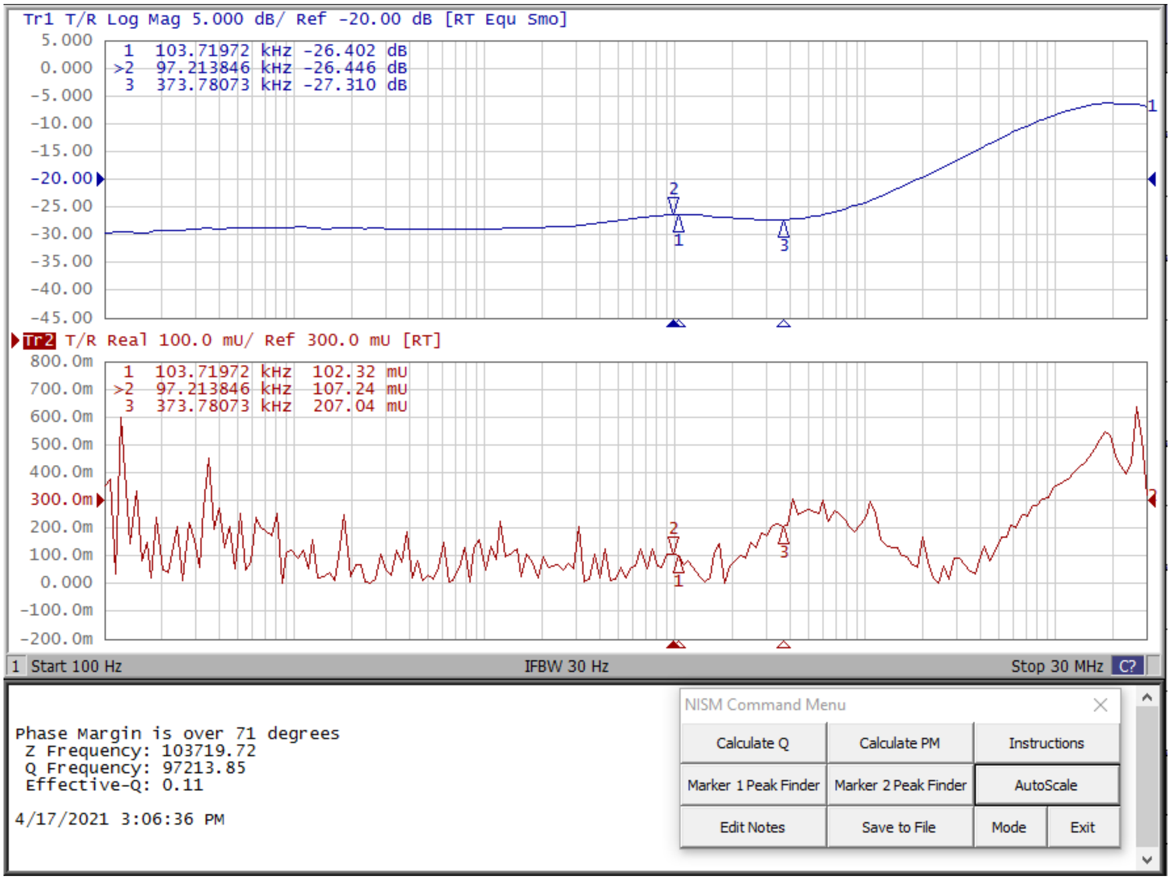

Fig. 13 - NISM Output Impedance results with J2102B on LM20143 FLAT VRM.

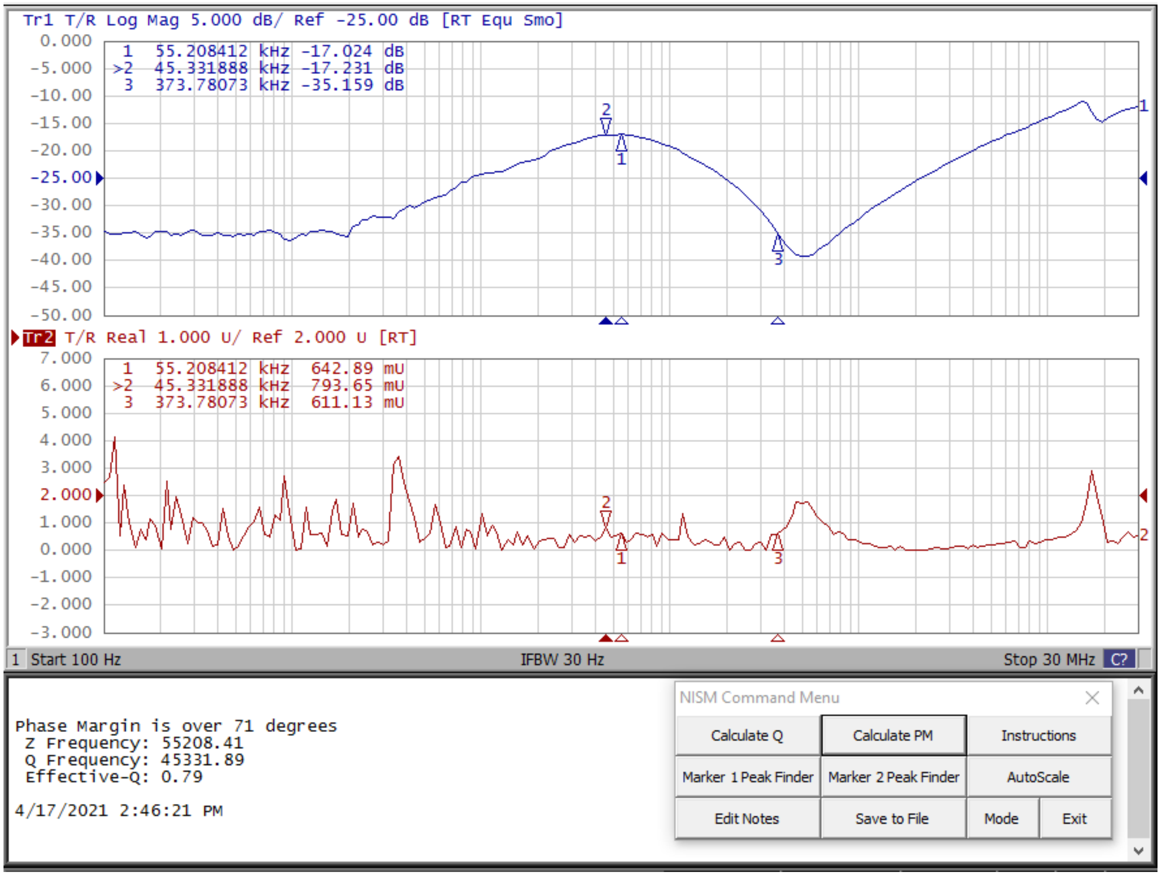

Fig. 14 - NISM Output Impedance results with J2160A with PS4501 VRM.

As shown by the results in Figures 11 and 14, it is possible to use NISM to accurately determine a VRM's control loop stability with the P2102A browser probe with the E5061B.

4.0 P2102A Calibration and NISM Setup Checklist with E5061B

Calibration of the testing setup for the shunt-through impedance with series resistance measurement with both the J2102B common mode transformer and the J2160A 2-port probe adapter.

4.1 2-Port Calibration and NISM Setup with the E5061B and J2102B Common Mode Transformer

After powering on the E5061B, with cables connected for calibration as shown in Figure 7, follow the steps below to calibrate your measurement setup prior to making measurements on your DUT.

Step 1: (On the E5061B) Press > **Cal** button
Step 2: Set > **Rs**, by specifying under Z_0 (as shown by Figure 15)

***Note: Rs only needs to be specified for P2102A-2X, 5X, 10X probes. For 1X probes this step can be ignored. For DC Block use 1X settings.**

Step 3: Select > **Calibrate**
Step 4: Select > **2-Port Cal***
Step 5: Select > **Transmission**
Step 6: *Place Probe on calibration substrate as appropriate. Reference Figure 16.*
Step 7: Select > **Port 1-2 Thru**
✔ *will appear next to the 'Port 1-2 Thru' LSK*
Step 8: Select > **Return**

Step 9: Ensure the **NISM.VBA** Macro is first copied to the analyzer's D:\ drive.

***Note: You may have to unzip the NISM folder if the software was sent via email in a zip file. In some cases, due to email system constraints, the zip file may need to be renamed from nism.txt to nism.zip, before being unzipped.**

Step 10: Press > **Macro Setup** button
Step 11: Select > **Load Project**
Step 12 Select > **NISM.VBA**
Step 13: Press > **Macro Run** button
Step 14: In 'Mode Menu' popup, Select > **Port 1 - Port 2**
Step 15: Select > **Calculate Q**
Step 16: First manually position marker 1 on trace one (output impedance) at the impedance peak. Then Select > Marker 1 Peak Finder.
Step 17: Manually position marker 2 on trace two (Effective Q waveform) on the peak <u>nearest in frequency to the impedance peak.</u> Then Select > Marker 2 Peak Finder.
Step 18: Select > **Calculate PM**

***Note: This measurement is limited to phase margins of approximately 71 degrees OR LESS.**

***Note: if you change or re-measure the output impedance, you will need to click the 'Calculate Q' button to re-measure the impedance and re-compute the Effective Q waveform.**

4.2 2-Port Calibration and NISM Setup with the E5061B and J2160A 2-Port Probe Adapter

After powering on the E5061B, with cables connected for calibration as shown in Figure 8, follow the steps below to calibrate your measurement setup prior to making measurements on your DUT.

Step 1: (On the E5061B) Press > **Meas** button
Step 2: Select > **Impedance Analysis Menu**
Step 3: Select > **Method Port 1 Refl**
Step 4: Select > **GP Shunt T 50Ω, R 50Ω**
Step 5: Select > **|Z|**
Step 6: Select > **Gain-Phase Setup**
Step 7: Set > **T input Z** = 50 Ω
Step 8: Set > **R Input Z** = 50 Ω
Set the attenuation for *T Attenuator & R Attenuator* as needed
Step 9: Press > **Cal** button
Step 10: Set > **Rs**, by specifying under Z_0 (as shown by Figure 15)

***Note: Rs only needs to be specified for P2102A-2X, 5X, 10X probes. For 1X probes this step can be ignored.**

Step 11: Select > **Calibrate**
Step 12: Select > **Response (Thru)**
Step 13: Ensure **Select Port > GP Port***
Step 14: *Place Probe on calibration substrate as appropriate. Reference Figure 16.*
Step 15: Select > **Thru**
Step 16: Select > **Done**
Step 17: Select > **Return**

Step 18: Ensure the **NISM.VBA** Macro is first copied to the analyzer's D:\ drive.

***Note: You may have to unzip the NISM folder if the software was sent via email in a zip file. In some cases, due to email system constraints, the zip file may need to be renamed from nism.txt to nism.zip, before being unzipped.**

Step 19: Press > **Macro Setup** button
Step 20: Select > **Load Project**
Step 21 Select > **NISM.VBA**
Step 22: Press > **Macro Run** button
Step 23: In 'Mode Menu' popup, Select > **T over R**
Step 24: Select > **Calculate Q**
Step 25: First manually position marker 1 on trace one (output impedance) at the impedance peak. Then Select > Marker 1 Peak Finder.
Step 26: Manually position marker 2 on trace two (Effective Q waveform) on the peak nearest in frequency to the impedance peak. Then Select > Marker 2 Peak Finder.
Step 27: Select > **Calculate PM**

***Note: This measurement is limited to phase margins of approximately 71 degrees OR LESS.**

***Note: if you change or re-measure the output impedance, you will need to click the 'Calculate Q' button to re-measure the impedance and re-compute the Effective Q waveform.**

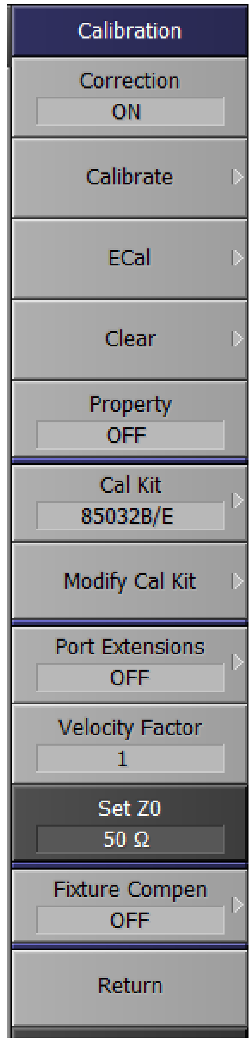

Fig. 15 - E5061B Calibration menu, where Z_0 is highlighted.

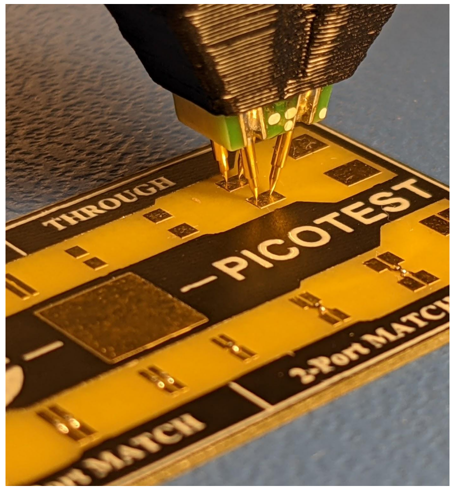

Fig. 16 - P2102A 2-port Calibration - Through.

5.0 Conclusion

With NISM, the 2-port shunt-through impedance method allows engineers to easily and effectively measure a VRM's output impedance and the control loop gain (phase) stability performance.

The P2102A browser probe allows you to very simply, quickly, and accurately make 2-port impedance measurements that help better design your power supply's stability and provide quick GO/NO-GO testing. When impedances are measured, not only can we determine a VRM's stability, but we can also determine what the power supply distribution network is composed of. We can even create a highly accurate model of the VRM from the impedance measurement that includes time domain, frequency domain and even EMI-related data. We can tell which parts of the impedance are based on control loop performance and which parts are based on printed circuit board and/or decoupling performance.

If you really want to measure planes or high frequency impedance, the P2104A 1-Port Probes [13] can be an even better option.

As shown in this document, to use NISM to make low impedance measurements with an E5061B VNA with the P2102A browser probe:

- It is essential to have the correct (low inductance) probes, high quality cables, and the common mode transformer (J2102B) or the 2-port probe adapter (J2160A).

- You must properly calibrate your setup, as this is essential to achieve high fidelity measurement and eliminate sources of test setup errors.
- A consistent, repeatable contact resistance that applies consistent tip pressure is necessary. This can be done with a probe holder like the N2787A shown, ClampMan [14], or one of the probe holders from PacketMicro [15].

6.0 References

1. NISM - https://www.picotest.com/measurements/NISM.html
2. Ultra-low Impedance (20 micro ohm) Measurement using 2-Port Shunt-Through - https://www.picotest.com/images/download/Ultra-low.pdf
3. Keyisght E5061B Vector Network Analyzer - https://www.keysight.com/us/en/product/E5061B/e5061b-ena-vector-network-analyzer.html
4. Picotest P2102A - 2 Port PDN Transmission Line Probe - https://www.picotest.com/products_PDN_Probe.html
5. Picotest J2102B-N - Common Mode Transformer - https://www.picotest.com/products_J2102B.html
6. Picotest J2160A 2-Port Probe Adapter Panel for E5061B - https://www.picotest.com/products_J2160A.html
7. Picotest PDN Cable® - https://www.picotest.com/pdn-cable.html
8. Pasternack PE9002 - N Male to BNC Female Adapter - https://www.pasternack.com/n-male-bnc-female-straight-adapter-pe9002-p.aspx
9. Keysight 3D Probe Positioner - N2787A - https://www.keysight.com/en/pd-1643963-pn-N2787A/3d-probe-positioner?cc=US&lc=eng
10. DUT - Picotest LM20143 - https://www.picotest.com/products_LM20143.html
11. DUT - Infineon PS5401 Eval - https://www.infineon.com/cms/en/product/evaluation-boards/eval_ps5401-int/
12. J2113A Semi-Floating Differential Amplifier - https://www.picotest.com/products_J2113A.html
13. Picotest P2104A 1-Port Probe - coming 2021 to https://www.picotest.com/products_PDN_Probe.html
14. ClampMan PCB Holder and Clamping Solution - https://www.picotest.com/products_clampman.html
15. PacketMicro TP150 Precision Positioner - https://www.picotest.com/products_TP150_Precision_Positioner.html