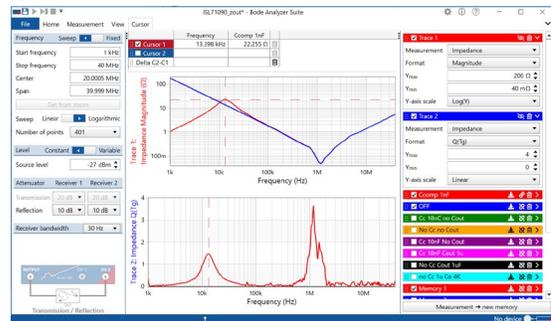
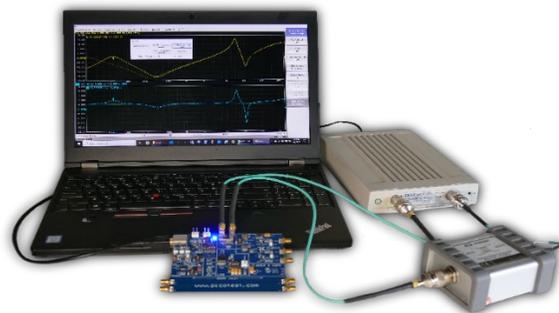




Non-Invasive Stability Margin Measurement (‘NISM’)

For Hardware VNAs and EDA Tools



Documentation

Version 2.0, 2024

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Table of Contents

Chapter 1 - Overview	4
Welcome	4
What's Included in the Software	9
Support.....	9
Chapter 2 –Measuring Stability (Phase) Margin on VNAs and Oscilloscopes	10
Introduction.....	6
Notes on VNA/FRA Usage	10
Installing and Running the Software – Keysight ENAs	11
Making Non-Invasive Stability Measurements – Keysight ENAs	11
Saving Data.....	21
Installing and Running the Software – Rohde & Schwarz	22
Making Non-Invasive Stability Measurements - Rohde & Schwarz	24
Installing the Software – Copper Mountain Technologies.....	30
Making Non-Invasive Stability Measurements – Copper Mountain Technologies	30
Installing and Using the Standalone PC Version of NISM.....	34
Chapter 3 – NISM Examples - Hardware Instruments	36
Example 1– T Over R Measurement.....	36
Example 2 – 1Port – 2Port Measurement	43
Example 3– 1-Port Measurement	49
Example 3– 2-Port Shunt-Through Measurement.....	51
Example 4– 2-Port Shunt-Through Measurement.....	53
Chapter 4 - Installing and Running NISM on Cadence PSpice	56
NISM Notes and FAQ	7
PSpice NISM Examples	56
Additional Theory – Stability Margin, Bode Plots from Output Impedance	72
Chapter 5 - Installing and Running the NISM on Keysight ADS	88
Chapter 6 - References	95

Chapter 1 - Overview

Welcome

Thank you for using the Picotest's Non-Invasive Stability Measurement ('NISM') software.

Since its inclusion in Vector Network Analyzer ('VNA') test instruments in 2010, NISM has proven its ability to accurately predict power system stability. The output impedance based assessment is superior in many ways to using Bode plots or the transient step load testing. It is analogous to translating the transient step load Q into phase margin (PM), except it is performed in the frequency domain. NISM is the software behind the stability measurement, converting output impedance directly to PM.

The motivations and need for NISM are clear. Many regulators, such as LDOs, don't provide access to the control loop. Newer regulators can have multiple internal control loops with not all loops exposed. Usually, the manufacturer will not detail this. What it means is that a Bode plot may not be possible or show real instabilities. In addition, phase and gain margins do not reveal the worst stability points (closest point to the -1,0 point on a Nyquist chart). Given the challenges associated with step load testing, the only practical way to assess stability is via NISM and its output impedance-based assessment.

The correlation between PM and the impedance-peaking in the closed-loop output impedance can be used to derive the PM of the control loop from one closed-loop output impedance measurement. If you can measure output impedance, you can measure a power supply's stability.

Based on proven control loop mathematics and minor loop gain theory, the NISM

methodology was pioneered by Steve Sandler (Picotest) in 2010. The conversion is embedded in VNAs, analog and EM simulators, and oscilloscopes with FRA features.

Summary of NISM Benefits and Features:

- NISM is an exact solution. It derives the phase margin from output impedance and group delay measurements
- The NISM assessment is based on Stability Margin. So, it is a more accurate predictor of stability than a Bode plot.
- The main usage of NISM is to determine the phase margin of regulators, switchers, POLs, and opamps, especially when the control loop is not accessible outside of the device, or if the device has multiple internal loops and only one of the loops is exposed outside the device.
- NISM works for open and closed loop circuits. You can measure the stability margin of all types of control loops and even passive filter circuits.
- NISM is available for various simulation platforms:
 - Cadence PSpice
 - Keysight ADS
- NISM is available on VNAs or Oscilloscopes with FRA features including:
 - OMICRON Lab Bode 100 and 500 VNAs (separate manual)
 - Keysight E5061B and E5071C ENAs
 - Rohde & Schwarz ZNL/ZNLE VNAs
 - Copper Mountain Technologies Compact VNAs
 - Tektronix MSO Oscilloscopes
- NISM is also available as a standalone NISM executable or a DLL that can be run via command line or embedded in programming languages such as Python.

NISM Usage Basics

- Measuring the output impedance when the power supply is powered ON and OFF demonstrates which peak is the active resonance that needs to be assessed by NISM. The active resonance is only present when the power supply is powered ON.
- NISM requires real and imaginary roots, so if the phase margin is above $\sim 65\text{-}70^\circ$ then the control loop is stable and there isn't an active resonance. NISM simply reports that the margin is greater than 65 degrees.
- NISM is a measure of control loop stability margin, which is then transformed to the equivalent phase margin of a 2nd order system. It may differ from the Bode plot result slightly given it is based on stability margin, which is usually worse than either phase or gain margin. In any case, the QTG result (i.e., derivative of the phase of the impedance or sharpness of the impedance peak) will always be accurate and indicative of the phase margin.

Introduction To NISM

The Non-Invasive Stability Margin Measurement ('NISM') is performed by a licensed software algorithm that uses proprietary mathematical conversion algorithms, based on minor loop gain. The conversion transforms impedance, normally output impedance, and the associated group delay waveform into phase margin.

NISM computes stability margin as per Nyquist theory. The Nyquist stability criterion is a graphical method used to analyze the stability of a system by examining the behavior of its transfer function in the complex plane. In control systems engineering, stability margin is a measure of how much the system can deviate from stability before becoming unstable. It represents the closest distance to the unstable point the stability margin can be quantified in terms of the distance from the Nyquist plot to the critical point $(-1, 0)$. If you imagine the Nyquist plot as a curve or trajectory in the complex plane, the stability margin is often considered as the minimum distance from the curve to the point $(-1, 0)$.

The stability margin in the context of the Nyquist theory is often associated with the phase margin and gain margin. These margins are determined from the Nyquist plot, which is a polar plot representing the frequency response of the system.

Phase Margin (PM): The phase margin is the amount by which the phase of the system's transfer function exceeds -180 degrees at the frequency where the magnitude of the transfer function is unity. A larger phase margin indicates greater stability. Generally, a phase margin greater than 0 degrees is desirable for stability.

Gain Margin (GM): The gain margin is the amount by which the system's gain can be increased before the system becomes unstable. It is expressed in decibels (dB). A larger gain margin corresponds to greater stability.

These margins provide insights into how much the system can tolerate variations in phase and gain before becoming unstable. High phase and gain margins are indicative of a more stable system.

NISM reports Stability Margin (SM). This means that the NISM result will, for most systems, be less than either the phase or gain margin would indicate. The Stability Margin is reported as a phase margin equivalent value for a 2nd order system.

The derivation is shown below (note that theta here is in radians).

The distance from the singular instability at (1,0) is

$$\text{dist}(\theta) := \sqrt{(1 - \cos(\theta))^2 + \sin(\theta)^2}$$

$$\text{SM}(\theta) = \sqrt{(1 - \cos(\theta))^2 + \sin(\theta)^2}$$

The phase margin

$$\theta = \arccos\left(1 - \frac{\text{SM}^2}{2}\right)$$

and the equivalent gain margin is calculated as 1-distance on the X-axis

$$\text{GM}_{\text{dB}}(\theta) = |20 \cdot \log(1 - \text{SM}(\theta))|$$

NISM Notes and FAQ

With the introduction of NISM into PSpice you can simulate the stability of any control loop or measure the equivalent phase margin of any filter resonance using impedance, even when control loop access is not present. If you are not familiar with NISM, there are many videos and papers on the topic with references below.

Model Requirements: Your simulation needs to be able to produce accurate impedance results over frequency. The model(s) must be valid for AC frequency domain analysis. The modeling of BOTH the output impedance of your power supply and the load impedance connected to your power supply is CRITICAL. NISM relies on the shape of the impedance and QTg (derivative of the phase of the impedance) curves.

Therefore, you need “AC/small-signal/averaged” models, as opposed to “transient” models – that is, models that are accurate for impedance. A large signal transient model will usually not be accurate for output impedance in the AC domain. Most vendor models are not accurate for AC output impedance. This is especially true if they are transient models.

Output impedance is generally not a tested parameter. Is virtually non-existent in power IC datasheets. This is a huge problem in the industry and needs to be corrected for many reasons. Therefore, output impedance accuracy may be challenging to confirm.

Output impedance is a critical design parameter that engineers are starting to learn is ESSENTIAL to design. Output impedance data is available for some parts, but you may have to request it. In most cases, you will have to utilize vendor evaluation boards to test for it and to correlate your power IC model. Picotest (www.picotest.com) or AEi Systems (www.aeng.com) can help you in this regard. It may also be the case, that PCB parasitics are

impactful to the result. If this is the case, you may need to find a way to include the PCB in your simulation model.

In any case, if the output impedance is not accurate, then the prediction of stability via Bode plots, NISM, or even the small signal step transient load response will NOT be accurate.

Simulating Output Impedance: In general, you will have to simulate impedance in order to run the NISM measurement equations. This requires an AC simulation where an AC current source with a magnitude of 1 (AC 1) is placed at the power supply output. Looking at the voltage in Probe will then effectively yield impedance (V_{out}/I_{in}).

Phase Margin Limits of NISM: NISM is not valid above about ~65-70 degrees. NISM software should simply report “Phase Margin > 70 degrees” if NISM indicates a margin > than 70. So again, thus could be a reasonable result.

NISM Accuracy vs. Bode Plots: In general, NISM is always correct. Bode plots often are not. See “When Bode Plots Fail Us” in the references. NISM is based on Stability margin as defined by Nyquist theory, which will be worse than either phase or gain margin. You can convert the off and on state impedances to a Bode plot as noted below to compare them.

Which frequency peak to use for the NISM assessment? The HS117 example below shows the output impedance for both the on and off states. The passive resonances should not be used as they are not part of the control loop. You can see which is which as they (passive induced resonances) appear in both the on and off state impedances.

NISM’s Output – Phase Margin

What does translation to 2nd order mean, in practical terms how NISM translates SM to PM? It means that the PM is representative of a typical 2nd order circuit in terms of step load response and the equivalent of PM. PM can be represented as equivalent GM if this is necessary.

How does this impact the NISM result in terms of accuracy?

NISM will be correct for the SM of the circuit. There is no telling how different it will be from the Bode plot or a transformed Bode (Bode from Output Impedance) will be, but it could be 20 degrees or more, for higher order systems as is seen in the OMICRON Lab SEPIC application note.

What if the loop is 1st order or 3-4-5th order in terms of accuracy?

1st order is 90 deg and above the NISM capability. The others there isn’t really an easy way to tell. Bode theory only claimed that a system is stable if it has positive GM and PM simultaneously. Since Bode plots aren’t a relative stability assessment, we can’t expect it to track a relative stability assessment. In general, the NISM assessment is more accurate than Bode plots. This is not to say that the Bode plot is not valuable, it just doesn’t highlight the

SM like NISM, which is the most indicative measure of stability. The Nyquist circle is a graph of the transfer function, and the SM is still the closest point to (1,0).

What's Included in the Software

Bode 500 and 100 Note: the NISM software feature is included with the OMICRON Lab Bode 500 and 100 VNAs. It does not have to be purchased separately or installed. Access to NISM is through the Bode 500/100 menu system.

Specific NISM software versions are available for Cadence PSpice, Keysight ADS, Keysight (E5061B, E5071C), R&S (ZNL and ZNLE), CMT Compact VNA instruments and Tektronix oscilloscopes. It must be installed in those systems as per the instructions in this manual.

NISM is included in PSpice as a built-in Measurement Equation.

Support

Please email info@picotest.com for NISM support. More information is available at <https://www.picotest.com/support.html>.

Chapter 2 –Measuring Stability (Phase) Margin on VNAs and Oscilloscopes

Notes on VNA/FRA Usage

Keysight E5061B Notes

For the E5061B, a 'nism' file folder is provided with several files (VBA, EXE, STA, etc.). The measurement macro used by the instrument is called NISM.VBA.

NISM.VBA–Works with the 2-port shunt thru measurement using the low frequency T/R Gain-Phase analyzer and both the 1-port (S11 reflection) and 2-port (S21 shunt thru) measurements using the high frequency channel (Port 1 and Port 2).

Please note that the low frequency T/R channel does not require a common mode coaxial transformer, since these inputs are semi-floating in the E5061B. A common mode coaxial transformer is required when using the high frequency channels of the E5061B. The Picotest J2102B is made for this purpose.

Keysight E5071C Notes

For the E5071C, one macro is provided since the same macro works with 1 or 2 port impedance measurements.

The file is called E5071CNISM.VBA.

E5071CNISM.VBA– Works with both the 1-port (S11 reflection) and 2-port (S21 shunt thru) measurements using any combination of the high frequency channels (Ports 1-Port 4).

A common mode coaxial transformer may be required when using the E5071C (in order to

attenuates the effects of low frequency ground loops when making 2-Port shunt thru impedance measurements). The Picotest J2102B (www.picotest.com/products_J2102B.html) is made for this purpose.

R&S ZNL Notes

For the R&S VNAs, there is a software installer which installs a 'nism' file folder on the instrument with several files. Currently the ZNL and the ZNLE support NISM.

Copper Mountain Technologies Notes

The Picotest NISM software is integrated in the S2VNA s/w application framework.

For the CMT VNAs, an executable file is provided that works with 1 or 2 port impedance measurements.

CMT_nism_plugin_c_sharp.exe (and nismDLL.dll in support of the EXE) – The executable application you run once your Copper Mountain Technologies VNA is connected to your PC.

Installing and Running the Software – Keysight ENAs

For the Keysight E5061B/E5071C

To install and run the NISM software:

1. Install and run the VBA macro files by first copying the 'nism' folder to the analyzer's D:/ drive. You must copy the entire folder.

You may have to unzip the nism folder if the software was shipped 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.

2. Press [Macro Setup], (Load Project), and load the macro NISM.VBA. Press [Macro Run] to run the macro.

Making Non-Invasive Stability Measurements – Keysight ENAs

Instructions on running the software are shown below.

PLEASE NOTE: This measurement is limited to phase margins of approximately 71 degrees OR LESS. Above this value, there are no imaginary roots in the output impedance

data and, therefore, there will not be a peak in the effective Q waveform. Therefore, in these cases, the software will only say that the margin exceeds 71 degrees. In some cases, you may only be able to measure phase margins of less than 65 degrees depending on the accuracy/noise of the measurement and the group delay waveform conversion.

To measure the stability (phase) margin of your circuit using a T/R measurement (gain/phase ports, E5061B only):

1. Load the Macro, **NISM.VBA** as instructed above. Please refer to the E5061B's user manual for instructions on loading and running the macro.
2. Click the [Macro Run] hardkey. The instrument is now in the macro state.
3. Select ToverR from the mode menu
4. Perform a THRU calibration.

Optional: Load a setup file if available. Several example setup files can be found at <https://www.picotest.com/support.html> in the Setup Files tab.

It is important to make sure that the instrument be in the correct configuration, otherwise, the macro may not be able to process and display the impedance data and computed margins properly.

5. Acquire the magnitude of the output impedance **IN LOG FORMAT** using the T/R ports in trace 1. This data would normally be taken at the output of your regulator, switcher, POL, opamp, filter, etc. Make sure the trace is the LOG MAGNITUDE. You can display the phase of the output impedance in trace two if you want, but the macro you will run in the next step will acquire it if you don't.

You can use any measurement configuration (1 port reflection, 2-port shunt, etc. as long as the measurement is suitable for the impedance level you are measuring). **MAKE SURE** to keep the measurement acquiring data (probe on the test point or cable connected to the DUT) **WHILE** you run the macro. That way the macro can acquire the phase data.

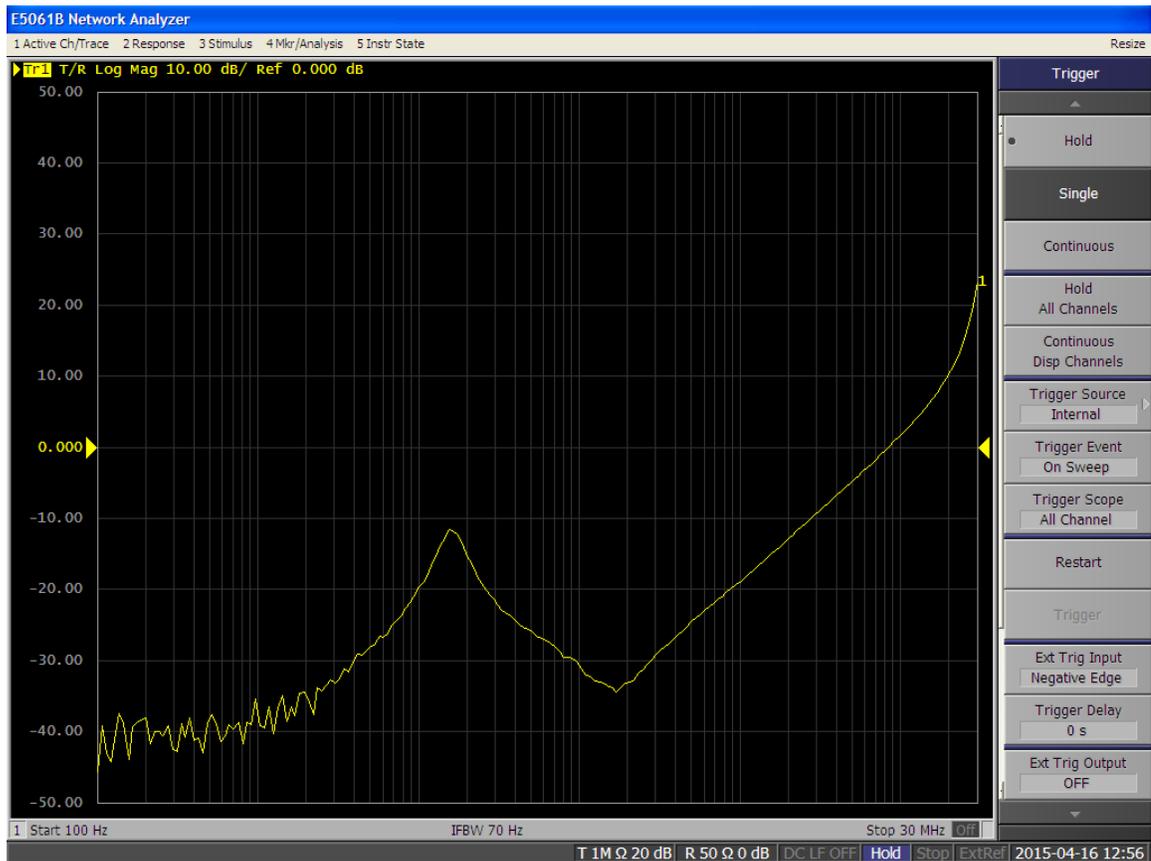


Figure 1: Step 4. Acquire the log magnitude of the output impedance using the T/R ports in trace 1.

6. Click Calculate Q in the Command Menu window. The macro will process the impedance data. After the macro runs, a second waveform will be displayed in trace 2; the Effective Q, which is related to the group delay/phase of the output impedance as shown in the next figure.

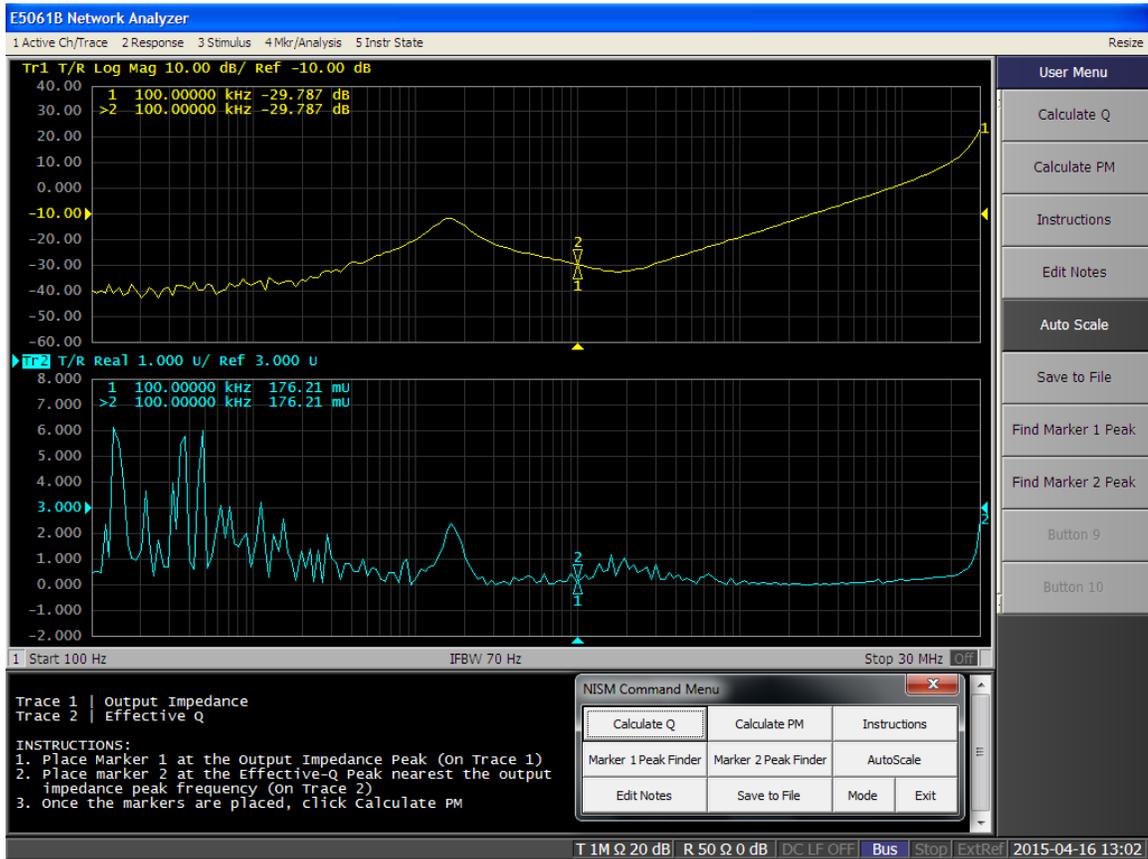


Figure 2: Step 5. After the macro runs, the impedance conversion process will occur and display the Effective Q trace.

7. Position marker 1 on trace one (output impedance) at the impedance peak. Position marker 2 on trace two (Effective Q waveform) on the peak nearest in frequency to the impedance peak.

The Marker Peak Finder buttons (Marker 1 Peak Finder/Marker 2 Peak Finder) on the NISM command menu assists in finding a local maximum once you place the marker near the impedance peak. It is useful to first move the marker near the peak.

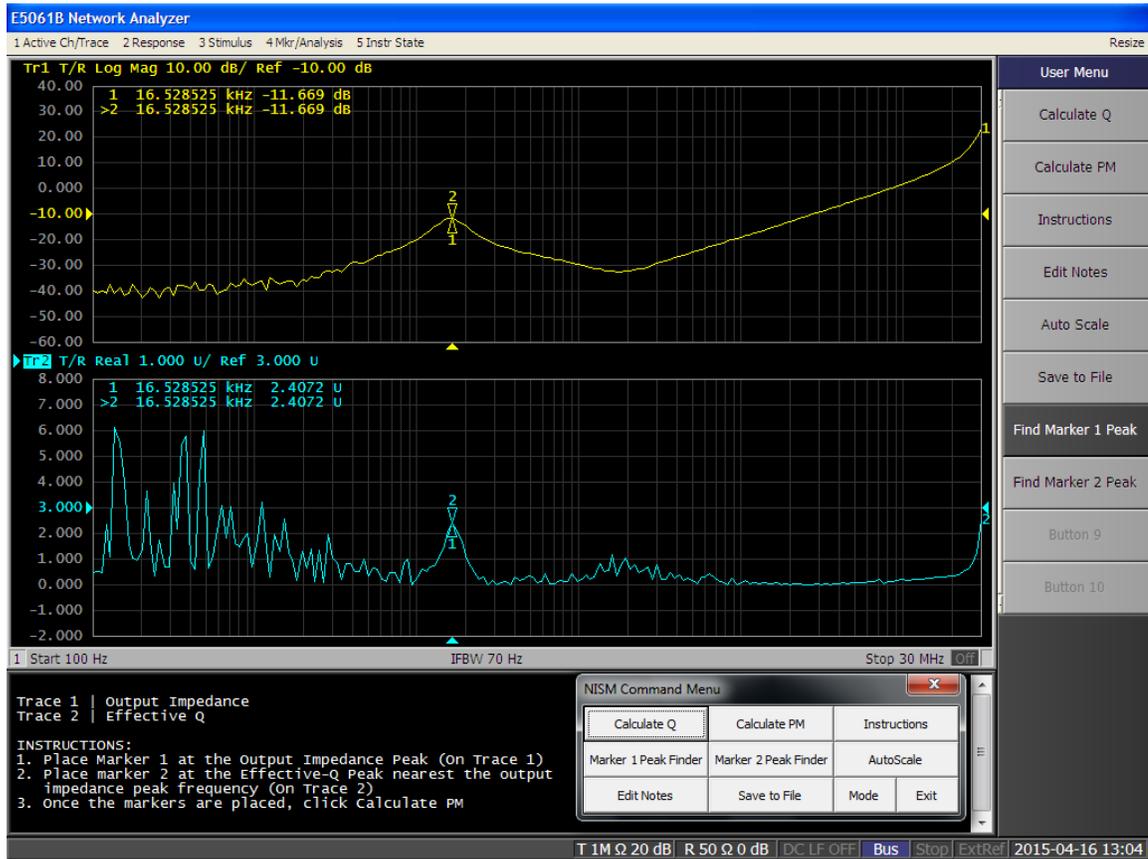


Figure 3: Step 6. Position marker 1 on trace 1 and marker 2 on trace 2 as detailed in the instructions at the bottom of the screen.

8. Click the “Calculate PM” button in the User menu. The phase margin will be displayed at the bottom of the instruction window. You may move the markers and click the Calculate button repeatedly to update the Phase Margin computation.

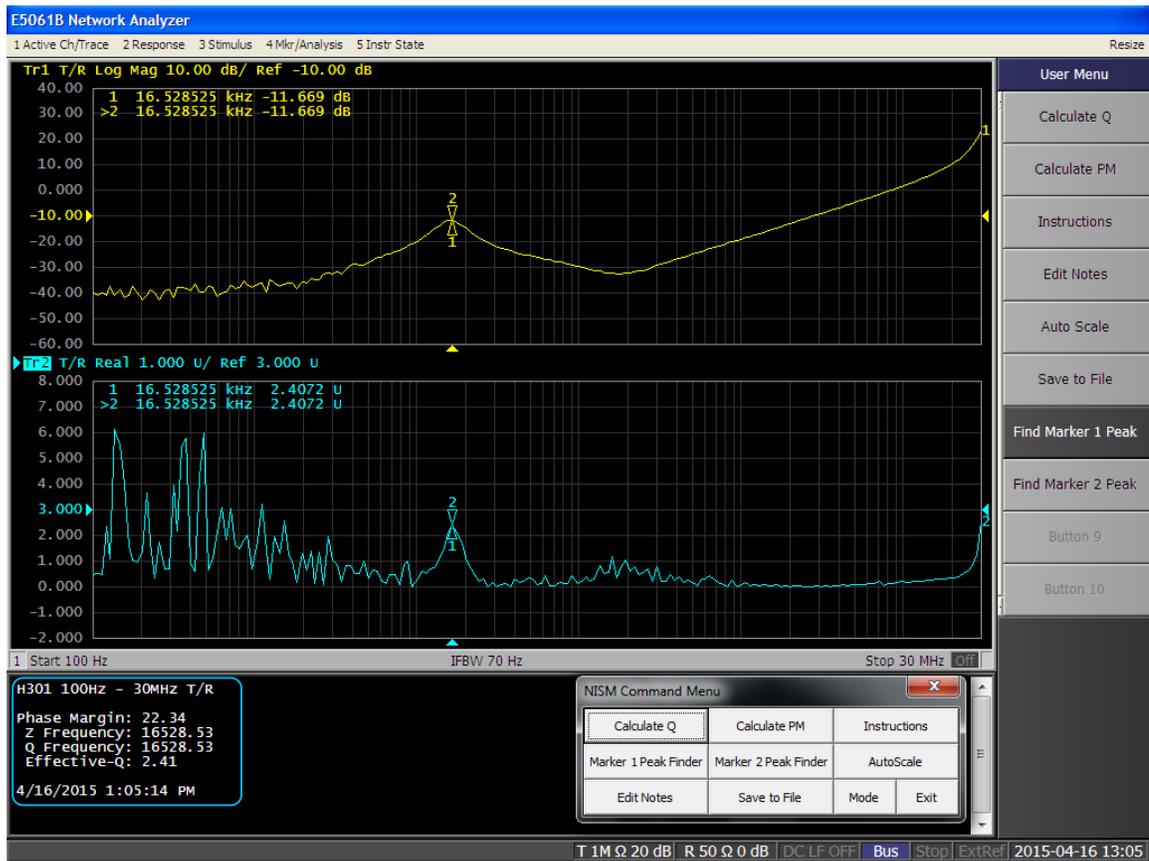


Figure 4: Step 7. After positioning the markers, click the “Calculate PM” button. The phase margin will be displayed at the bottom of the instruction window.

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.

To Measure Stability (Phase) Margin of your circuit using Port 1/Port 2 High Frequency Ports (for 1-port or 2-port) measurements:

1. Load the Macro. For the E5061B, use **NISM.VBA**. For the E5071C, use **E5071C NISM.VBA**.
2. Click the [Macro Run] hardkey.
3. Perform an OPEN/SHORT/THRU calibration.
4. Select Port 1 - Port 2 from the mode menu
5. Adjust the scopes settings as required for your particular measurement.
6. Acquire the output impedance in LOG MAGNITUDE format (S11) in trace 1. Next, open another trace and set trace 2 to also be in LOG MAGNITUDE format (S11). For a more detailed example of how to appropriately setup the instrument for a NISM 1Port-2Port measurement, see Example 2 in Chapter 3 below.

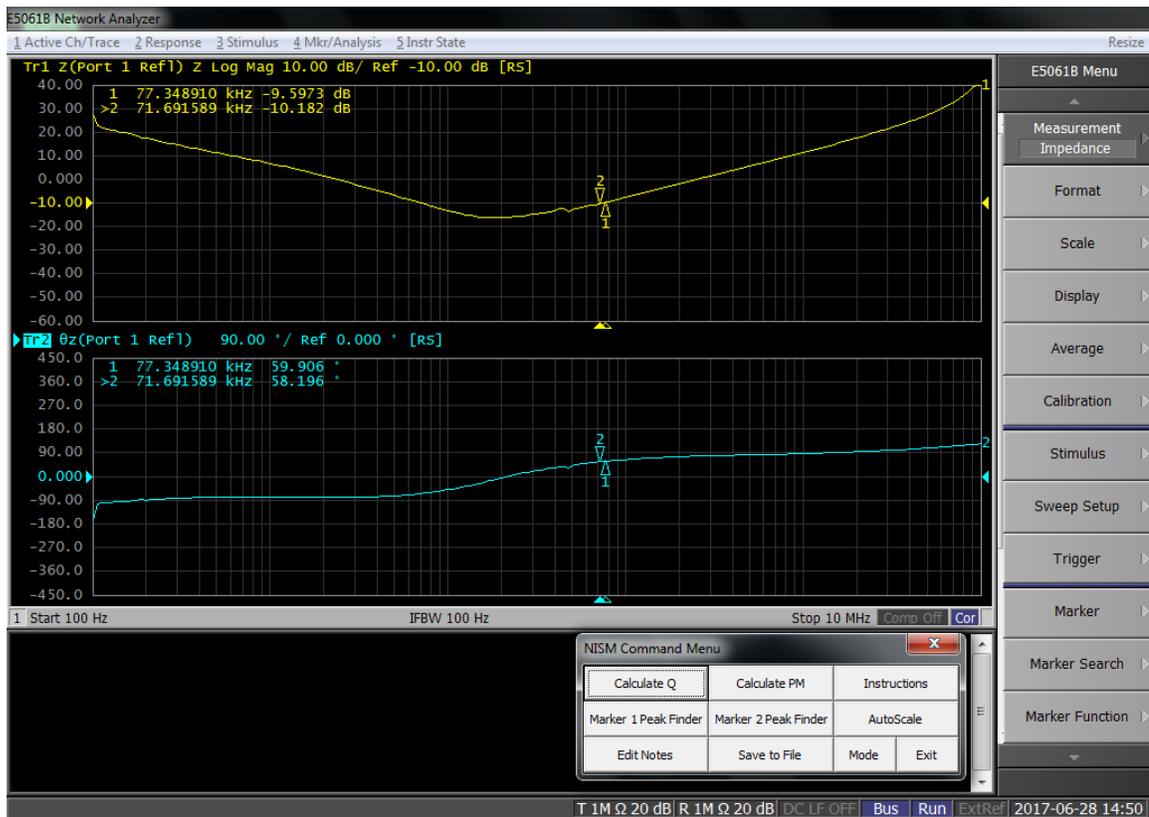


Figure 5: Step 4. Make sure that trace 1 is in log magnitude S11 Format.

- Click Calculate Q in the Command Menu. After the macro runs, phase of the output impedance waveform will be replaced by a new waveform; the Effective Q, which is related to the Group Delay of the output impedance. As the macro runs, make sure your test probe is on the test point and the output impedance data that is being collected is valid.

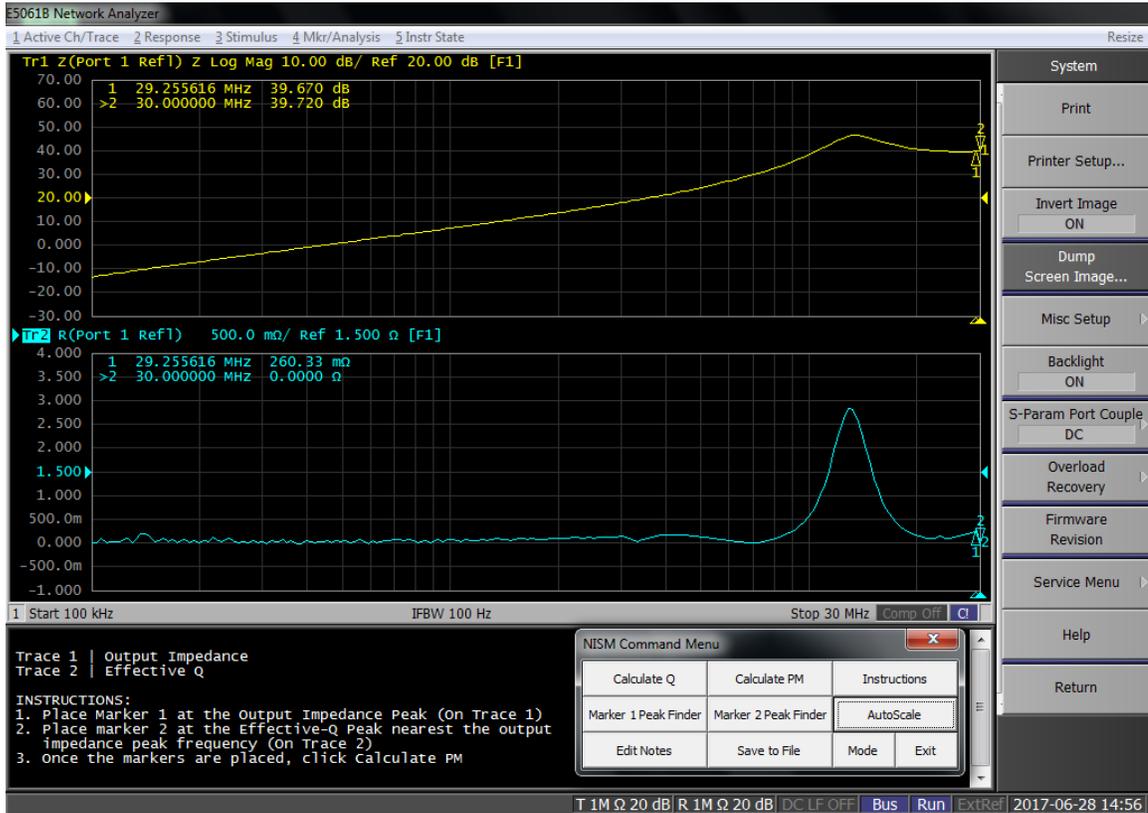


Figure 6: Step 5. After the macro runs, the impedance conversion process will begin and the phase trace will be replaced with the Effective Q waveform.

8. Position marker 1 on trace 1 (output impedance magnitude) at the impedance peak. Position marker 2 on trace two (Effective Q) on the peak nearest in frequency to the impedance peak. The Marker Peak Finder buttons on the NISM command menu assist in finding the local maxima once you place the marker near the impedance peak.

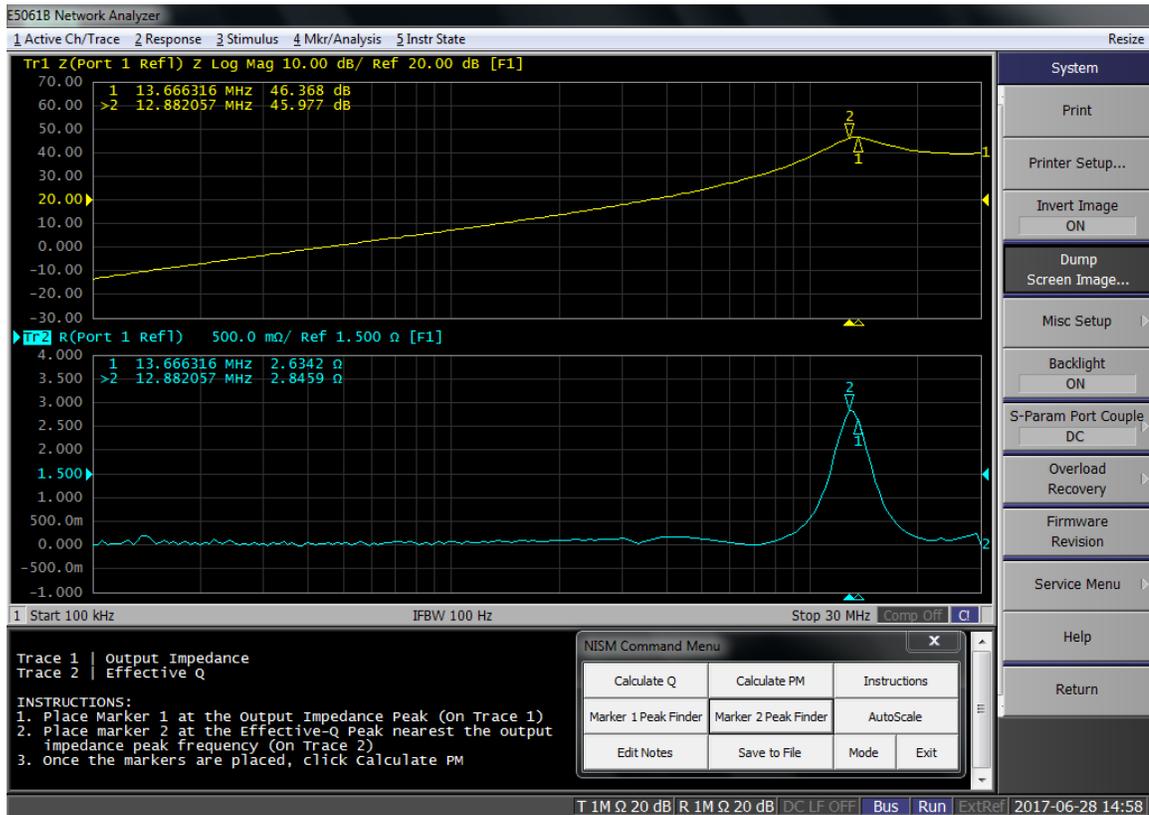


Figure 7: Step 6. Position marker one on trace 1 and marker 2 on trace 2 as detailed in the instructions at the bottom of the screen.

- Click the “Calculate PM” button. The phase margin will be displayed at the bottom of the instruction window. You may move the markers and click the Calculate PM button repeatedly in order to update the Phase Margin computation.

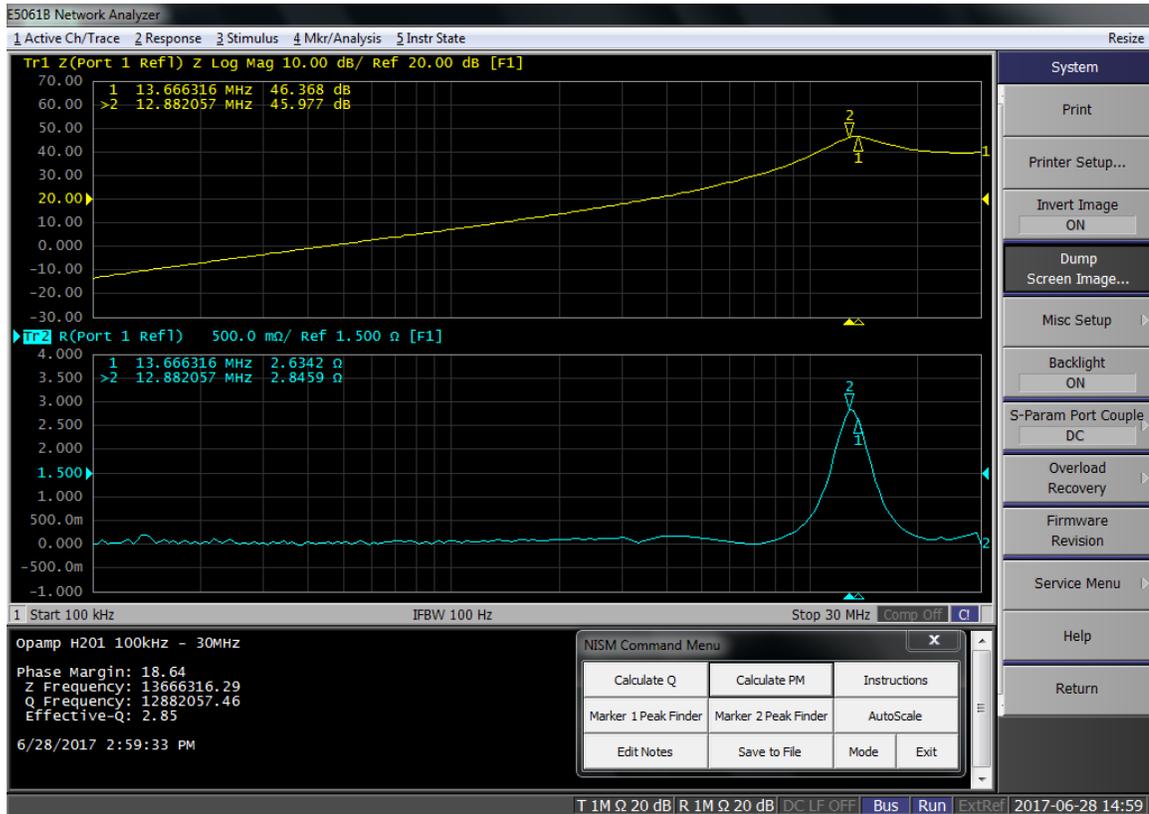


Figure 8: Step 7. After positioning the markers, click the “Calculate PM” button. The phase margin will be displayed at the bottom of the instruction window.

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

Saving Data

Once you have calculated and displayed the phase margin, you can save the information by clicking the **Save to File** button on the Command Menu. Save to File will prompt you to enter measurement notes if you have not already, then it will save all the files to the location of your choosing with the measurement notes as the prefix for the file name.

Annotating Your Measurement

You can save a note detailing your measurement along with the data.

To set a note for the measurement:

1. Click the Edit Note button on the Command Menu.
2. Enter your notes and click OK.

To set the location where data will be saved:

1. Click Save to File. A file browser will pop (if it doesn't, it may be hidden behind the network analyzer window).
2. Navigate to the desired location and click OK.

Note: The Save dialog may be hidden behind the Network Analyzer's main window. You will have to move the Save dialog to the foreground.

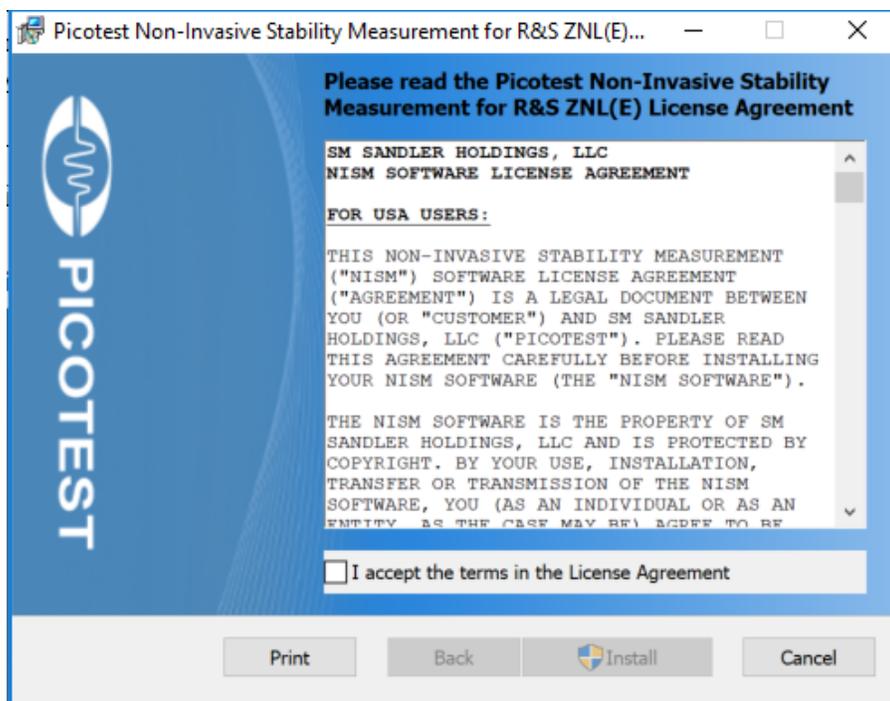
Several files will be saved to disk. They will have a filename made up of your Measurement Note plus the name of the waveform. The data is saved in CSV file format; the images are saved in PNG format.

Installing and Running the Software – Rohde & Schwarz

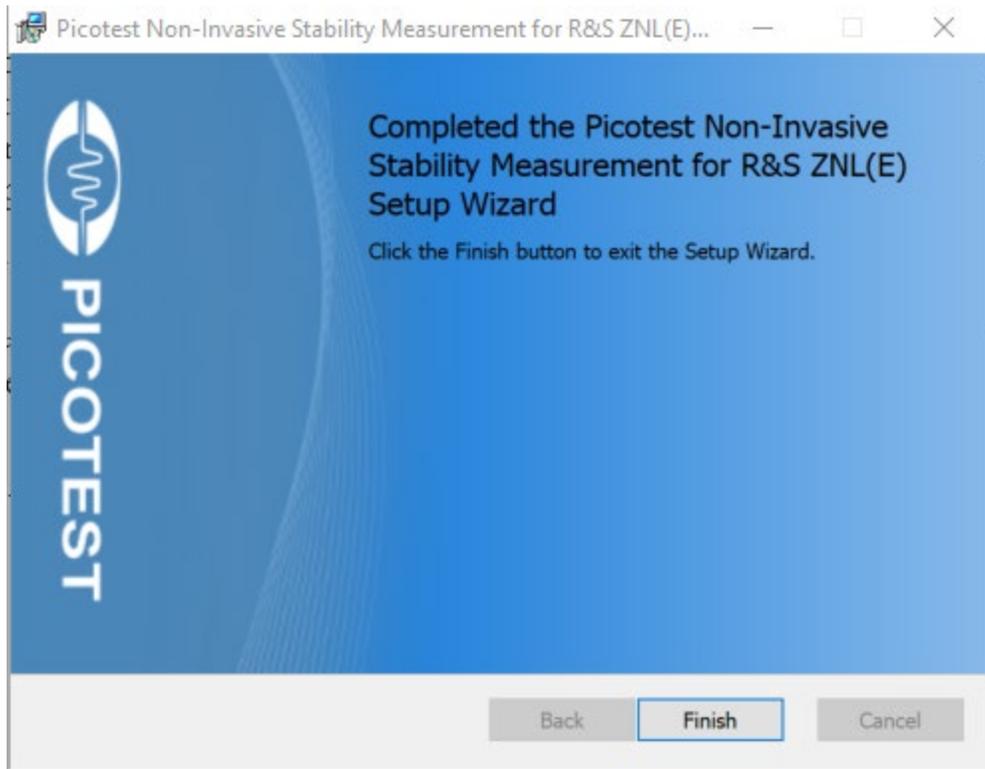
For the Rohde & Schwarz ZNL/ZNLE

To install and run the NISM software:

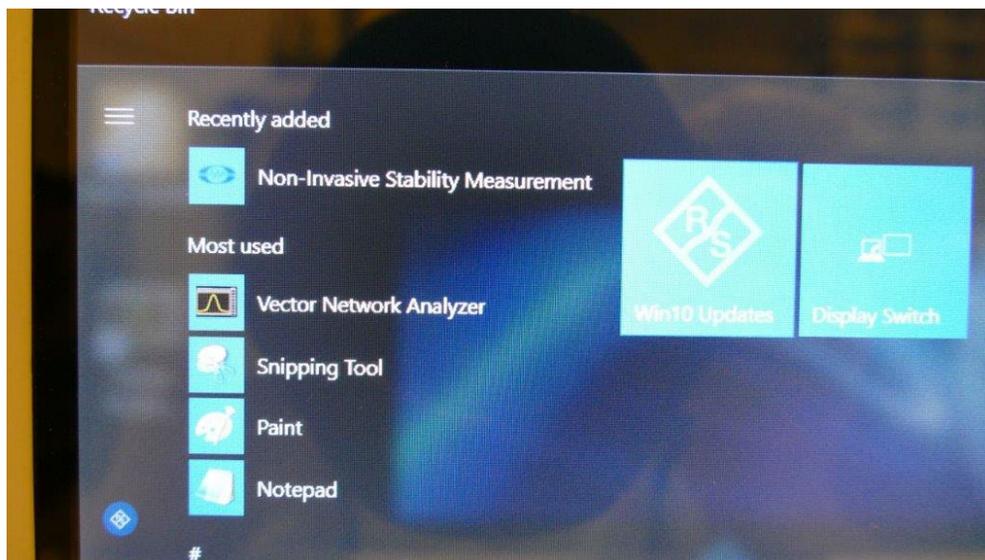
1. Copy the “Picotest Non-Invasive Stability Measurement for R&S ZNL(E) xxx.msi” file to the instrument
2. Run the Picotest Non-Invasive Stability Measurement for R&S ZNL(E) xxx.msi installer.



3. When installation is complete, select Finish.



4. To run the software, select Non-Invasive Stability Measurement.



Making Non-Invasive Stability Measurements - Rohde & Schwarz

Instructions on running the software are shown below.

PLEASE NOTE: This measurement is limited to phase margins of approximately 71 degrees OR LESS. Above this value, there are no imaginary roots in the output impedance data and, therefore, there will not be a peak in the effective Q waveform. Therefore, in these cases, the software will only say that the margin exceeds 71 degrees. In some cases, you may only be able to measure phase margins of less than 65 degrees depending on the accuracy/noise of the measurement and the group delay waveform conversion.

To measure the stability (phase) margin of your circuit using an impedance measurement:

1. Run the Non-Invasive Stability Measurement program.



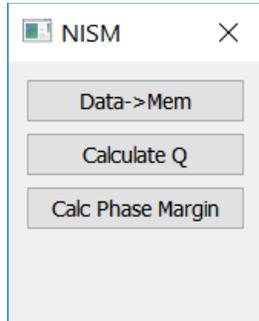
Figure 9: Initialized state of the instrument after running the NISM software. Not the NISM dialog to the right.

There are three functions/buttons in the NISM dialog:

Data -> Mem – Saves Trace 1

Calculate Q – Computes the $Q(Tg)$ response based on the Group Delay function. It is the Q of the impedance waveform

Calc Phase Margin – Takes data from the Trace 1 impedance waveform and Trace 2 $Q(Tg)$ waveform and displays the phase margin



2. Measure the impedance of the control loop (or other loop) whose phase margin you would like to test.

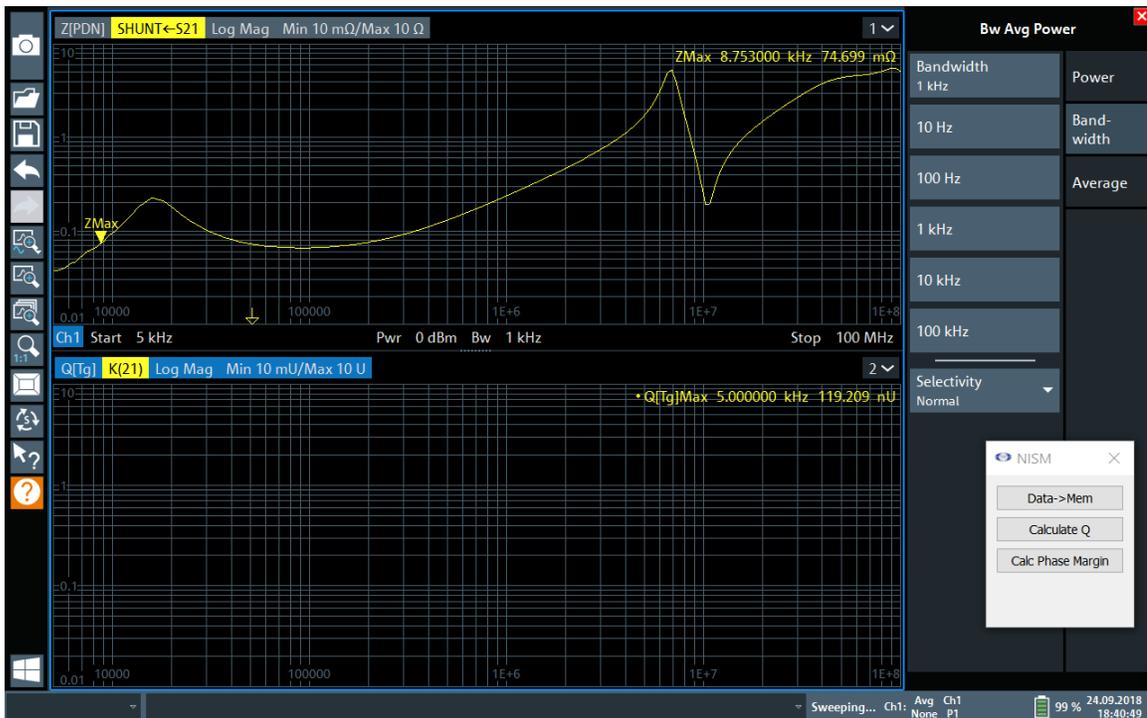


Figure 10: Impedance is measured as trace 1. Click Calculate Q.

3. Click the Calculate Q button.

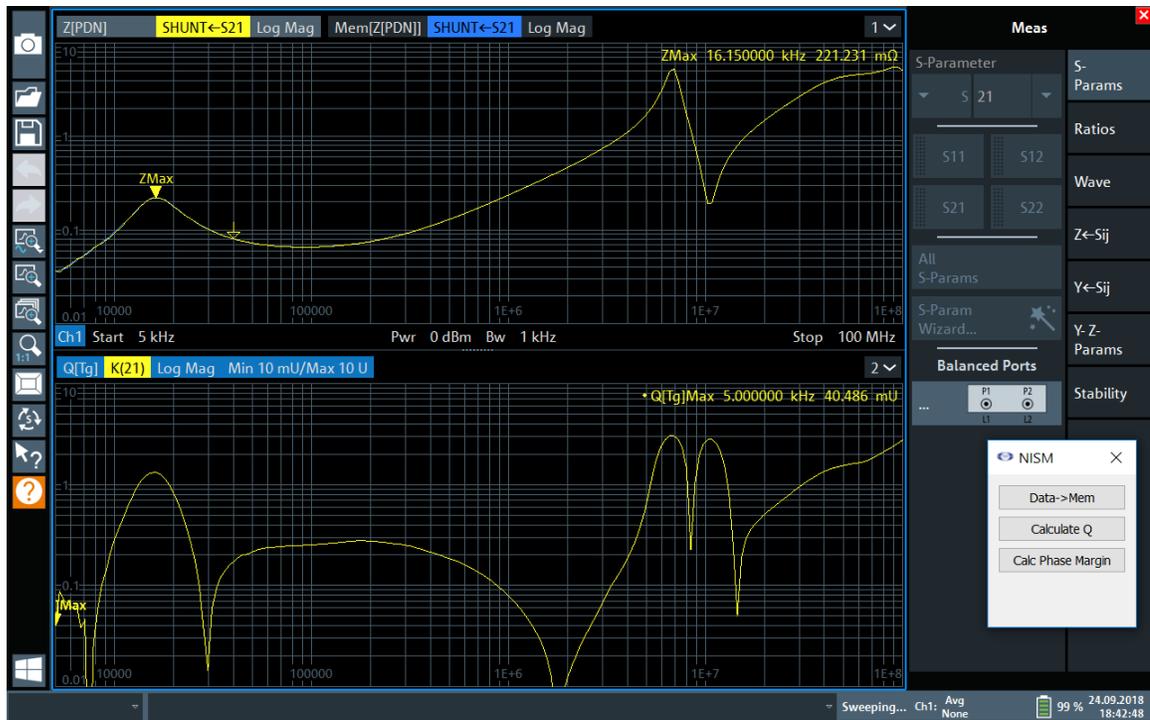


Figure 11: The $Q(T_g)$ waveform is created in trace 2 from the impedance waveform in trace 1.

4. Position the cursor on Trace 1 at the impedance peak. Position the cursor on Trace 2 at the $Q(Tg)$ peak nearest the impedance peak.

This is normally the bandwidth of the control loop or power circuit you are trying to measure. Other (higher frequency) resonances may be passive or active.

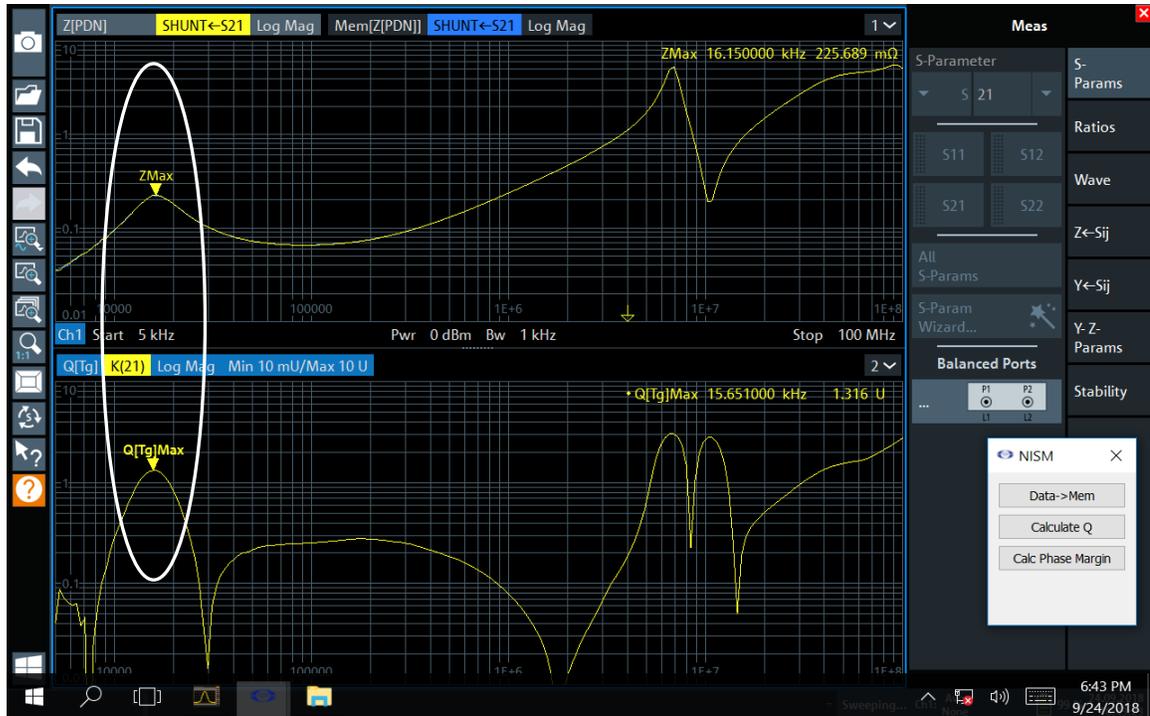


Figure 12: Place the cursors at the waveform peaks.

- Click the Calc Phase Margin button.

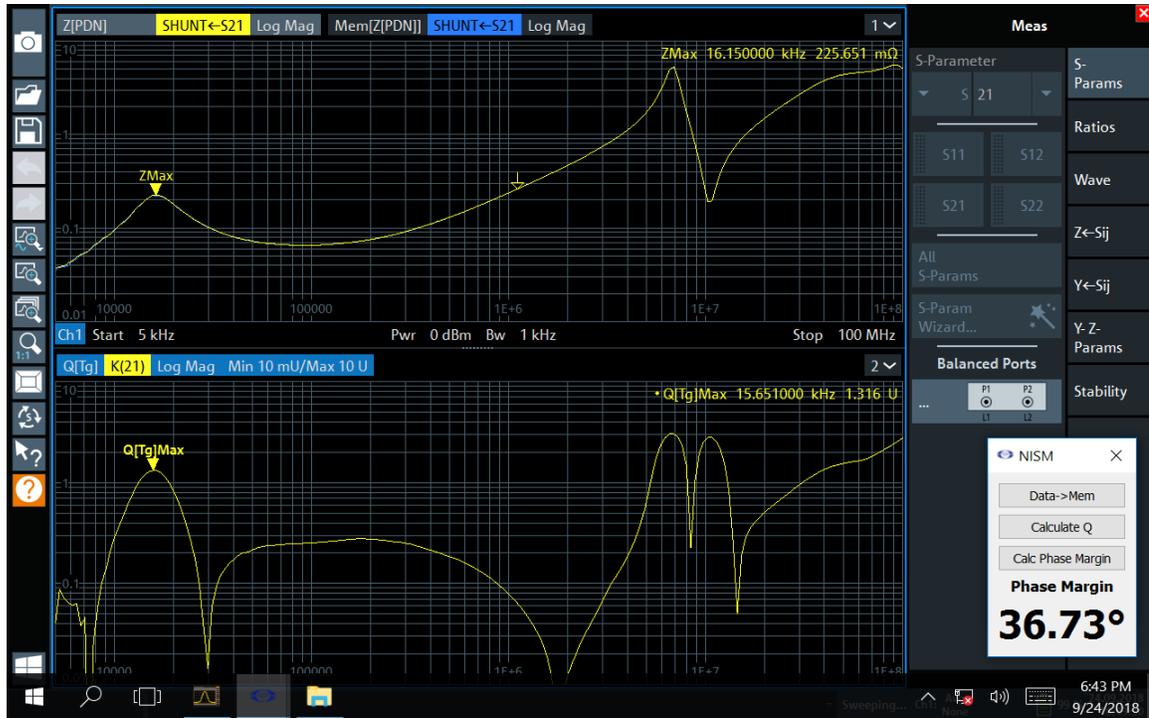


Figure 13: After clicking the Calc Phase Margin button the Phase Margin is displayed in the dialog.

You can measure the loop in the off state to see if the resonance is impacted by power-on state. This is a useful pairing of impedance measurements since it will tell you whether the resonance is passive or part of the active control loop. You can then choose to change the circuit design accordingly to address either resonance.

In the figure below, since the high frequency resonances are always present, they are passive and not part of the active control loop resonance at lower frequency.

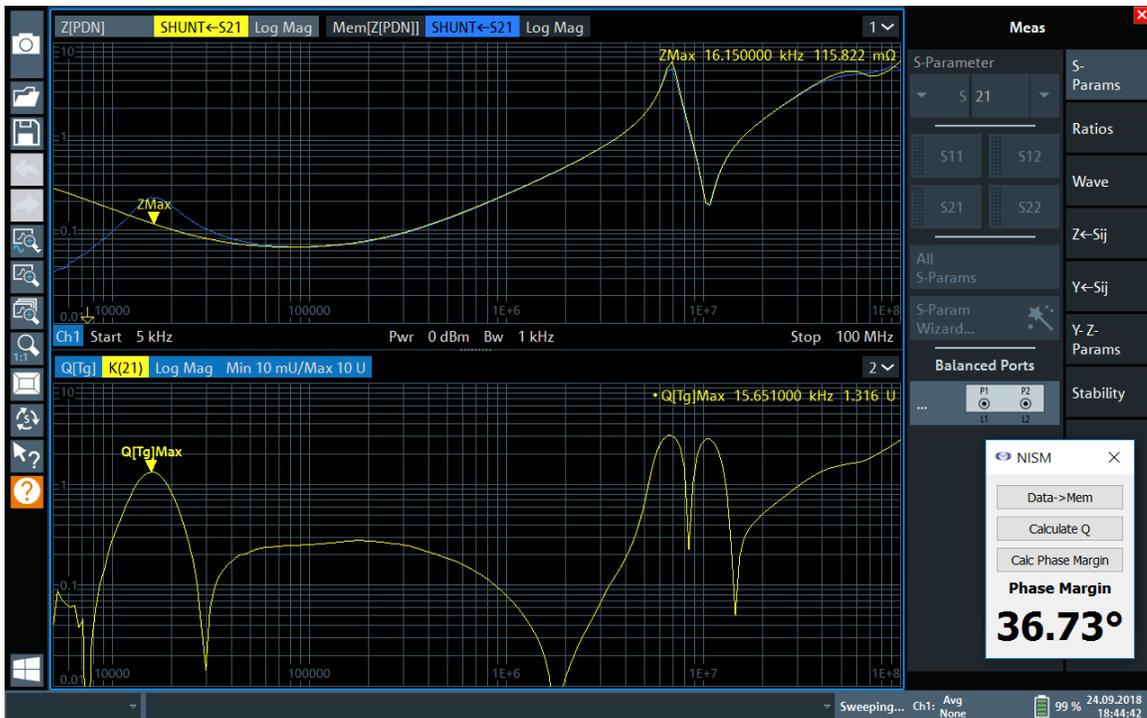


Figure 14: The powered on state (blue) is shown against the power-off state (yellow, impedance measured in the off-state). The powered-on trace was saved to memory using the Data -> Mem button to do the comparison.

Installing the Software – Copper Mountain Technologies

For the Copper Mountain Technologies Compact VNAs the NISM software does not get installed, it is an executable you run. You can run the “CMT_nism_plugin_c_sharp.exe” from any directory. Make sure that the nismDLL.dll is also located in the same folder as the executable file.

NISM Software Features and Operation

- The plugin NISM control window is always on top
- The user may select either S11 (1-port test setups) or S21 (for 2-port setups) impedance calculation
- The “Measure Stability Factor” button starts automatically updating the phase margin measurement as the cursor moves. If the user moves either the marker on trace 1 or the marker on trace 2, the phase margin measurement results update automatically. It should be noted that the stability margin result is only valid when cursor1/cursor 2 are on the impedance/group delay peaks (peak near the crossover bandwidth of the loop).
- The “Save Data” button appends values to a text file.

Making Non-Invasive Stability Measurements – Copper Mountain Technologies

Operational Steps:

1. Start the Copper Mountain Technologies VNA environment by running the S2VNA software.
2. The S2VNA status in the bottom right corner should indicate “ready.”
3. Go to “system” -> “misc setup” -> “network remote control settings” -> make sure “socket server 5025” is ON and if not -> turn “socket server” on.
4. Set the VNA for S11 or S21 measurement and select the respective impedance analysis transformation from the analysis menu:
5. Connect all the necessary cables and attenuators (if needed) for your measurement. Set stimulus settings and perform the calibration.
6. Measure the output impedance (magnitude).
7. Off State Impedance: It is useful at this point to record and store the off-state impedance (unpowered). Save the OFF measurement to memory (under the display menu and check the display data and memory)
8. Run the executable “CMT_nism_plugin.exe.”
The following dialog will appear.

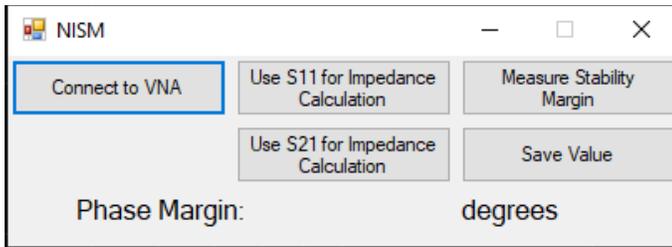


Figure 15: The CMT NISM dialog.

9. Click “Connect to VNA” -> then select either “Use S11 for Impedance Calculation” if you are using a 1-port measurement setup or “Use S21 for Impedance Calculation” if you are using a 2-port setup. There is no feedback for this operation, but it sets internal VNA parameters. Other settings (such as impedance transformations, scaling, IF bandwidth, frequency range, etc.) can also be set.
10. Click “Measure Stability Margin.” The NISM software directs the VNA to make two sweeps. The impedance trace will be shown at the top and the $Q(Tg)$ response based on the Group Delay function (the Q of the peak in the impedance waveform) both auto-scaled. The software will place markers at the largest peak. The largest peak is not necessarily the one associated with the control loop. Therefore, you may have to move the cursors for both waveforms to the correct peaks whose phase margin you want to measure. The correct peak is the one where the peak is visible in the ON measurement, but not in the OFF measurement. Therefore, it is good practice to show both measurements

Please Note: the margin value is ONLY VALID when the impedance and $Q(Tg)$ cursors are placed on the waveform peaks at/near the control loop bandwidth (crossover) frequency.

11. Click “Stop Measuring Stability Margin.” to perform another NISM measurement.
12. You can click “Save Value” to create a .txt file containing the stability margin value. This file is generated in the same directory as the NISM_plugin_CMT_c_sharp.exe.

On and Off State Impedance: As with other impedance measurements it is recommended that OFF and ON measurements be made/saved so that you can see which peaks related to the control loop and which peaks are due to passive resonances. Impedance peaks/resonances that are present in the on-state but not present in the off state (unit unpowered) indicate peaks associated with the active control loop and are the ones that can be measured. This can be seen in the figure below (lite track is the off state impedance). With the control loop active, the resonance at 40kHz appears and can be measured.

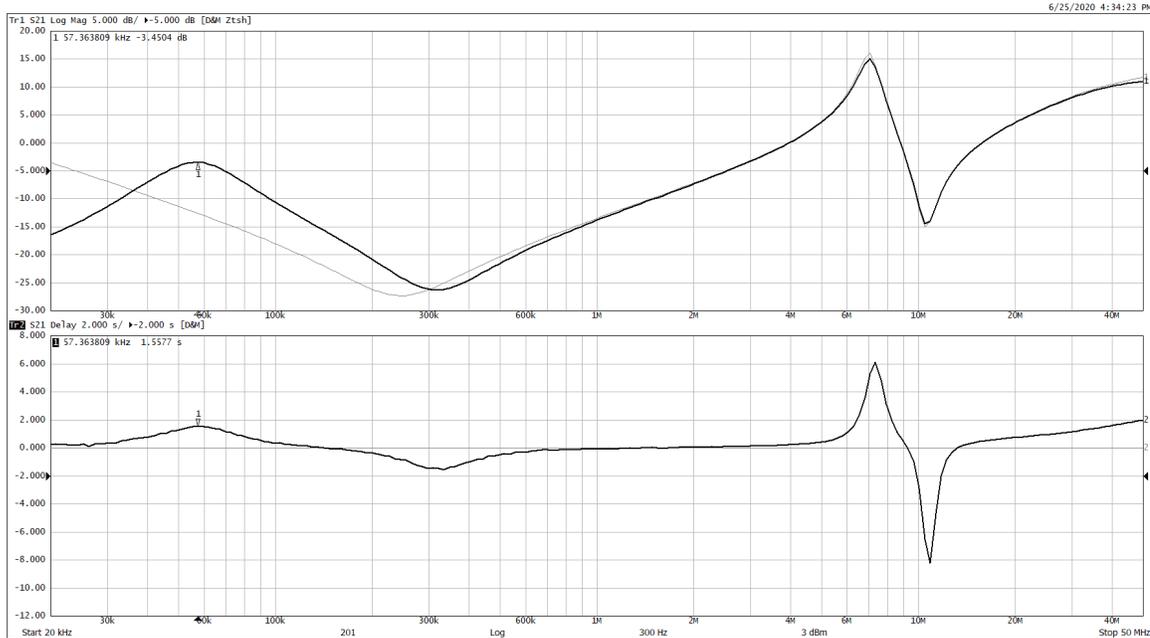


Figure 16: the top trace (lite) is the off state impedance. The darker trace is the on state impedance (powered). The lower trace is the Q of the group delay based on the upper on state impedance waveform. The NISM software configures this setup. Cursors should be placed on the peaks associated with the control loop.

Note: The lack of a peak indicates good stability. If this is measured, NISM will indicate “> 65 degrees” which is the maximum limit of the measurement.

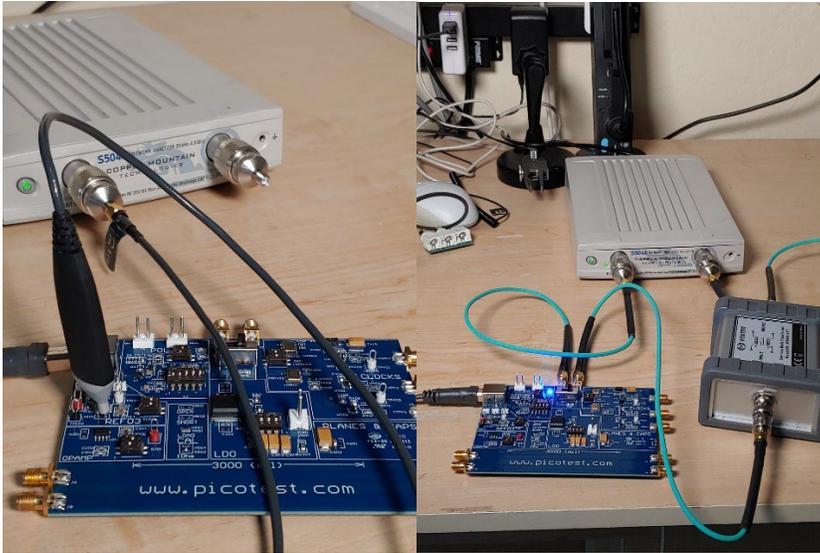


Figure 17: 1-port measurement setup (left) and 2-port shunt through measurement setup (right).

Installing and Using the Standalone PC Version of NISM

The NISM conversion from impedance and $Q(Tg)$ is available in a standalone form for Windows operating system PCs.

To use the software and perform a calculation:

- Copy the standalone NISM.exe application to your PC
- Graph the impedance magnitude and group delay curves for the circuit you wish to evaluate for stability.
- Enter three arguments via STDIN
 - Argument 1 is Z frequency (Frequency of the impedance magnitude peak you want to assess (as a number not in DB) - (type of number is a double). This generally corresponds to the control loop bandwidth of the VRM you are assessing.
 - Argument 2 is the $Q(Tg)$ frequency at the peak of the group delay. This peak will be close in frequency to the impedance magnitude peak (double). It may be large or small depending on the stability (larger peaks correspond to worse stability)
 - Argument 3 is $Q(Tg)$ (double). This is the actual peak Q value in the group delay curve.

```
$ ./nism 13666316.2929557 12882057.4646071 2.845500012792792  
18.627703
```

This will return the Phase Margin (double) via STDOUT.

Note: Pay attention to pathing - the method above is using relative pathing. i.e., NISM.exe must be ran from the local directory. If you wish to run the application from another directory, modify the pathing to be absolute.

STDIO allows NISM to be called from any language or environment that can interact with the operating system.

For example, in Python:

```
nismrunner.py  
1 import os  
2  
3 result = os.popen('nism 13666316.2929557 12882057.4646071 2.845500012792792')  
4  
5 print(result.read())
```

Example Circuit

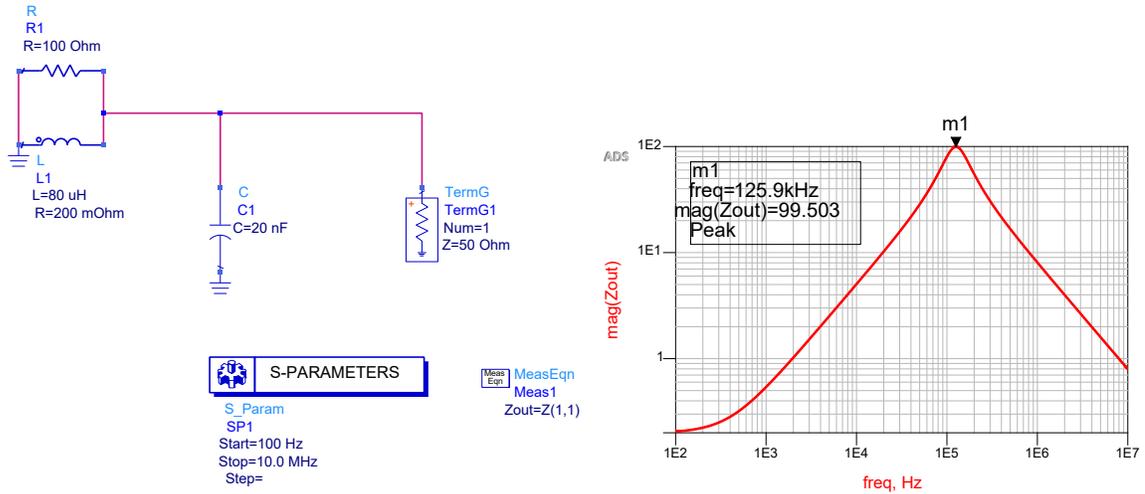


Figure 18: Sample circuit (left) and Impedance Magnitude (right).

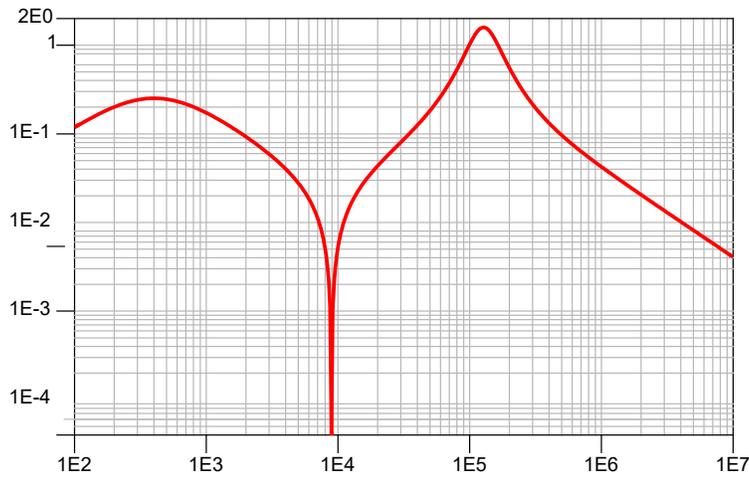


Figure 19: Group delay Q(Tg) plot .

Q (Tg) plot can be created as $\text{Freq} * \text{Pi} * \text{ABS}(\text{diff}(\text{phase}(\text{Zout}))) / 360$ in ADS.

The call to NISM.EXE would then be **“NISM 125900, 1288000, 1.589”**

This would yield an equivalent PM result of 32.376 degrees.

Chapter 3 – NISM Examples - Hardware Instruments

This chapter provides several example Non-invasive stability measurements using the Picotest VRTS3 demonstration board.

Example 1– T Over R Measurement

In this example for the E5061B, we will assess the stability of a low-drop out linear regulator using only the LDO's output impedance. Referring to the VRTS3 manual (<https://www.picotest.com/downloads/VRTS03/VRTS3-User-Guide.pdf>) we will measure test point H301 on the Picotest VSRT3 Demo board. The test setup can be found in this document, <https://www.picotest.com/articles/Agilent-App-Notes/Non-Invasive-Assessment-of-Voltage-Regulator-Phase-Margin.pdf>. A setup diagram is shown below.

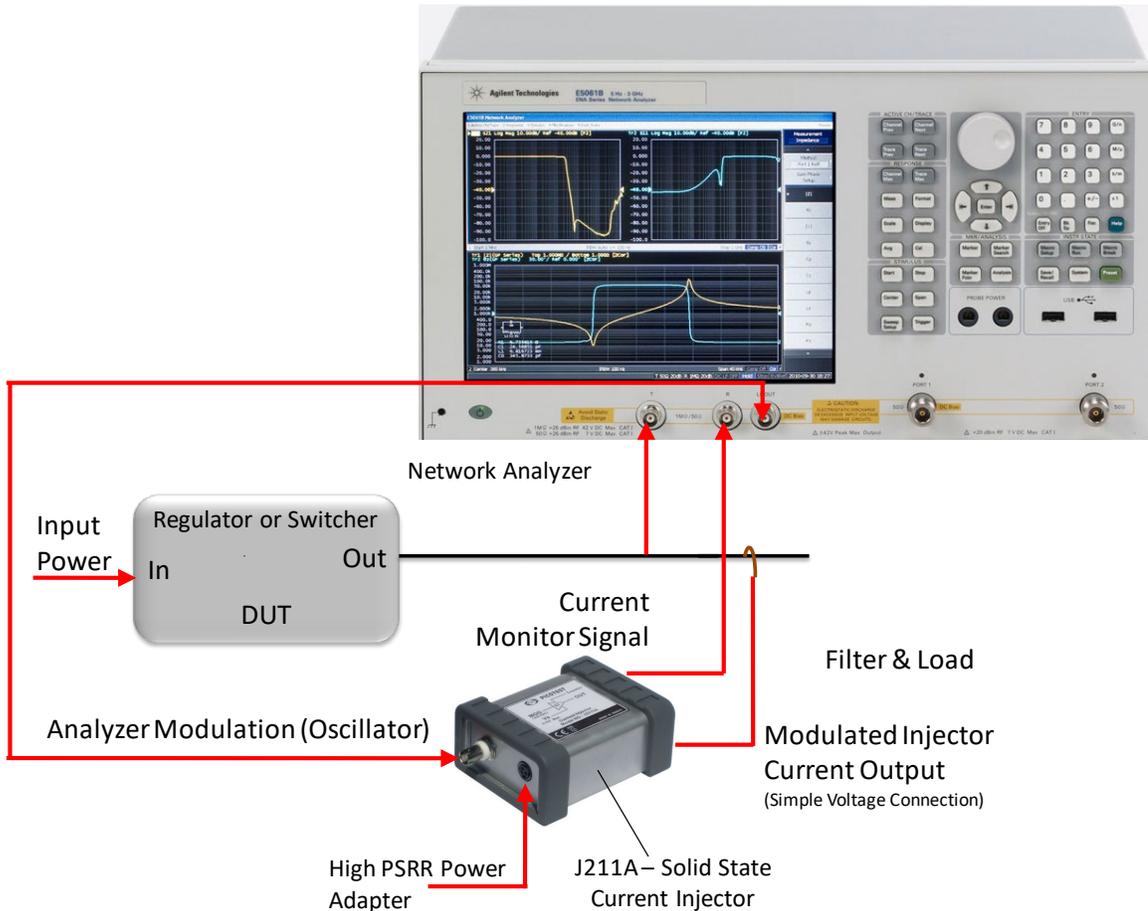
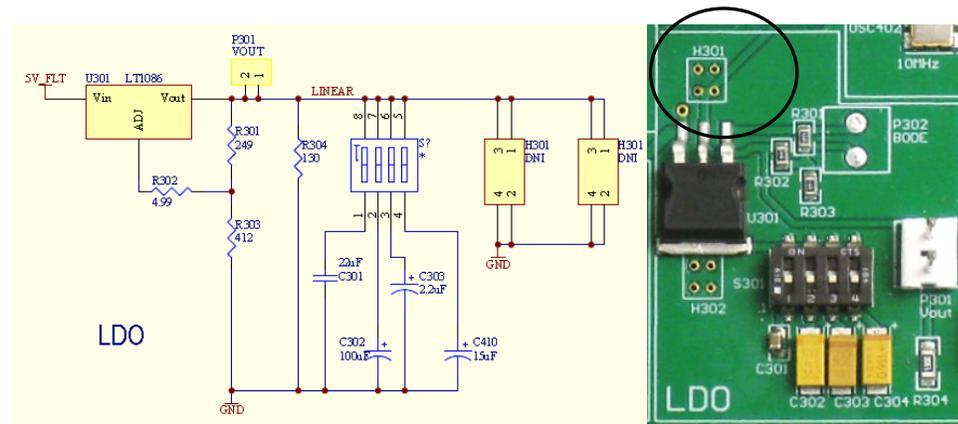


Figure 20: The impedance test setup. Connections to the injector can be made with BNC cables. The connections from the E5061B to the VRTS3 board can be made with simple voltage probes.

The test setup to measure impedance of regulators uses the J2111A Current Injector, https://www.picotest.com/products_J2111A.html. An Injector user manual can be found here, <https://www.picotest.com/downloads/INJECTORS/Injector-Manual-1.3.pdf>.

We are going to use the T/R (GP) ports to measure the LDO impedance. The circuit and board image are shown below. Once you have your hardware set up correctly, you can begin adjusting the instruments measurement settings. Follow the step-by-step instructions below.



VRTS3 LDO circuit and H301 test point.

Instrument Setup: from the instrument's main menu,

1. Click Measurement S11
 - a. Click Measurement Port [S-Parameter]
 - i. Click Gain-Phase
 - ii. Click Return
 - b. Click Gain-Phase Setup
 - i. Click R Input Z
 1. Click 50Ohms
 - ii. Click R Attenuator
 1. Click 0 dB
 - c. Click Return
2. Click Average
 - a. Click IF Bandwidth
 - i. Change IF Bandwidth to 70Hz
 - ii. Click Return
3. Click Stimulus
 - a. Click Start
 - i. Change Start to 100Hz
 - ii. Click Return
4. Click Sweep Setup
 - a. Click Sweep Type
 - i. Click Log Freq

The instrument should now be set up correctly.

Next, we'll measure stability (Phase) margin of the circuit.

1. Load and run the macro, **NISM.VBA**.
2. Probe the board at H301 and measure the impedance magnitude in trace 1.
3. Click the [Macro Run] hardkey.
4. Make sure to keep the measurement active (probed) while you run the macro. That way the macro can acquire the phase data.

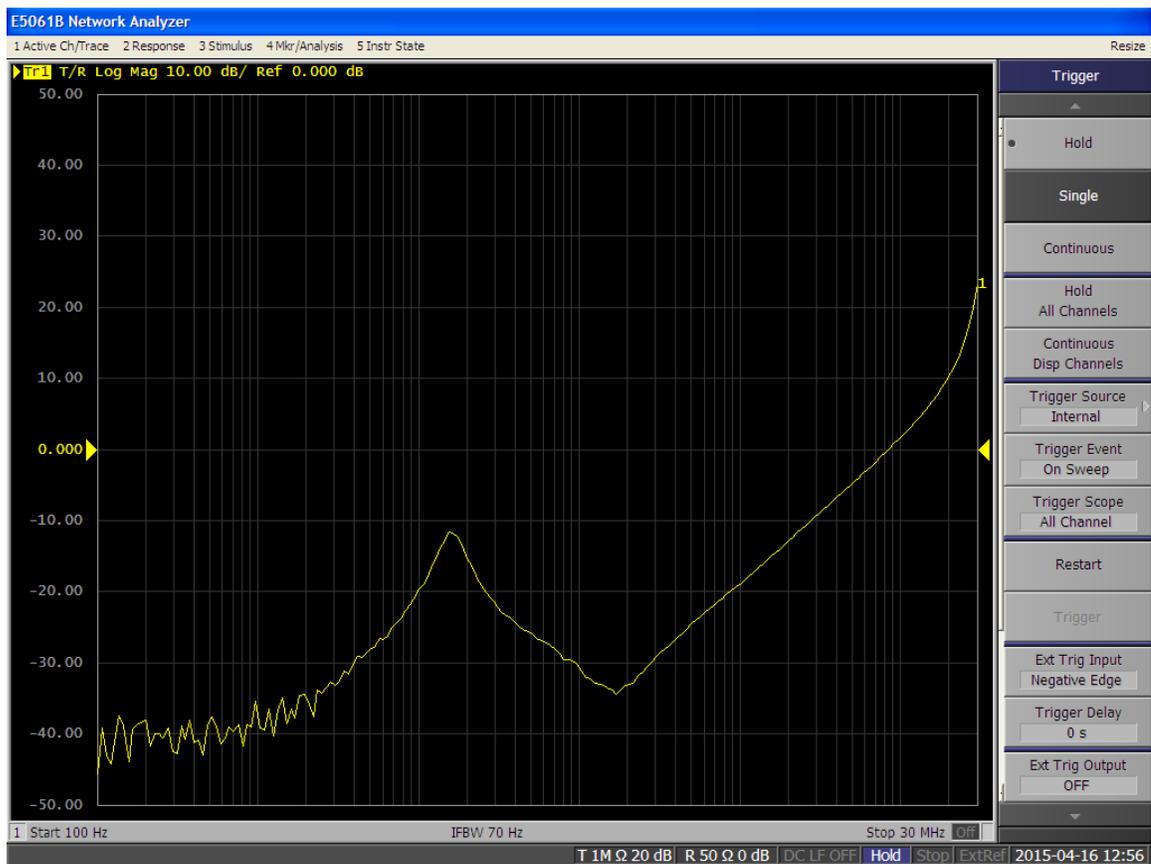


Figure 21: Step 4. Acquire the magnitude of the output impedance using the T/R ports in trace 1.

- Click the Calculate Q button in the Command Menu. The macro will process the impedance data. After the macro runs, a second waveform will be displayed in trace 2; the Effective Q, which is related to the Group Delay of the output impedance, as shown below.

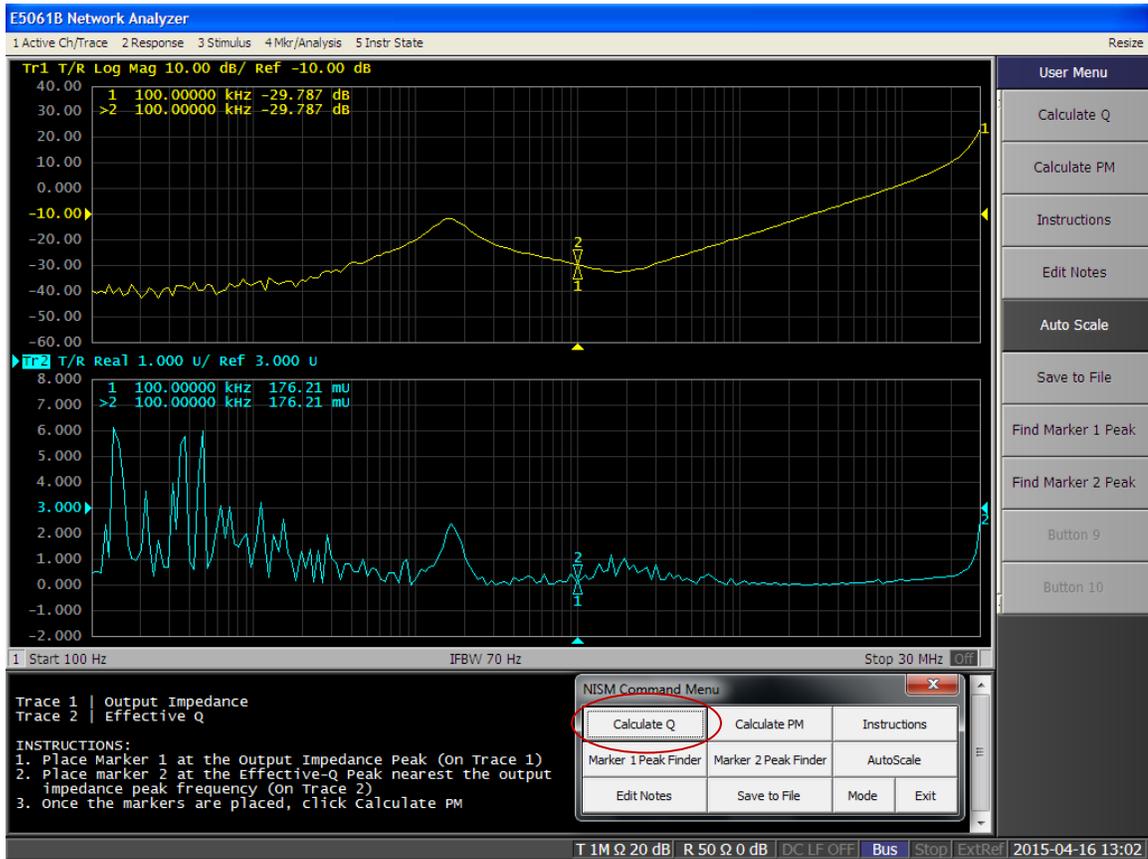


Figure 22: Step 5. After the macro runs (Calculate Q button), the impedance conversion process will occur and display the Effective Q trace.

6. Position marker 1 on trace one (output impedance) near the impedance peak. Position marker 2 on trace two (Effective Q waveform) on the peak nearest in frequency to the impedance peak frequency. The Marker Peak Finder buttons on the NISM command menu assist in finding a local maximum once you place the marker near the impedance peak.

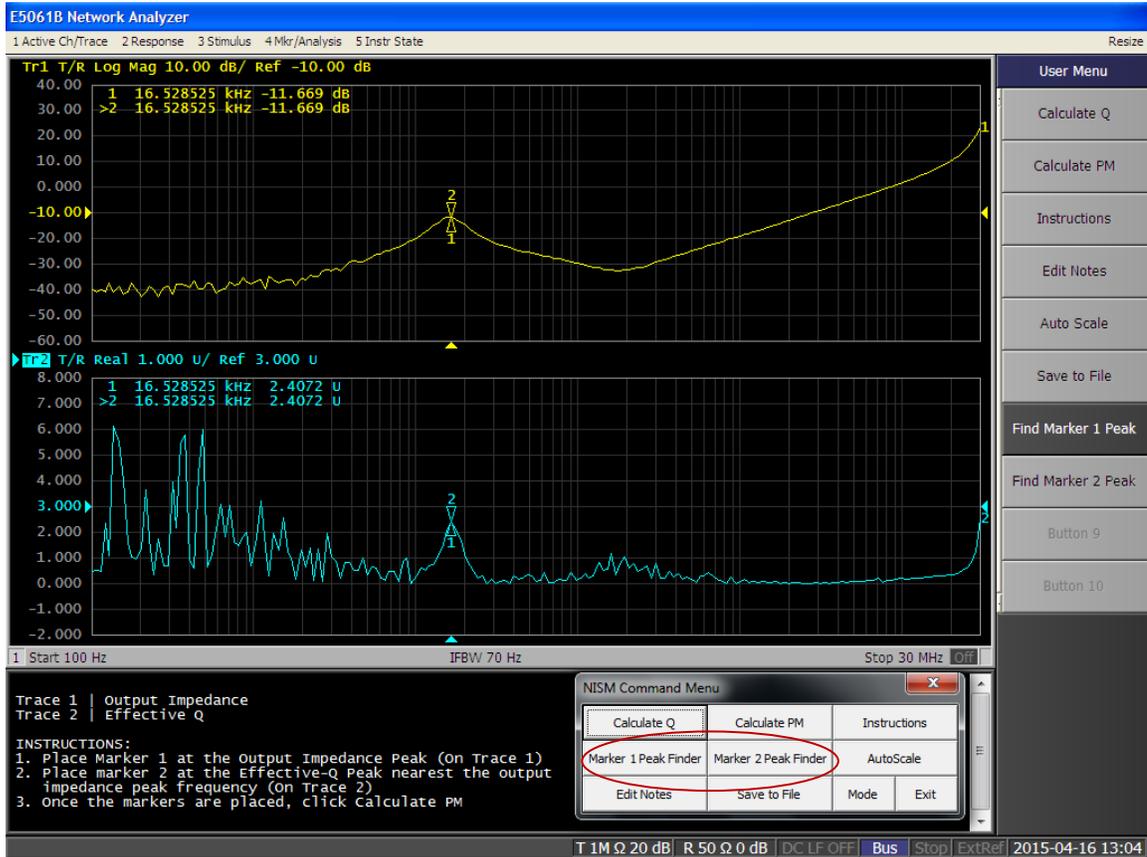


Figure 23: Step 6. Position marker 1 on trace 1 and marker 2 on trace 2 as detailed in the instructions at the bottom of the screen.

- Click the “Calculate PM” button in the User menu. The phase margin will be displayed at the bottom of the instruction window. You may move the markers and click the Calculate PM button repeatedly to update the Phase Margin computation.

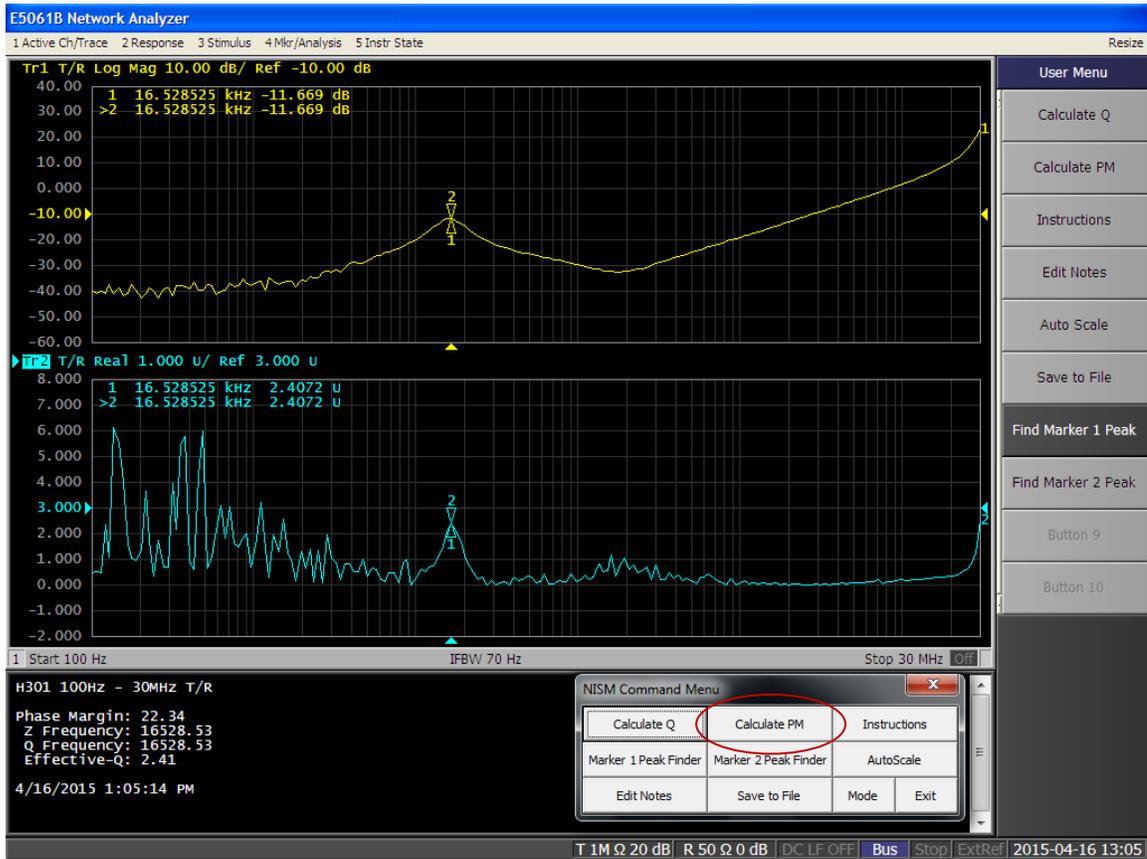


Figure 24: Step 7. After positioning the markers, click the “Calculate PM” button. The phase margin will be displayed at the bottom of the instruction window.

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

See the section on Saving Data or the native E5061B print data file dialogs to save your measurement results.

This concludes Example 1.

Example 2 – 1Port – 2Port Measurement

In this example, we will use the high frequency Ports 1 & 2 to measure the stability of an opamp via its output impedance. To do this we will probe the H201 test point on the Picotest VSRT3 Demo board and use the NISM.VBA macro.

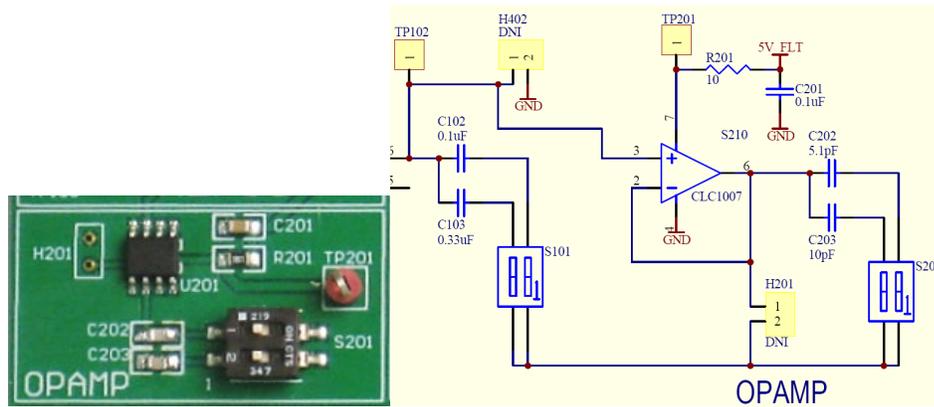


Figure 25: Opamp circuit and H201 test point. The H201 test point can be measured using the Picotest 1 Port PDN probe. The picture above shows the reference being tested. The H201 test point is just below the reference.

For more information about the test board required for this example measurement, please see [https://www .picotest.com/products_VRTS03.html](https://www.picotest.com/products_VRTS03.html). The output impedance of the opamp can be measured by connecting the Picotest 1-Port PDN probe to Port 1 on the E5061B.

Once you have your hardware set up correctly, begin adjusting the instruments measurement settings. Follow the step-by-step instructions below:

From the instrument's main menu,

1. Click measurement S11
 - a. + Click impedance analysis menu
 - i. Click $|z|$
 - ii. Click Return
 - b. Click Display
 - i. Click Num of Traces
 1. Click 2
 2. Click Return
2. Click on Trace two
 - a. Click measurement S11
 - i. Click impedance analysis menu
 1. Click $|z|$
 2. Click Return
3. Click Average
 - a. Click IF Bandwidth
 - i. Change bandwidth to 100Hz
 - ii. Click Return
4. Click Stimulus
 - a. Click Start
 - i. Change Start to 100k
 - b. Click Stop
 - i. Change Stop to 50M
 - c. Click Return
5. Click Sweep Setup
 - a. Click Power
 - i. Change Power to -20dB
 - ii. Click Return
 - b. Click Sweep Type

- i. Click Log Freq
 - c. Click Return
 6. Click Calibration
 - a. Click Calibrate
 - i. Click 1Port Cal
 1. Click Open (on the VRTS3)
 2. Click Short (on the VRTS3)
 3. Click Load (on the VRTS3)
 4. Click Done
 5. Click Return
 - ii. Click Return
 - b. Click Return

The instrument should now be set up correctly,

Next, you can convert the impedance to Stability (Phase) Margin using NISM.

1. Load the Macro, **NISM.VBA**.
2. Click the [Macro Run] hardkey.
3. Select Port 1 from the mode menu.
4. Probe the test point and acquire the output impedance MAGNITUDE data (S11) in trace 1.

This data would normally be taken at the output of your regulator, switcher, POL, opamp, filter, etc. You can use any measurement configuration (1 port reflection, 2-port shunt, etc. to gather the data if the measurement is suitable for the impedance level you are measuring).

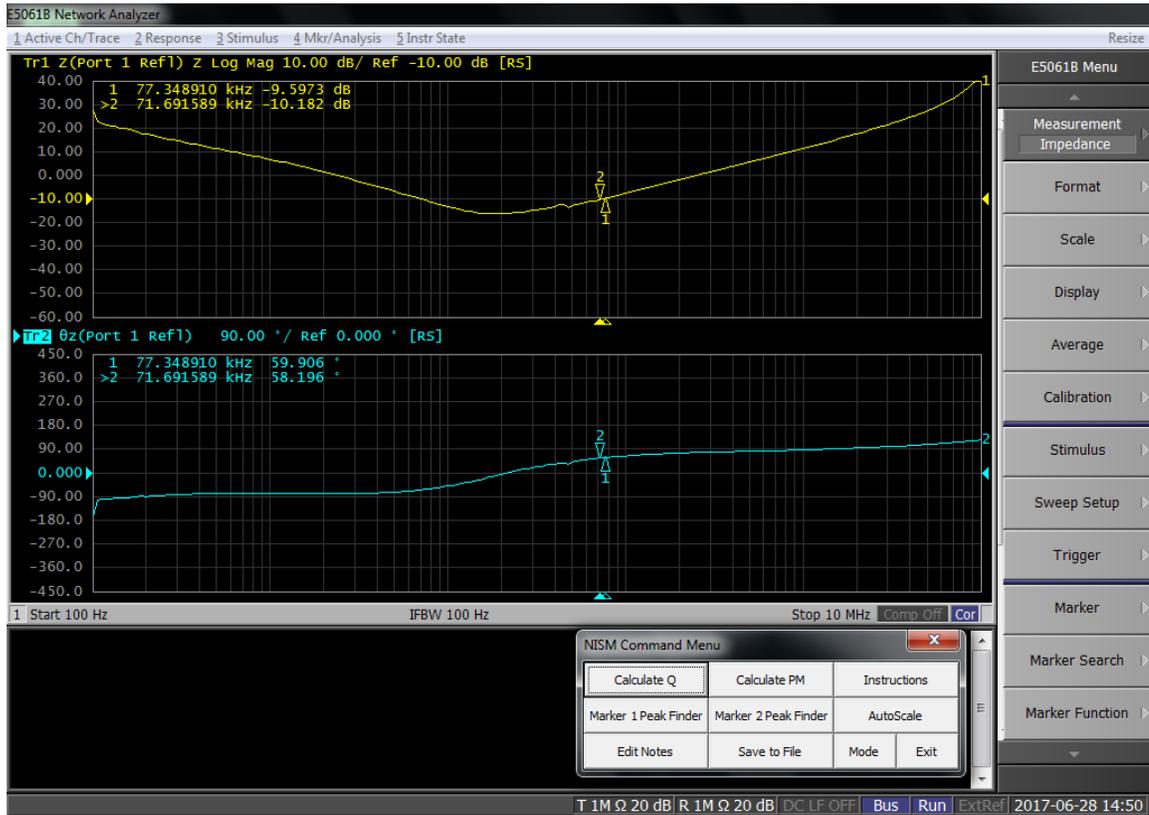


Figure 26: Step 4. Acquire the magnitude of the output impedance in trace 1.

- Click Calculate Q. After the macro runs, the output impedance phase waveform will be replaced by a new waveform; the Effective Q, which is related to the Group Delay of the output impedance. As the macro runs, make sure your test probe is on the test point and the output impedance data that is being collected is valid.

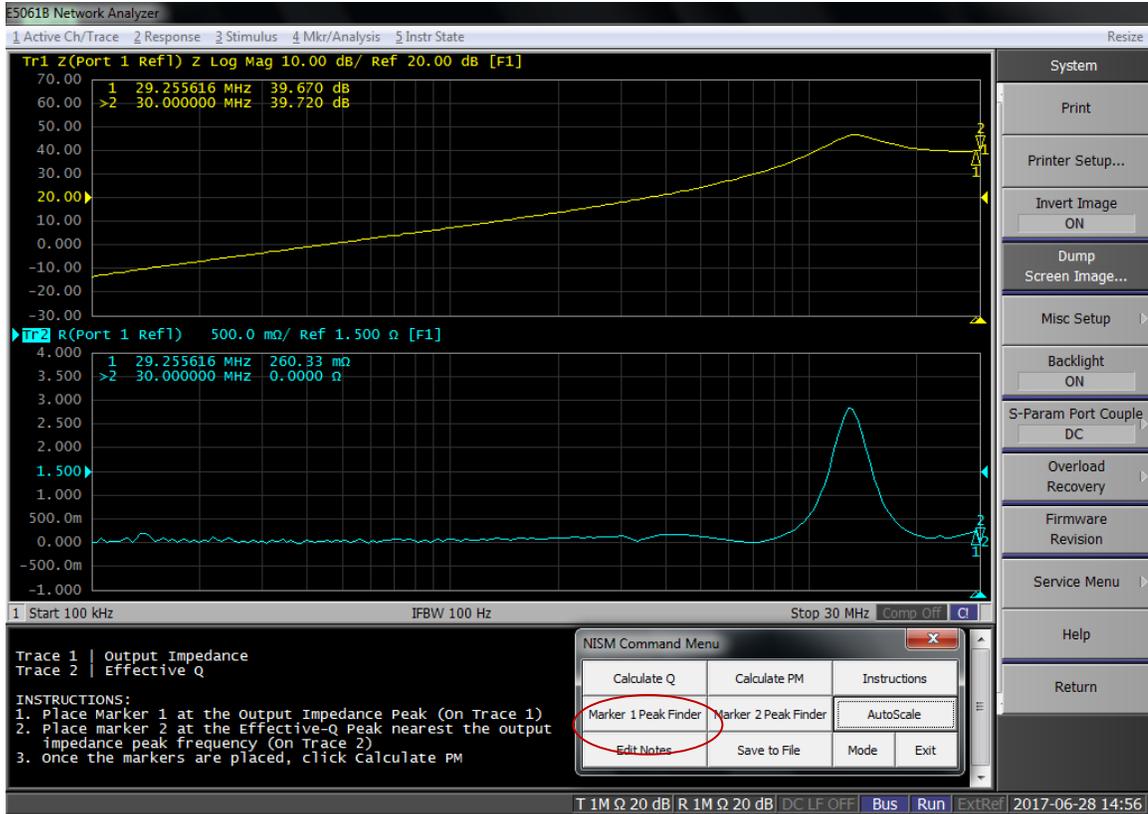


Figure 27: Step 5. After the macro runs, the impedance conversion process will begin and the Effective Q waveform will appear in trace 2.

- Position marker 1 on trace 1 (output impedance magnitude) at the impedance peak. Position marker 2 on trace two (Effective Q) on the peak nearest in frequency to the impedance peak. The Marker Peak Finder buttons on the NISM command menu will assist in finding a local maximum once you place the marker near the impedance peak.

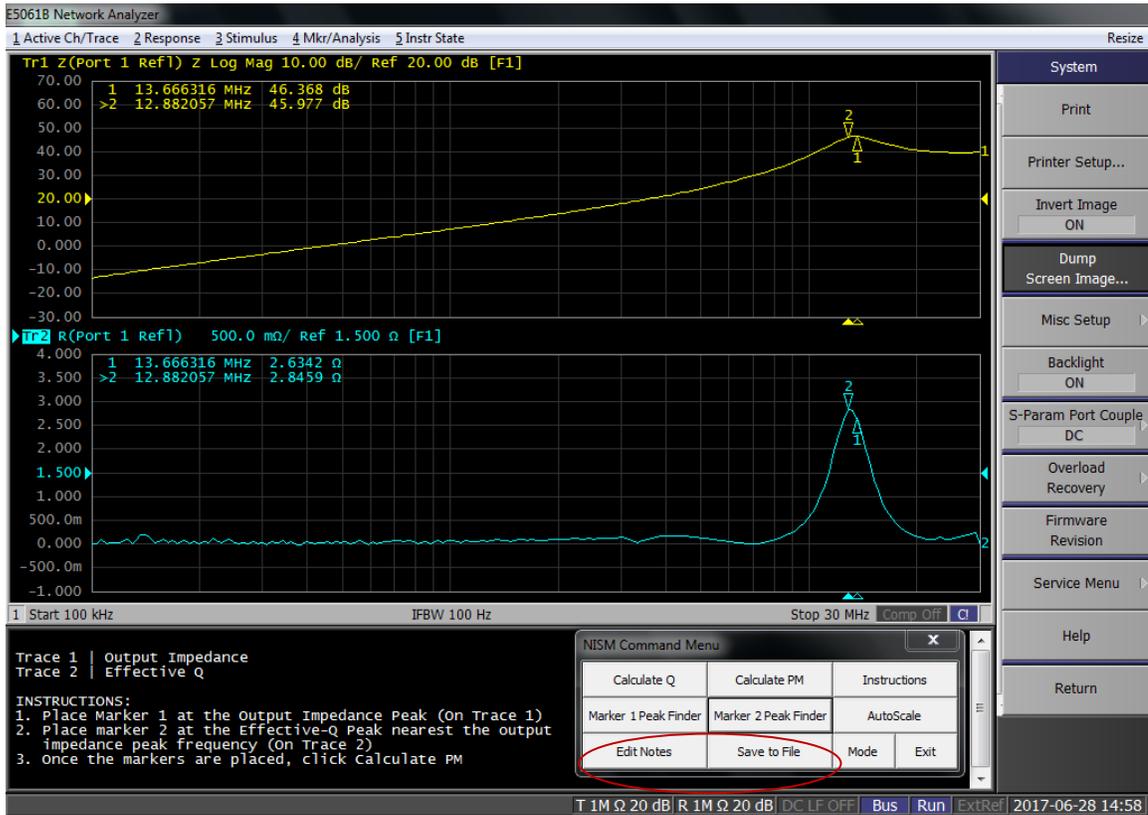


Figure 28: Step 6. Position marker one on trace 1 and marker 2 on trace 2 as detailed in the instructions at the bottom of the screen.

7. Click the “Calculate PM” button. The phase margin will be displayed at the bottom of the instruction window. You may move the markers and click the Calculate button repeatedly to update the Phase Margin computation.



Figure 29: Step 7. After positioning the markers, click the “Calculate PM” button. The phase margin will be displayed at the bottom of the instruction window.

Note: if you change settings or re-measure the output impedance, you will need to click the Initial Setup button to re-compute the Effective Q waveform.

See the section on Saving Data or the native E5061B print data file dialogs to save your measurement results.

This concludes Example 2.

Example 3– 1-Port Measurement

In this example for the R&S ZNL, we will assess the stability of a high frequency opamp using only the opamp’s output impedance. Referring to the VRTS3 manual (<https://www.picotest.com/downloads/VRTS03/VRTS3-User-Guide.pdf>) we will measure S11 at H201 S201 on the Picotest VSRT3 Demo board.

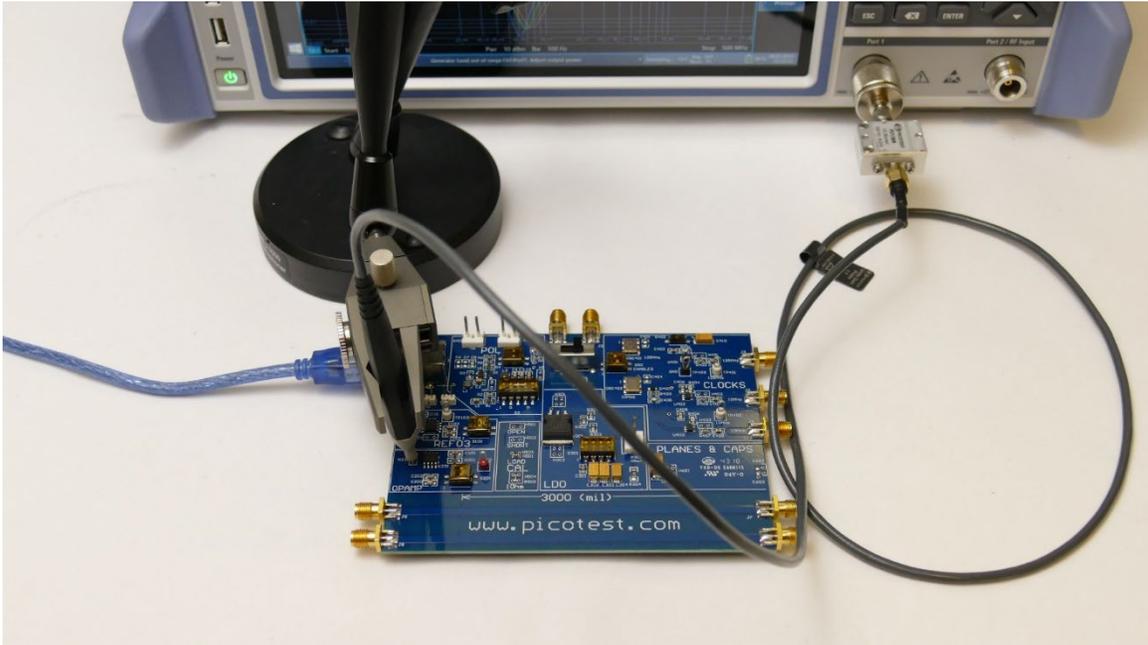


Figure 30: Test setup for a 1-port impedance measurement using a Picotest P2100A 1-Port 50 ohm Transmission Line PDN Probe and the Picotest P2130A DC block.

Note: Using a 1-Port 50Ohm probe and a DC blocker allows measurements greater than about 100milliOhms.

The steps are as follows:

1. Connect the 1-port probe and DC block to Port 1
2. Perform the SOL calibration using the calibrator on the VRTS3 board.
3. Select Start->Run->Non-Invasive Stability on the ZNL to run the NISM software
4. Select Z11 and make the measurement
5. Click Data->Mem in the NISM dialog
6. Click Calculate Q in the NISM dialog
7. Place markers on the impedance and $Q(T_g)$ peaks
8. Click Calc Phase Margin

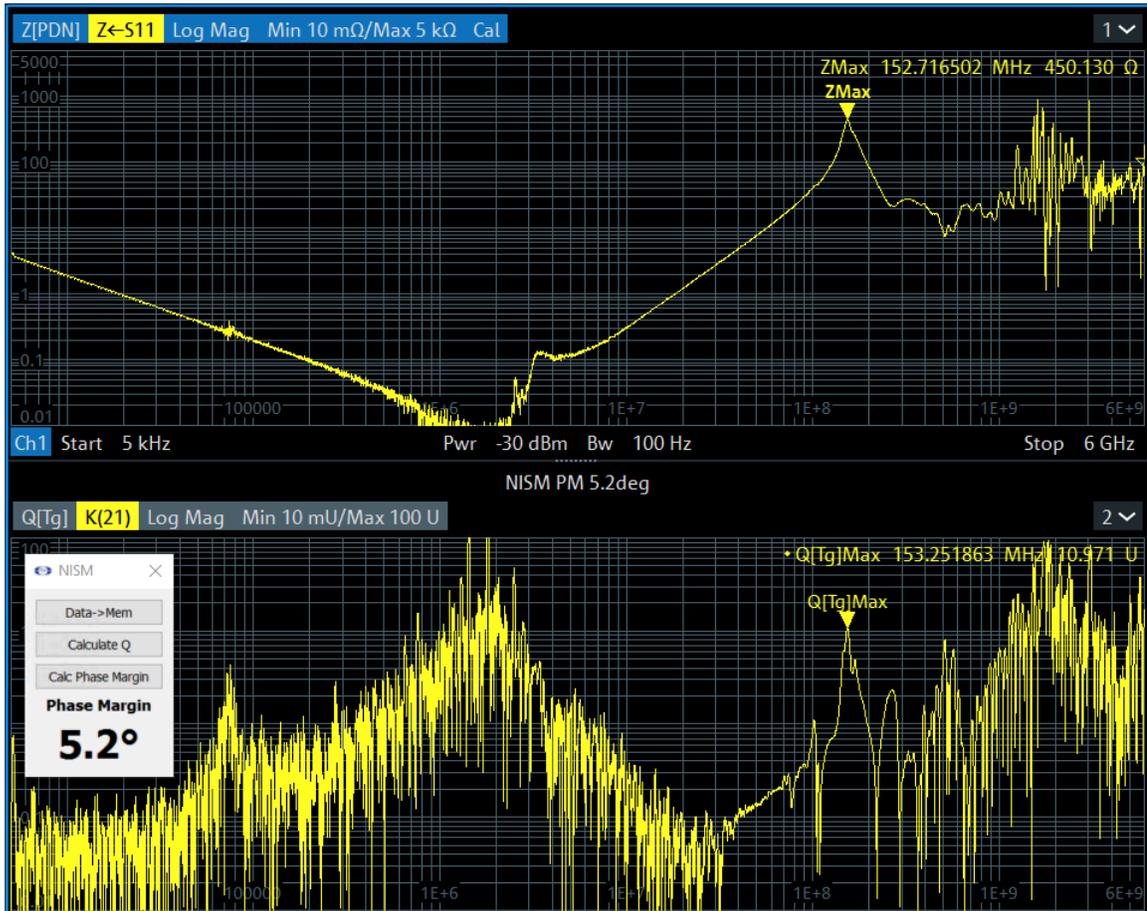


Figure 31: VRTS3 Opamp - 1-Port S11 measurement at H201 S201-On-Off shows the opamp's phase margin to be 5.2 degrees.

Example 3— 2-Port Shunt-Through Measurement

In this example for the R&S ZNL, we will assess the stability of an LDO using only the LDO's output impedance. Referring to the VRTS3 manual (<https://www.picotest.com/downloads/VRTS03/VRTS3-User-Guide.pdf>) we will measure S21 at H301 on the Picotest VSRT3 Demo board.

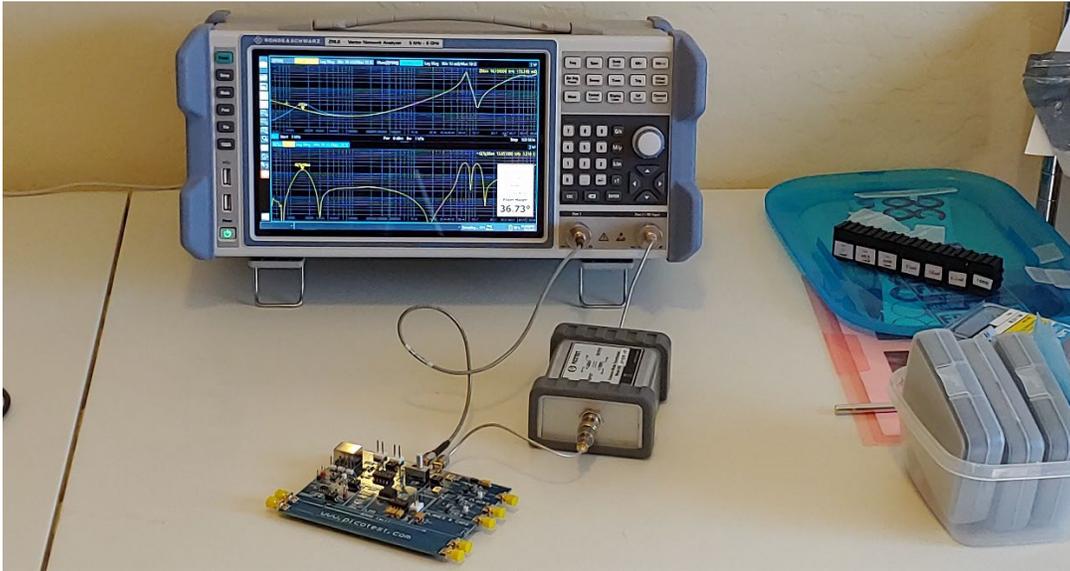


Figure 32: Test setup for a 2-port shunt-through impedance measurement using a Picotest J2102B coaxial transformer ground loop breaker. The SMA cables connect to the output of the LDO on the VRTS3 board.

The steps are as follows:

1. Connect 2 50 ohm SMA cables to the VTRS3 board and the ZNL. Through Port 2 connect the Picotest J2102B group loop breaker.
2. Perform a thru calibration.
3. Select Start->Run->Non-Invasive Stability on the ZNL to run the NISM software
4. Select Z21 and make the measurement
5. Click Data->Mem in the NISM dialog
6. Click Calculate Q in the NISM dialog
7. Place markers on the impedance and $Q(Tg)$ peaks
8. Click Calc Phase Margin

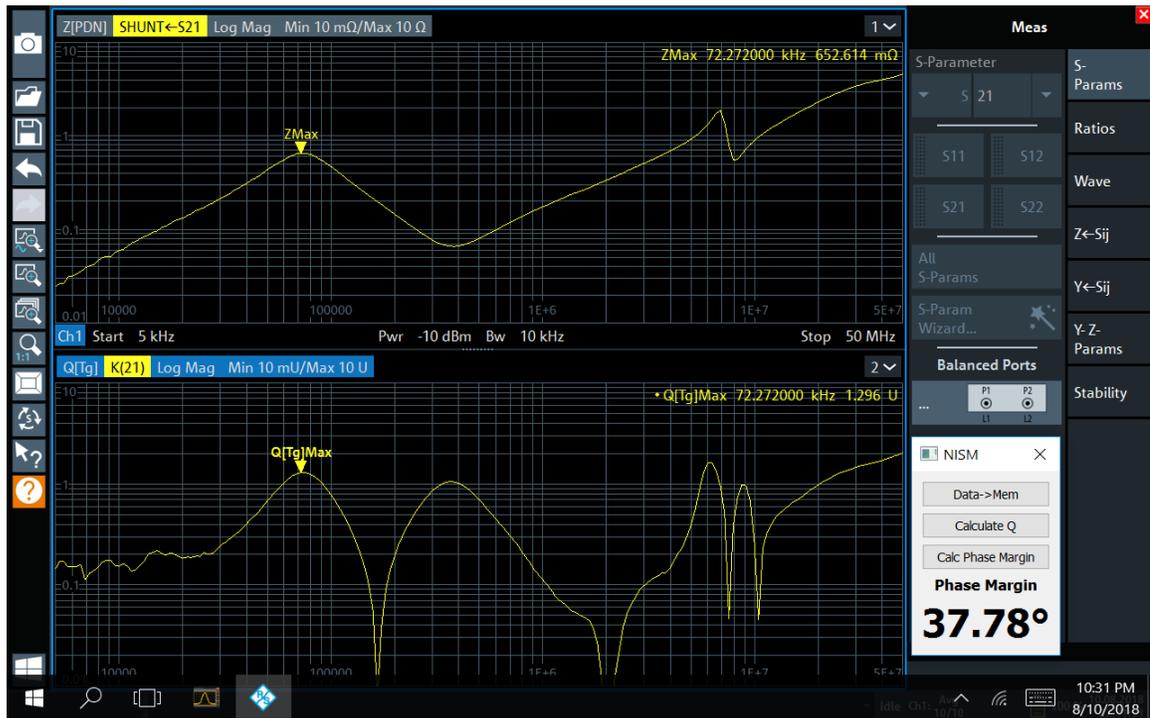


Figure 33: VRTS3 LDO - Shunt-S21 at H301 S301-On-Off-Off-Off PM 37.78 shows the LDOs phase margin to be 37.78 degrees. This is slightly different from the picture above due to different output capacitance settings (the VTRS3 allows the LDO to be tested using a variety of output capacitors).

Example 4— 2-Port Shunt-Through Measurement

In this example for the Copper Mountain Technologies Compact S5065 VNA, we will assess the stability of an LDO using only the LDO's output impedance. Referring to the VRTS3 manual (<https://www.picotest.com/downloads/VRTS03/VRTS3-User-Guide.pdf>) we will measure S21 at H301 on the Picotest VSRT3 Demo board.

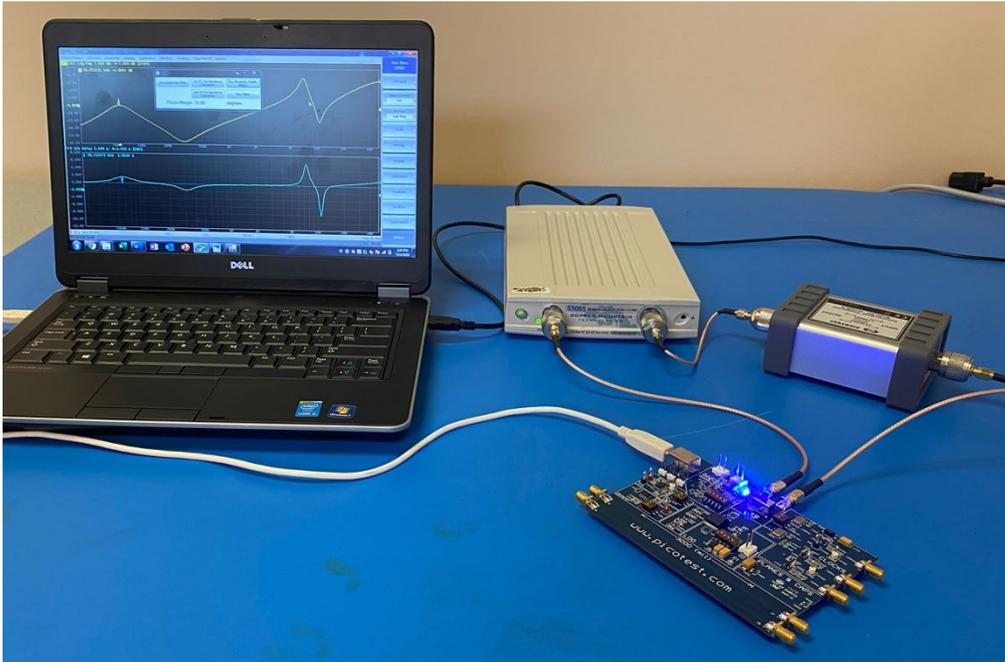


Figure 34: Test setup for a 2-port shunt-through impedance measurement on the CMT Compact S5065 using a Picotest J2102B coaxial transformer ground loop breaker. The Picotest PDN Cable® connect to the output of the LDO on the VRTS3 board.

1. Connect two 50 ohm PDN Cables to the VRTS3 board and the CMT Compact S5065. Through Port 2 connect the Picotest J2102B group loop breaker.
2. Perform a thru calibration.
3. Record the LDO's output impedance (magnitude).
4. Run the NISM software, CMT_nism_plugin.exe.
5. Follow the steps as outlined in the previous section to obtain the stability margin below.

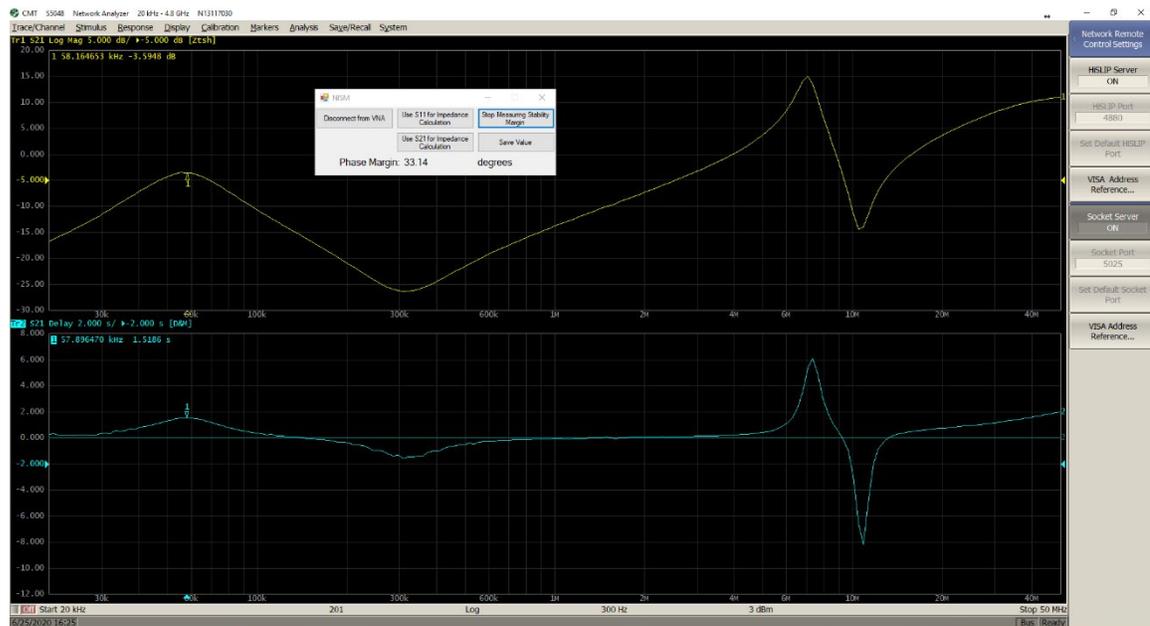


Figure 35: CMT S5065 measurement of the VRTS3 LDO - Shunt-S21 at H301 shows the LDOs phase margin to be approximately 33 degrees. This may be slightly different from the picture above due to different output capacitance settings (the VRTS3 allows the LDO to be tested using a variety of output capacitors) or the quality of the calibration.

Chapter 4 - Installing and Running NISM in Cadence PSpice

The NISM functionality is included if you have PSpice version 23.1 or greater (SPB23.1 hotfix) or greater.

To run the NISM in PSpice:

- Display the impedance magnitude waveform at the output of your power supply.
- Display the QTG waveform from the impedance waveform.
- Determine the impedance/QTG peak of interest. Usually the bandwidth of the control loop. You can differentiate impedance peaks due to passive resonances by plotting off state impedance along with the on-state impedance.
- Evaluate the NISM or NISM_range measurement equation. The phase margin will be displayed.

PSpice NISM Examples

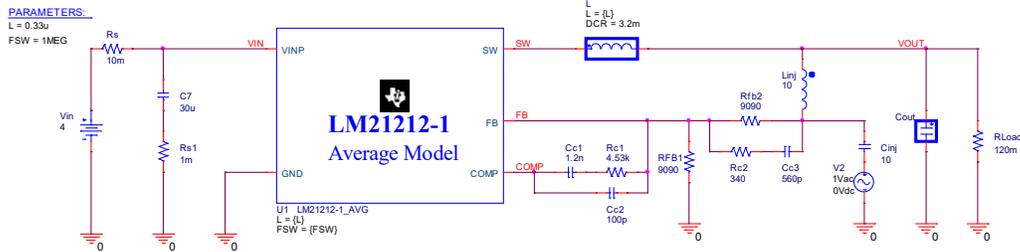
The first example uses the following project available from TI's website for one of their average models. Please download the project from the link below, extract its contents, and open the LM21212-1_AVG.opj file from PSpice to follow along.

Design #1 – LM21212-1 PSpice Average Model <https://www.ti.com/lit/zip/snvm395>

LM21212-1 AVERAGE MODEL



Title	LM21212-1 12A High Efficiency Synchronous Point of Load Buck Regulator with Frequency Synchronization		
Size	Document Number		Rev
D	Datasheet :SNVS671D	EVM:SNVA467A	1.0
Date:	Monday, March 18, 2013	Sheet	1 of 1



Application Notes:

1. The LM21212-1 Average model is encrypted and will only run in PSPICE Versions 15.7 and above.
2. The testbench has been configured for VIN = 4V, VOUT= 1.20V & IOUT = 10A
3. Only the required pins for AC analysis have been modelled.
4. To change the inductor value or switching frequency, please make changes in the parameter section.
5. Thermal characteristics, operating quiescent current and shutdown current of the part have not been modelled.
6. The AC simulation runs from 100Hz to 1.5MHz and takes a few seconds to run on a 4 core 2.8GHz machine

Figure 36: The LM21212-1 average model from TI. The test circuit is configured to simulate the loop gain Bode plot.

You will need to modify the simulation schematic so that it is configured for simulating the output impedance. Do the following:

1. Delete Linj and replace it with a wire.
2. Delete Cinj and V2.
3. Place an AC current source between VOUT and ground. Its polarity is not relevant to what is plotted.

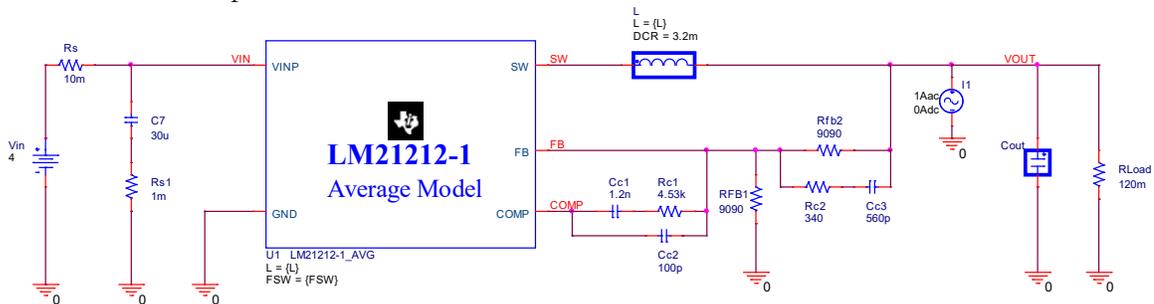


Figure 37: The LM21212-1 Average model from TI. The test circuit is configured to simulate the closed loop (on state) output impedance plot.

4. Add the following macro to PSpice A/D (Probe).

$$QTG(x) = ABS(D(P(x)))/360 * FREQUENCY * PI / 1Hz$$

Note that this is known as the Q of the group delay. It normally doesn't have the absolute value in its definition, but it is used here as a matter of convenience as this quantity is normally plotted using a log-y scale and PSpice does not plot quantities with negative values in a log-y scale.

$$Q(Tg) = \pi * f * Tg$$

5. Simulate the circuit and then in the PSpice A/D window plot the following waveforms:
 - In the top plot, plot DB(V(VOUT)) and DB(V(OFF))
 - QTG(V(VOUT))

Note that the QTG plot uses a log-y scale.

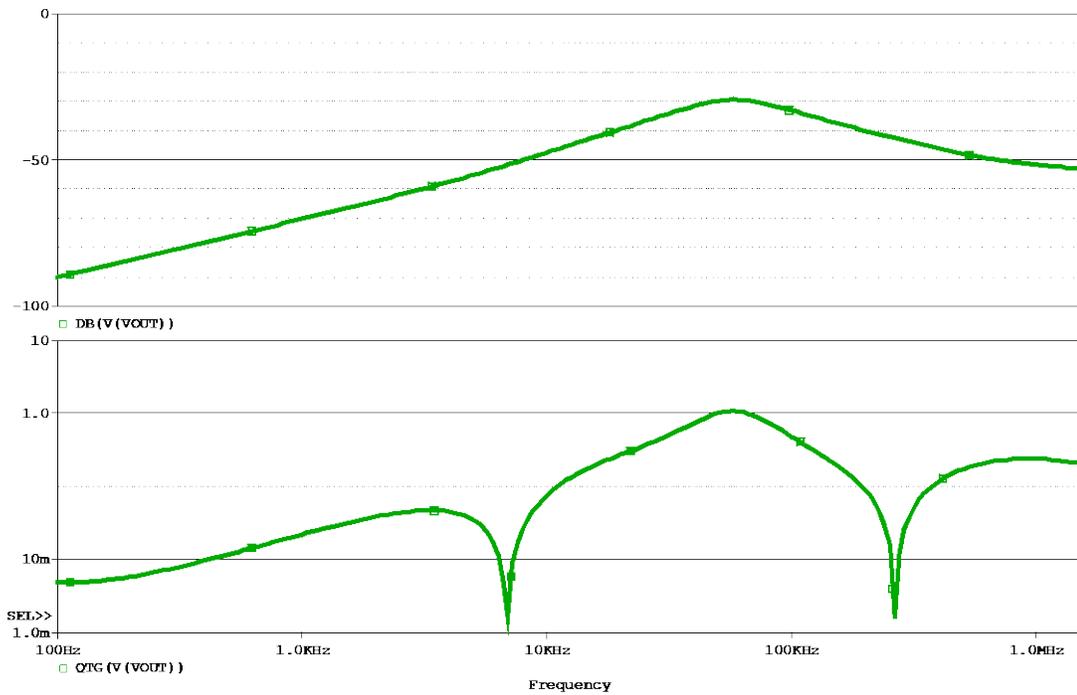


Figure 38: The output impedance and QTG plots of the LM21212-1 Average model.

The peaks in the output impedance magnitude and QTG plot are the global maximums over the frequency range simulated so there are multiple options for the measurement equations.

NISM(V(Vout)) or NISM_Range(V(Vout), 10k, 300k) can be used. The range used for the latter option must include the global maximums. In addition, DB(V(Vout)) can be used instead of V(Vout).

Measurement Results			
	Evaluate	Measurement	Value
	<input checked="" type="checkbox"/>	NISM(V(Vout))	43.6892657106
	<input checked="" type="checkbox"/>	NISM_Range(V(Vout),10k,300k)	43.6892657106
	<input checked="" type="checkbox"/>	Max(QTG(V(Vout)))	1.0780095246
▶	<input checked="" type="checkbox"/>	Max_XRange(QTG(V(Vout)),10k,300k)	1.0780095246
Click here to evaluate a new measurement...			

Figure 39: The NISM measurement equation options for the LM21212-1 Average model.

The resulting NISM is approximately 43.7 degrees.

Measurement equations for the maximum QTG value are also shown above. This can be used as the value to determine stability if the order of the system is unknown or not 2nd-order.

In many high reliability applications, an acceptable phase margin at end-of-life is 30 degrees. This corresponds to a Q of 2. It is, therefore, desirable that the nominal Q be between 0.707 and 1 in order to account for various tolerances. The stability being impactful to transient response, noise, PSRR, reverse transfer, and other power supply characteristics. It is left to the reader to determine an acceptable Q as per their application.

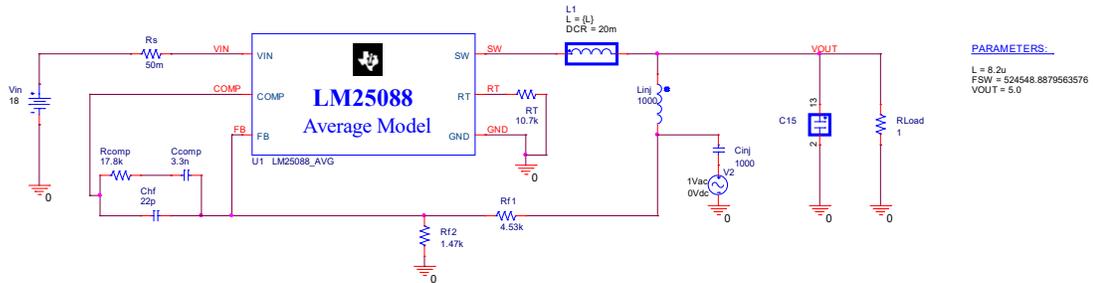
The second example uses another project available from TI's website of one of their average models. Please download the project from the link below, extract its contents, and open the LM25088_AVG.opj file in PSpice to follow along.

Design #2 - LM25088 PSpice Average Model <https://www.ti.com/lit/zip/snvm388>

LM25088 AVERAGE MODEL



Title		
LM25088 Wide Input Range Non-Synchronous Buck Controller		
Size	Document Number	Rev
9	Datasheet :SNVS609G EVM:SNVA383C	1.0
Date:	Thursday, March 14, 2013	Sheet 1 of 1



Application Notes:

1. The LM25088 Average model is encrypted and will only run in PSPICE Versions 15.7 and above.
2. The testbench has been configured for VIN = 18V, VOUT= 5.0V & IOUT = 5A.
3. Only the required pins for AC analysis have been modelled.
4. Inductor Value L ,Switching Frequency FSW & Vout desired has passed as parameters.
5. Thermal characteristics, operating quiescent current and shutdown current of the part have not been modelled.
6. The AC simulation runs from 10Hz to 200kHz and takes approximately 1 sec to run on a 4 core 2.8GHz machine.

Figure 40: The LM25088 Average model from TI. The test circuit is configured to simulate the loop gain Bode plot.

Then modify the simulation schematic so that it is configured for simulating the output impedance. Do the following:

1. Delete Linj and replace it with a wire.
2. Delete Cinj and V2.
3. Place an AC current source between VOUT and ground. Its polarity is not relevant to what is plotted.

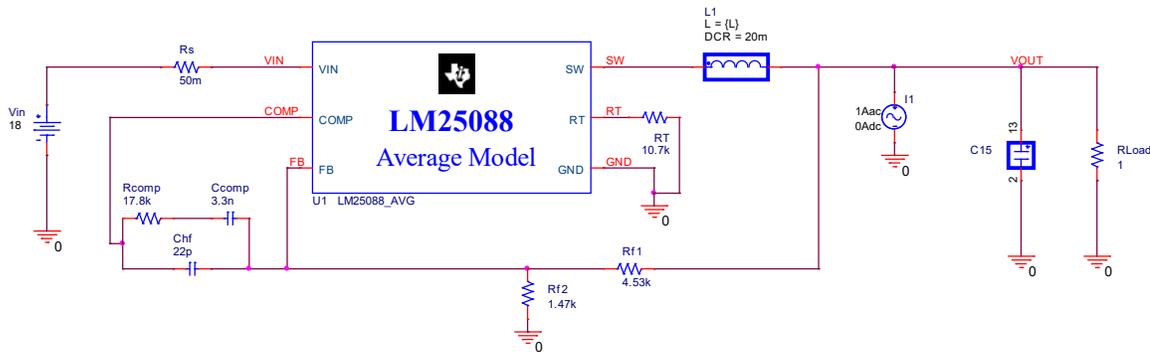


Figure 41: The LM25088 Average model from TI. The test circuit is configured to simulate the closed loop (on state) output impedance plot.

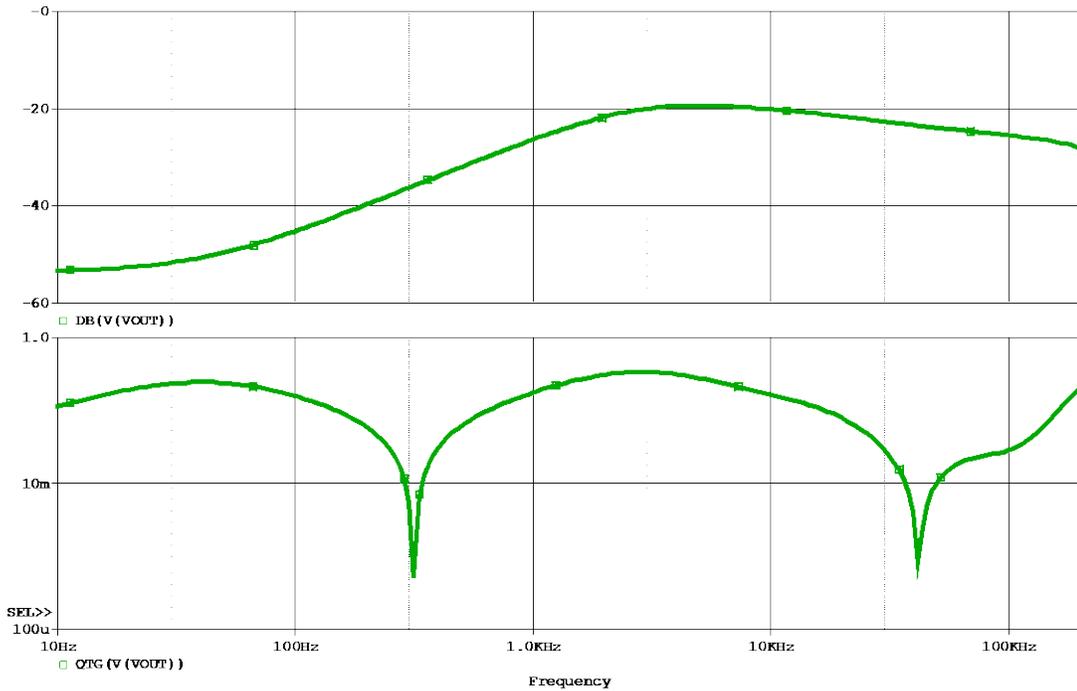


Figure 42: The output impedance and QTG plots of the LM25088 Average model.

The peaks in the output impedance magnitude and QTG plot are the global maximums over the frequency range simulated so there are multiple options for the measurement equations.

NISM(V(Vout)) or NISM_Range(V(Vout), 1k, 100k) can be used. The range used for the latter option must include the global maximums. In addition, DB(V(Vout)) can be used instead of V(Vout).

Measurement Results			
	Evaluate	Measurement	Value
	<input checked="" type="checkbox"/>	NISM(V(VOUT))	73.6644056989
	<input checked="" type="checkbox"/>	NISM_Range(V(VOUT),1k,100k)	73.6644056989
	<input checked="" type="checkbox"/>	Max(QTG(V(VOUT)))	338.2889222599m
	<input checked="" type="checkbox"/>	Max_XRange(QTG(V(VOUT)),1k,100k)	338.2889222599m
Click here to evaluate a new measurement...			

Figure 43: The NISM measurement equation options for the LM25088 Average model.

The resulting NISM shows good stability and is greater than 70 degrees. Measurement equations for the maximum QTG value are also shown above. This can be used as the value to determine stability if the order of the system is unknown or not 2nd-order.

Design #3 – HS117 Three-Terminal Linear Regulator

Another PSpice example is shown below of an HS117 three-terminal linear regulator.

This and other examples are available at no charge. Please email info@aeng.com or info@picotest.com to request the files.

The HS117 and many other accurate IC models are available in the AEi Systems Power IC Model Library for PSpice (<https://www.aeng.com/library.htm>).

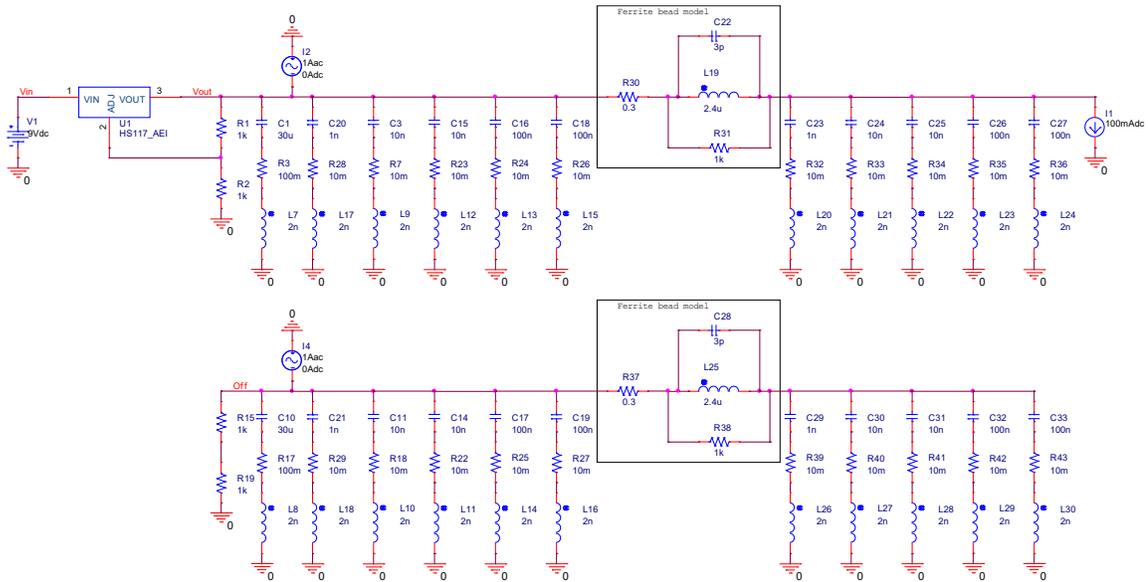


Figure 44: The HS117 test circuit is configured to simulate the on state and off state output impedances.

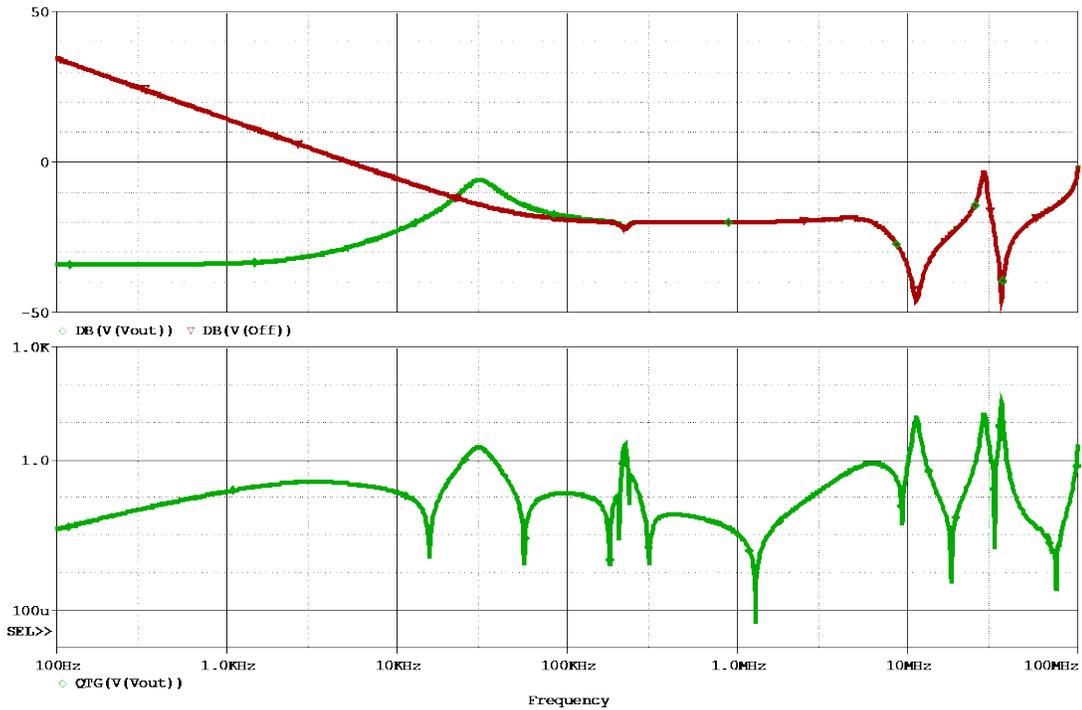


Figure 45: The on state and off state output impedance QTG and magnitude plots of the HS117 three-terminal linear regulator.

The correct peak to use for NISM occurs near 30kHz because this is where the magnitude peak is greater than the off state output impedance (where the control loop is active). The impedance magnitude peaks near 30MHz and 100MHz appear in both the on state and off state output impedances so these are due to passive resonances and should not be used to determine the NISM of the regulator. Therefore, NISM(V(Vout)) cannot be used and NISM_Range(V(Vout), 10k, 100k) is the correct choice. In addition, DB(V(Vout)) can be used instead of V(Vout).

Measurement Results		
Evaluate	Measurement	Value
<input checked="" type="checkbox"/>	NISM(V(Vout))	1.9128860401
<input checked="" type="checkbox"/>	NISM_Range(V(Vout),10k,100k)	24.6287541045
<input checked="" type="checkbox"/>	Max(QTG(V(Vout)))	33.7088615893
<input checked="" type="checkbox"/>	Max_XRange(QTG(V(Vout)),10k,100k)	2.1421193209
Click here to evaluate a new measurement...		

Figure 46: The NISM measurement equation options for the HS117 three-terminal linear regulator.

The resulting NISM is approximately 24.6 degrees.

As before, measurement equations for the maximum QTG value are also shown above. This can be used as the value to determine stability if the order of the system is unknown or not 2nd-order.

Design #4 – Simple Example - Input Filter

NISM work on circuits with or without a feedback loop (open or closed loop). The example below simulates the output impedance of a filter. We can use NISM to determine the effective Q of the filter. As with control loop stability, a Q of < 2 is often used as a requirement in good practice.

For instance, this 2nd-order filter could be a ferrite bead-decoupling capacitor input filter that goes to the VCC pin of an IC.

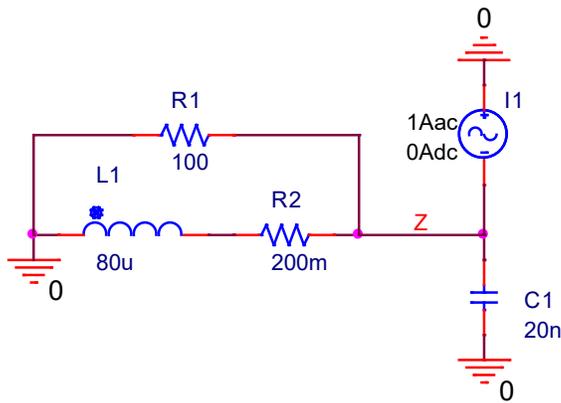


Figure 47: The test circuit to simulate the output impedance of the input filter.

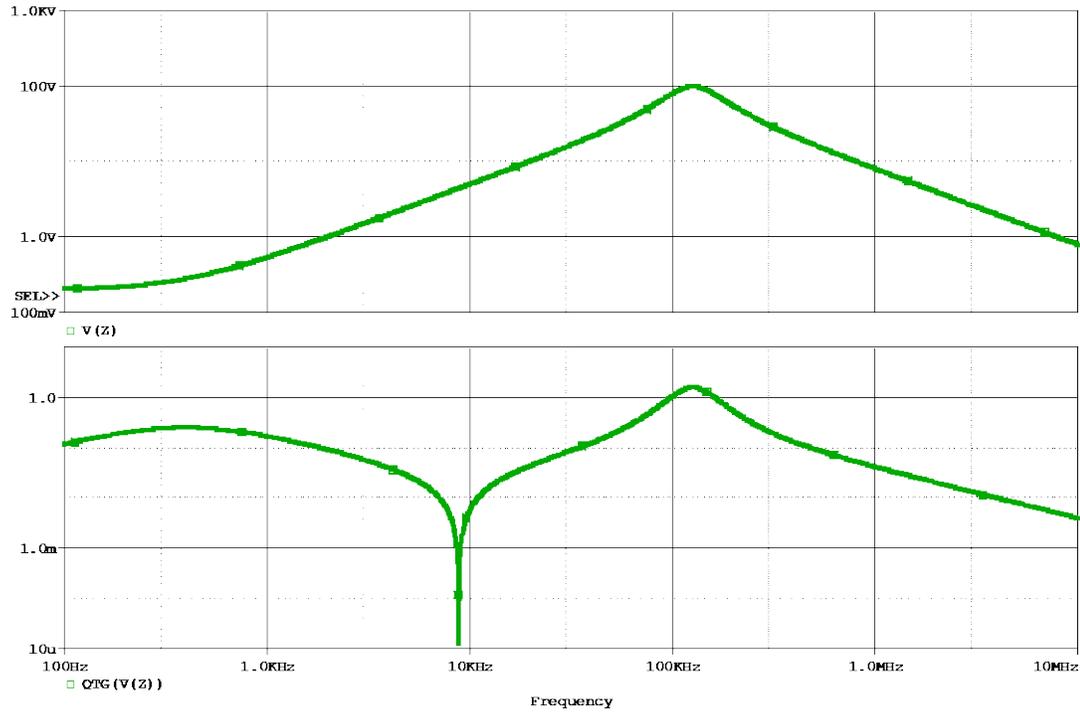


Figure 48: The output impedance and QTG plots of the input filter.

Note that 2000 points per decade are used in the simulation results above.

The peaks in the output impedance magnitude and QTG plot are the global maximums over the frequency range simulated so there are multiple options for the measurement equations.

NISM(V(Z)) or NISM_Range(V(Z), 10k, 1Meg) can be used. The range used for the latter option must include the global maximums. In addition, DB(V(Z)) can be used instead of V(Z).

Measurement Results			
	Evaluate	Measurement	Value
	<input checked="" type="checkbox"/>	NISM(V(Z))	32.2590696017
	<input checked="" type="checkbox"/>	NISM_Range(V(Z),10k, 1Meg)	32.2590696017
	<input checked="" type="checkbox"/>	Max(QTG(V(Z)))	1.5732558489
	<input checked="" type="checkbox"/>	Max_XRange(QTG(V(Z)),10k,1Meg)	1.5732558489
Click here to evaluate a new measurement...			

Figure 49: The NISM measurement equation options for the input filter.

The denominator of the output impedance expression can be represented as:

$$D(s) = 1 + \frac{s}{\omega_o Q} + \left(\frac{s}{\omega_o}\right)^2$$

Performing this analysis results in the following solutions for ω_o and Q:

$$\omega_o = \sqrt{\frac{R1 + R2}{C1 * L1 * R1}}$$

$$Q = \frac{(R1 + R2) * \sqrt{\frac{C1 * L1 * R1}{R1 + R2}}}{L1 + C1 * R1 * R2}$$

Evaluating both results in $\omega_o = 791.36 * 10^3$ radians per second ($f_o = 125.949\text{kHz}$) and $Q = 1.574845$. The maximum QTG value is related to the Q value but not equal to it. The frequency at which the maximum impedance and QTG occur is 125.893kHz which is close to f_o .

The filter is underdamped when the damping factor is between 0 and 1, which occurs when Q is greater than 0.5. There is no ringing when the filter is critically damped (when the damping factor is 1 or Q is 0.5) or overdamped (when the damping factor is greater than 1 or Q is less than 0.5). There is some ringing in the current load step response when Q is greater than 0.5 which can happen when the resistance of R1 is greater than 31.6Ω with all other component values unchanged.

In addition, the observed ringing frequency (or damped natural frequency) ω_d is a function of the resonant frequency ω_o and damping factor ξ :

$$\omega_d = \omega_o \sqrt{1 - \xi^2}$$

A step load transient simulation can be performed to observe the ringing frequency and duration which correspond to ω_o and Q.

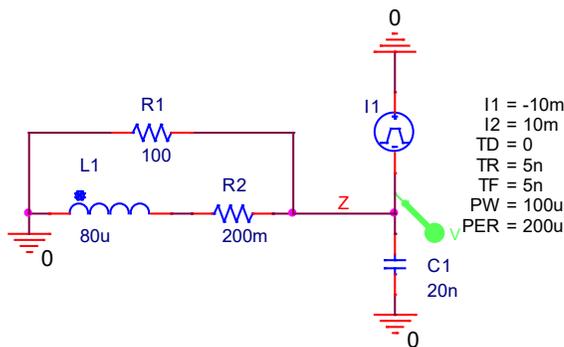


Figure 50: The test circuit to simulate the load current step response of the input filter.

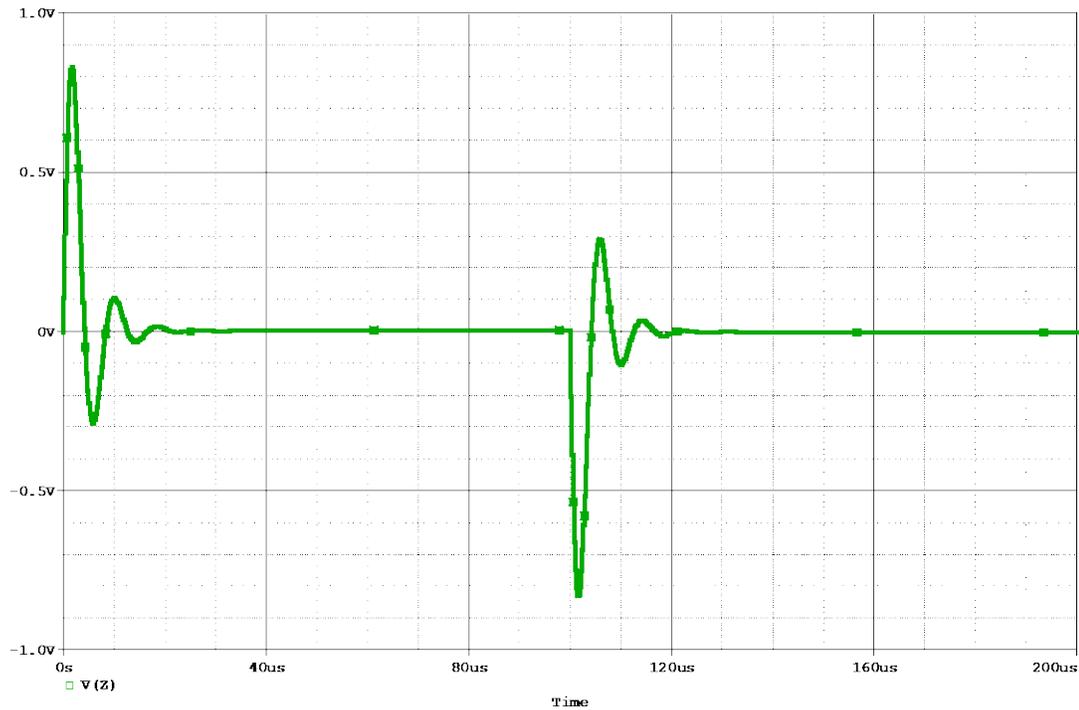


Figure 51: The step load response of the input filter.

The ringing period is 8.372us which corresponds to a ringing frequency of 119.4kHz. This relates well to the predicted value of 119.4kHz. A rule of thumb is that the number of rings is approximately equal to Q .

The calculation of the damped natural frequency is shown below for $R1 = 100\Omega$.

$$Q = 1.575$$

$$\xi := \frac{1}{2 \cdot Q}$$

$$\xi = 0.317$$

$$\omega_d := \omega_o \cdot \sqrt{1 - \xi^2} = 750.416 \times 10^3 \frac{1}{s}$$

$$f_d := \frac{\omega_d}{2 \cdot \pi} = 119.432 \times 10^3 \frac{1}{s}$$

Figure 52: Damped natural frequency calculation of the input filter.

$R1$ is then reduced to 10Ω which corresponds to a Q of 0.16 so there is no ringing predicted. Note that the value of the QTG curve is close to 0.16 at the resonant frequency of the filter.

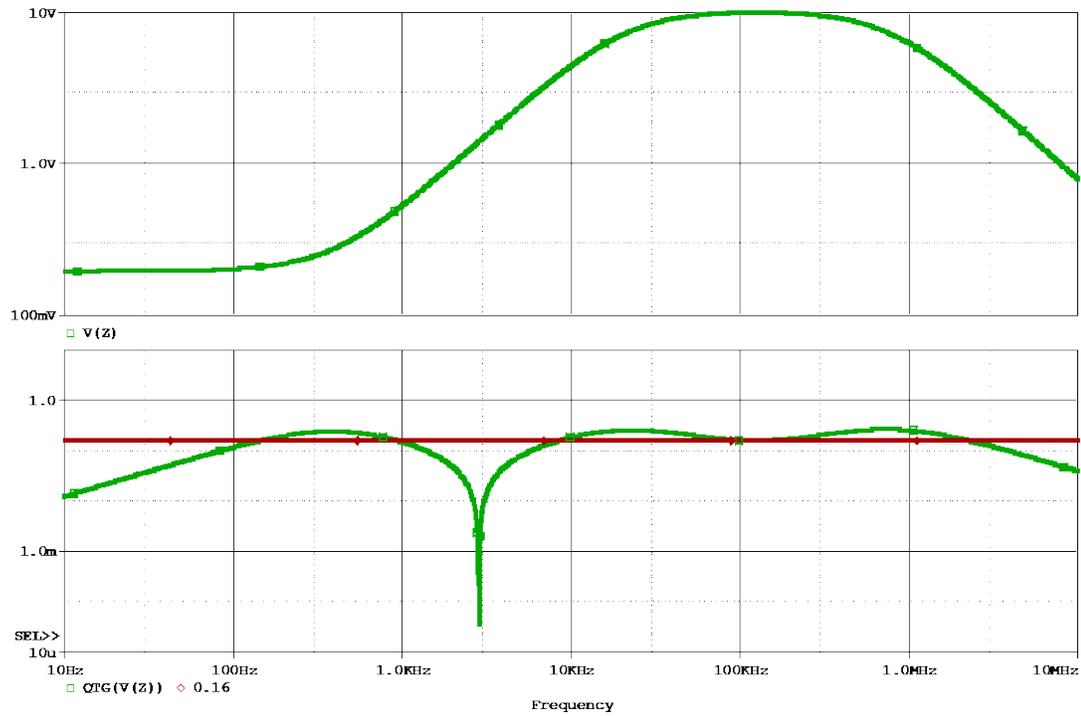


Figure 53: The output impedance and QTG plots of the input filter with $R1 = 10\Omega$.

Measurement Results			
	Evaluate	Measurement	Value
	<input checked="" type="checkbox"/>	NISM(V(Z))	-nan
	<input checked="" type="checkbox"/>	NISM_Range(V(Z),10k,1Meg)	-nan
	<input checked="" type="checkbox"/>	Max(QTG(V(Z)))	263.5300469032m
	<input checked="" type="checkbox"/>	Max_XRange(QTG(V(Z)),10k,1Meg)	263.5300469032m
Click here to evaluate a new measurement...			

Figure 54: The NISM measurement equations options for the input filter with $R1 = 10\Omega$.

Note that the NISM measurement equations return -nan and that the maximum values of QTG are not equal to 0.16.

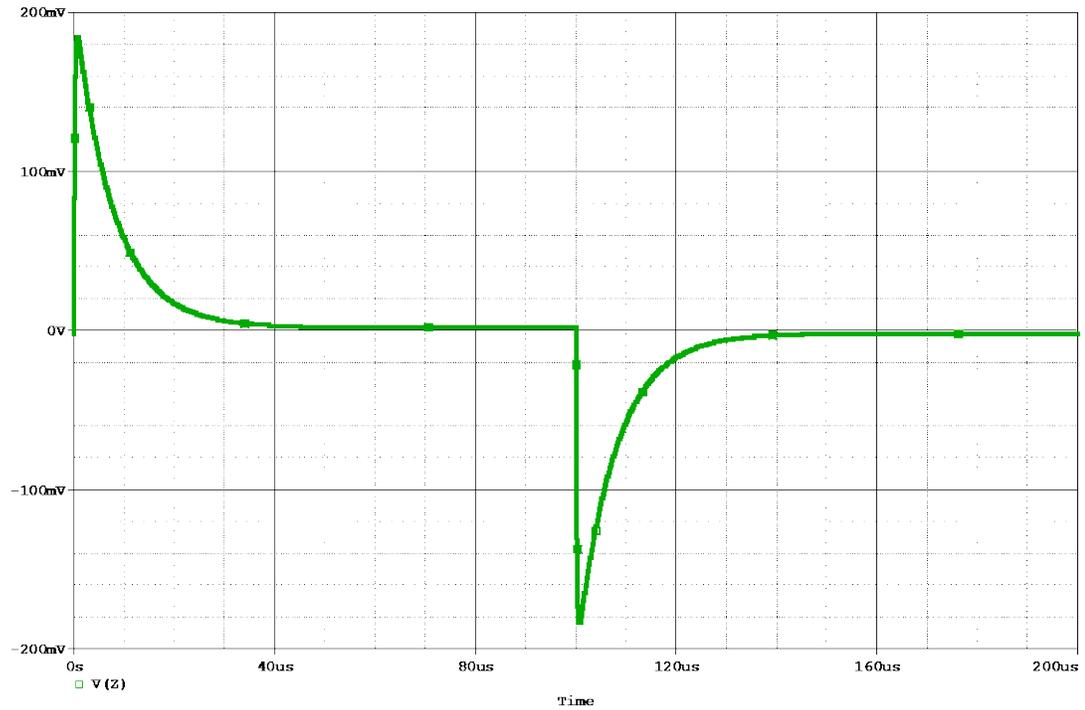


Figure 55: The step load response of the input filter with $R1 = 10\Omega$.

$R1$ is increased to 500Ω which corresponds to a Q of 7.714 so there is a large amount of ringing predicted in the step load response.

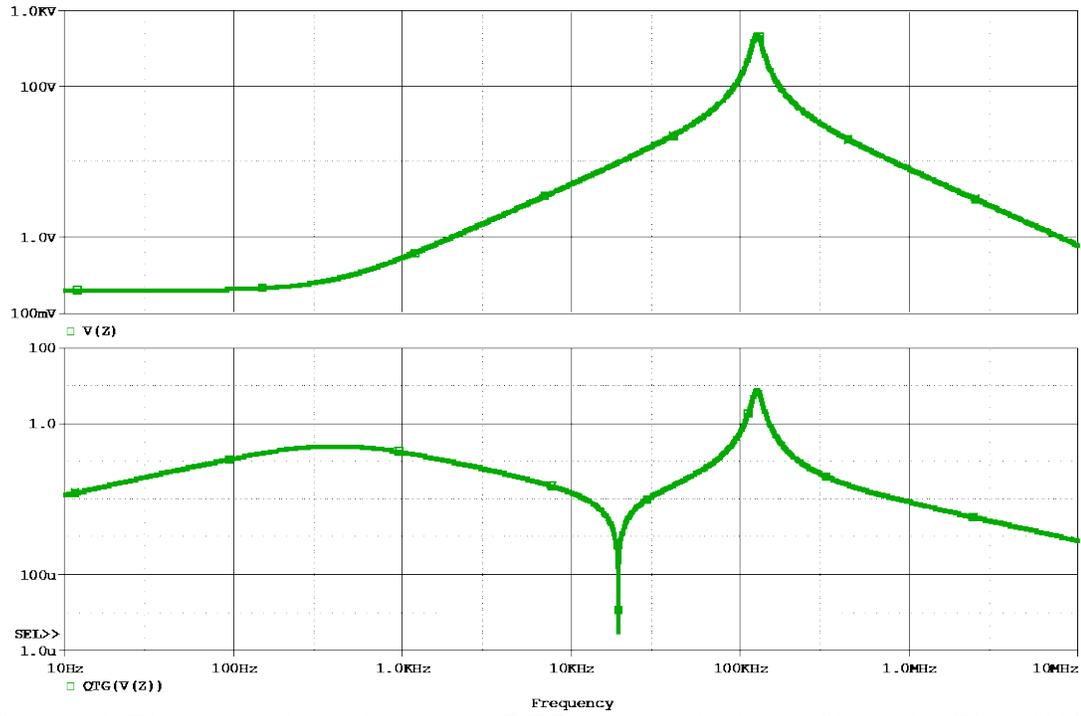


Figure 56: The output impedance and QTG plots of the input filter with $R1 = 500\Omega$.

Measurement Results			
	Evaluate	Measurement	Value
	<input checked="" type="checkbox"/>	NISM(V(Z))	7.3740240957
	<input checked="" type="checkbox"/>	NISM_Range(V(Z),10k,1Meg)	7.3740240957
	<input checked="" type="checkbox"/>	Max(QTG(V(Z)))	7.7118017883
	<input checked="" type="checkbox"/>	Max_XRange(QTG(V(Z)),10k,1Meg)	7.7118017883
Click here to evaluate a new measurement...			

Figure 57: The NISM measurement equations options for the input filter with $R1 = 500\Omega$.

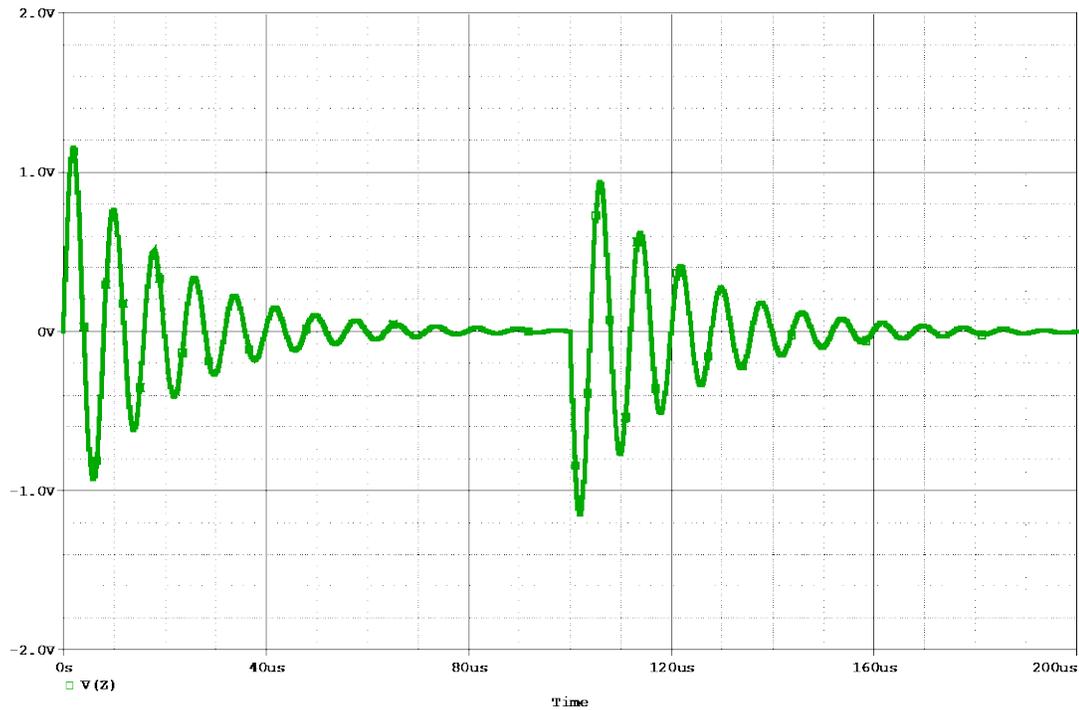


Figure 58: The step load response of the input filter with $R1 = 500\Omega$.

The simulated ringing period is $7.963\mu\text{s}$ which corresponds to a ringing frequency of 125.6kHz .

$$\omega_o = 790.728 \times 10^3 \frac{1}{\text{s}}$$

$$f_o = 125.848 \times 10^3 \frac{1}{\text{s}}$$

$$Q = 7.714$$

$$\xi := \frac{1}{2 \cdot Q}$$

$$\xi = 0.065$$

$$\omega_d := \omega_o \cdot \sqrt{1 - \xi^2} = 789.065 \times 10^3 \frac{1}{\text{s}}$$

$$f_d := \frac{\omega_d}{2 \cdot \pi} = 125.584 \times 10^3 \frac{1}{\text{s}}$$

Figure 59: Damped natural frequency calculation of the input filter with $R1 = 500\Omega$.

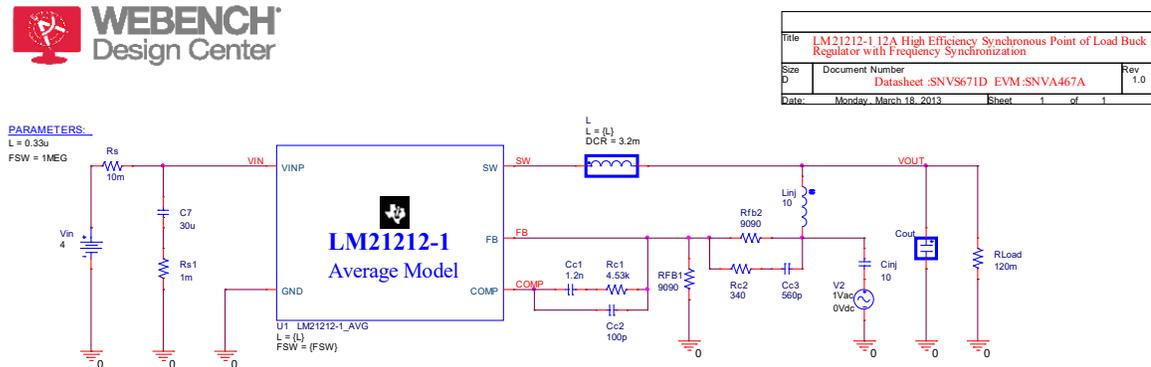
Additional Theory – Stability Margin, Bode Plots from Output Impedance

The NISM from the output impedance measurement can be related to the various stability margins from the loop gain Bode plot. The output impedances for the on state and off state can also be used to derive the loop gain Bode plot. The examples below use the PSpice projects from the first three PSpice NISM examples.

Design #1 – LM21212-1 PSpice Average Model <https://www.ti.com/lit/zip/snvm395>

If you were following along from the PSpice NISM Examples section, you'll first revert the project so that it simulates the loop gain Bode plot as shown below. Then, click on PSpice > Run to simulate.

LM21212-1 AVERAGE MODEL



Application Notes:

1. The LM21212-1 Average model is encrypted and will only run in PSpice Versions 15.7 and above.
2. The testbench has been configured for VIN = 4V, VOUT= 1.20V & IOUT = 10A
3. Only the required pins for AC analysis have been modelled.
4. To change the inductor value or switching frequency, please make changes in the parameter section.
5. Thermal characteristics, operating quiescent current and shutdown current of the part have not been modelled.
6. The AC simulation runs from 100Hz to 1.5MHz and takes a few seconds to run on a 4 core 2.8GHz machine

Figure 60: The LM21212-1 Average model from TI. The test circuit is configured to simulate the loop gain Bode plot.

StabilityDistance(x) is the distance from the Nyquist plot of the loop gain to the unstable point (1, 0). It is useful for determining the worst stability point/frequency. The Stability Distance can be converted to phase margin. The equivalent equation to StabilityDistance(V(VOUT)) is $\text{SQRT}(\text{PWR}(\text{R}(\text{V}(\text{VOUT}))-1,2)+\text{PWR}(\text{IMG}(\text{V}(\text{VOUT})),2))$.

It will be useful to add the following as a macro in the PSpice A/D window. Copy the following line:

$$\text{STABILITYDISTANCE}(x) = \text{SQRT}(\text{PWR}((\text{R}(x) - 1), 2) + \text{PWR}(\text{IMG}(x), 2))$$

Then from the PSpice A/D window add the macro by going to Trace > Macros..., and paste the line into the definition box.

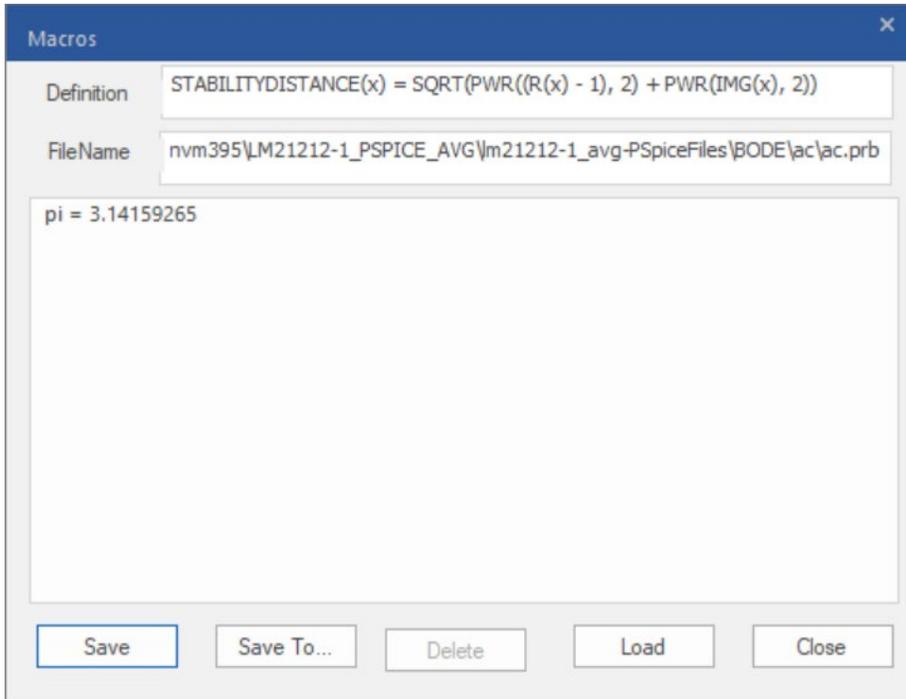


Figure 61: The Macros window is used to define a new macro StabilityDistance.

Then click on the Save To... button. The Local File is the default option, and this makes it available in future simulations of this simulation profile only. Choose the Global File if you wish to make this macro available for all simulations by default. Note that the Global File option makes the macro available on the computer being used and this specific PSpice version only (e.g. PSpice 23.1 if being used but not 22.1).

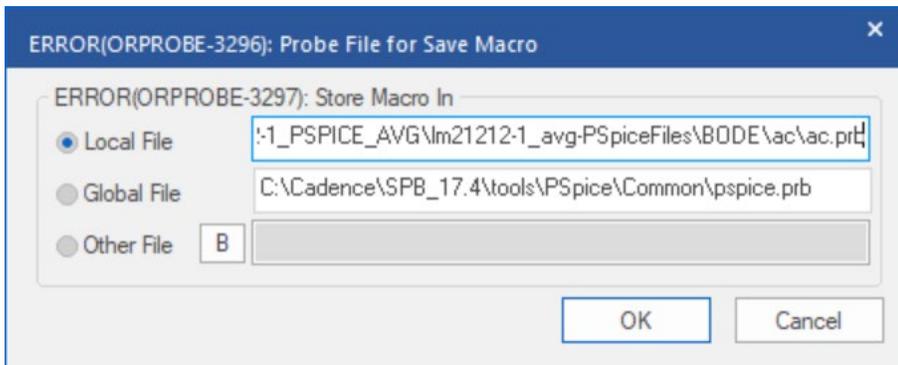


Figure 62: The Save To Macros window.

In addition, the following measurement will be added to PSpice A/D.

In the PSpice A/D window, click on Trace then Measurements. Then click on New in the Measurements window.

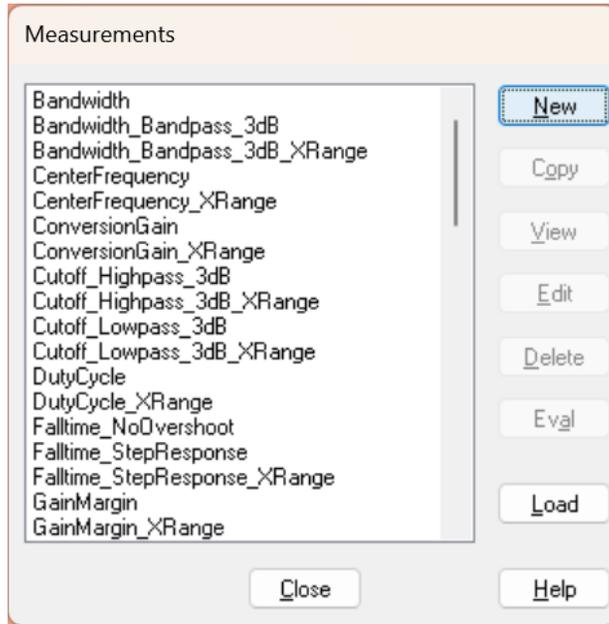


Figure 63: The Measurements window is used to define a new measurement StabilityMargin.

Enter StabilityMargin as the measurement name, choose the file to keep the measurement in, and click on OK. The example below chooses the global file so that the measurement is available in the future without having to re-add the measurement.

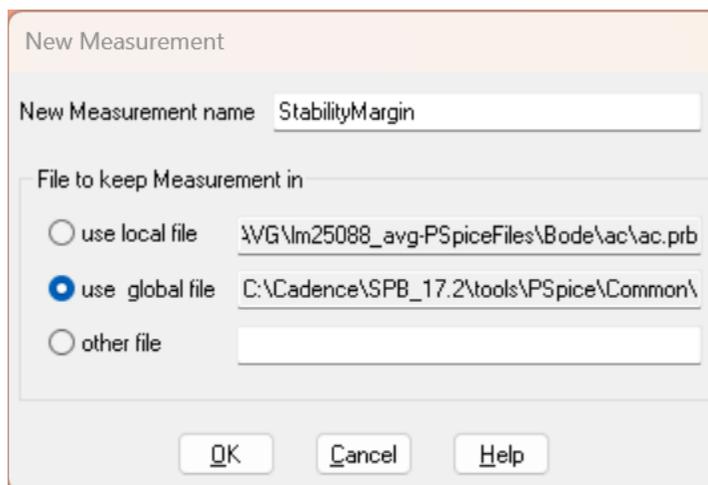


Figure 64: The New Measurements window.

Copy the following lines:

```
StabilityMargin(1) = (ATAN(SQRT(1-(1-y1*y1/2)*(1-y1*y1/2))/(1-
y1*y1/2)))*360/(2*3.14159265)
*
*#Desc#* Find the stability margin in degrees, given the distance from
the singular unstable point.
*
*#Arg1#* Distance from singular unstable point trace
*
  {
    1| search min !1;
  }
```

Then paste the copied text and click on OK.

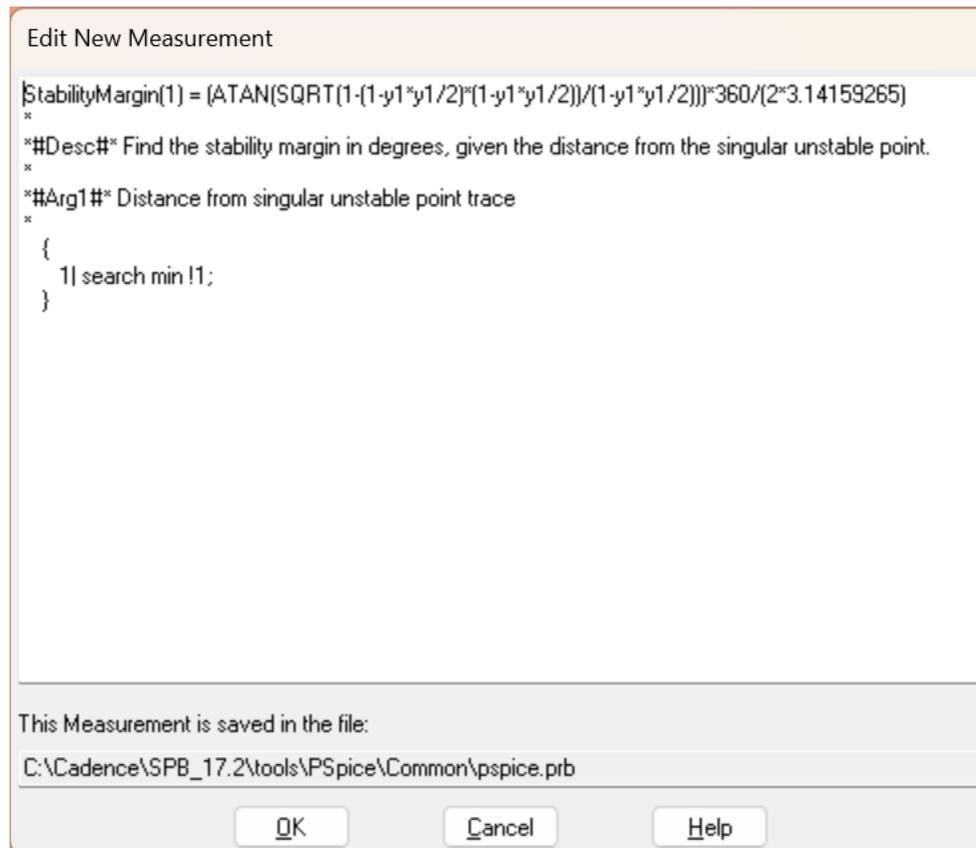


Figure 65: The Edit New Measurement window.

Then in the PSpice A/D window plot the following waveforms:

1. StabilityDistance(V(VOUT))
2. DB(V(VOUT))
3. P(V(VOUT))

Note that the StabilityDistance plot uses a log-y scale.

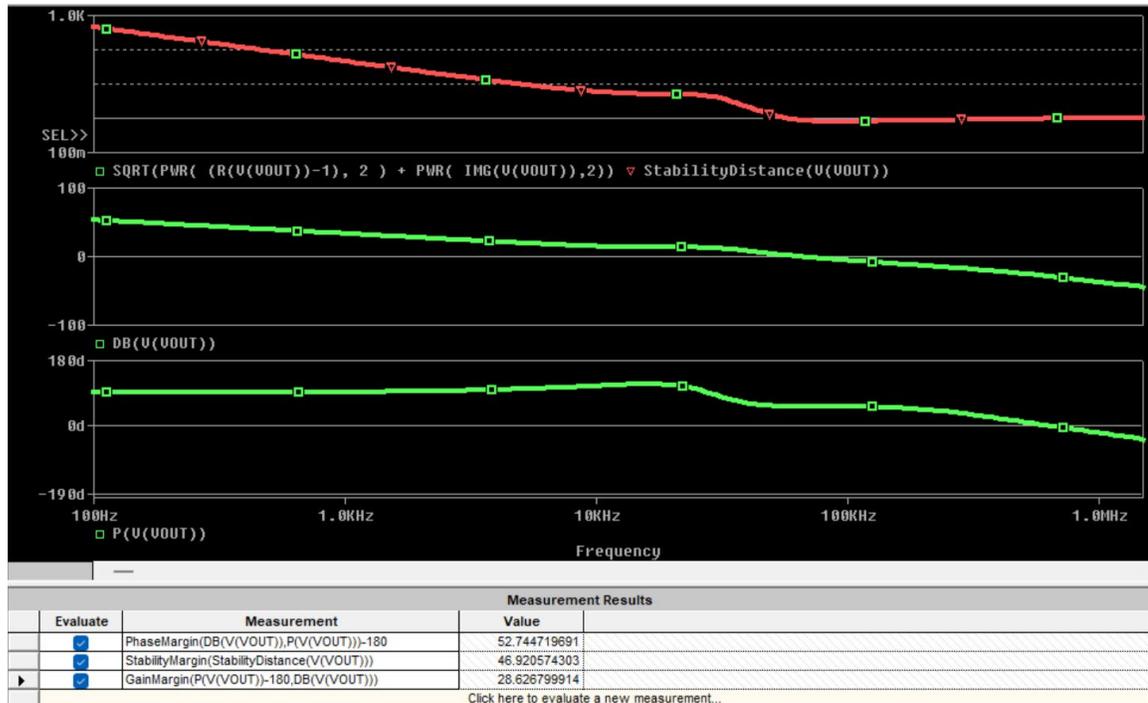


Figure 66: The loop gain Bode plot and stability distance plot of the LM21212-1 Average model.

The resulting phase margin is 52.7 degrees, the gain margin is 28.6dB, and the stability margin is 46.9 degrees. Note that the stability margin is worse than the phase margin. Note from Figure 39 that the NISM is approximately 43.7 degrees.

Then modify the simulation schematic so that it is configured for simulating the output impedance. Do the following:

1. Delete Linj and replace it with a wire.
2. Delete Cinj and V2.
3. Place an AC current source between VOUT and ground. Its polarity is not relevant to what is plotted.

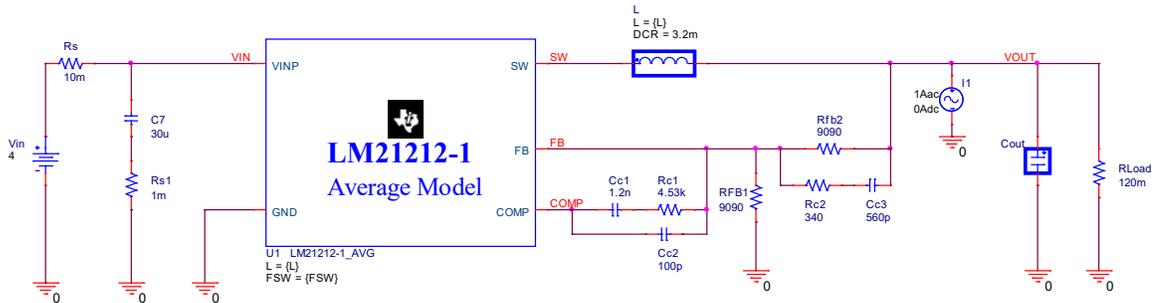


Figure 67: The LM21212-1 Average model from TI. The test circuit is configured to simulate the closed loop (on state) output impedance plot.

Then copy the above circuit in PSpice and paste inside PSpice. This is done so we can simulate the open loop (off state) output impedance. Then the VIN, SW, FB, and COMP net aliases will need to be removed and the VOUT net alias will need to be changed to OFF as noted by the red arrows in the schematic below. These net aliases changes make this pasted circuit independent from the original one. In addition, a large-valued inductor will need to be added between the FB pin node and the top of RFB4 and a large-valued capacitor will need to be added from the FB pin node to ground. These additions make it so that the regulator operates in the open loop configuration since there is a substantially diminished feedback signal from the resistor divider that reaches the FB pin.

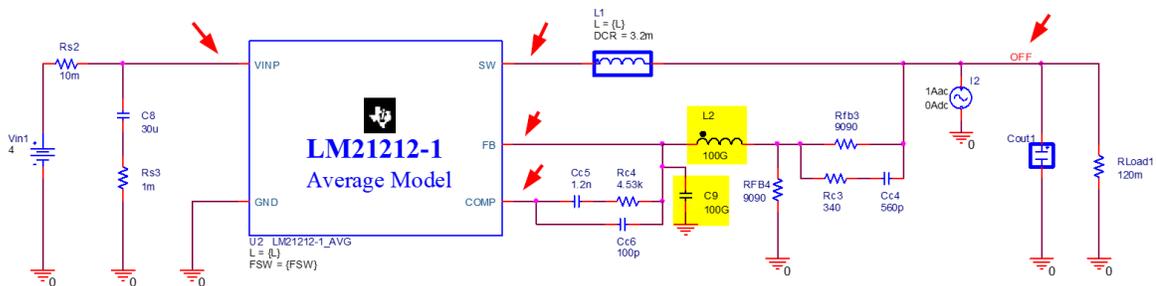


Figure 68: The LM21212-1 Average model from TI. The test circuit is configured to simulate the open loop (off state) output impedance plot.

The open loop output impedance of the LM21212-1 is comparable to its load capacitor so the average model block must be included when simulating the open loop (off state) output impedance. This is not always the case, that the VRM impedance needs to be included, but it is often so.

As will be seen in the next example, the open loop (off state) output impedance will simply be the impedance of the capacitor load as the open loop output impedance looking into the SW output pin of the regulator IC is much greater in magnitude than the capacitor load.

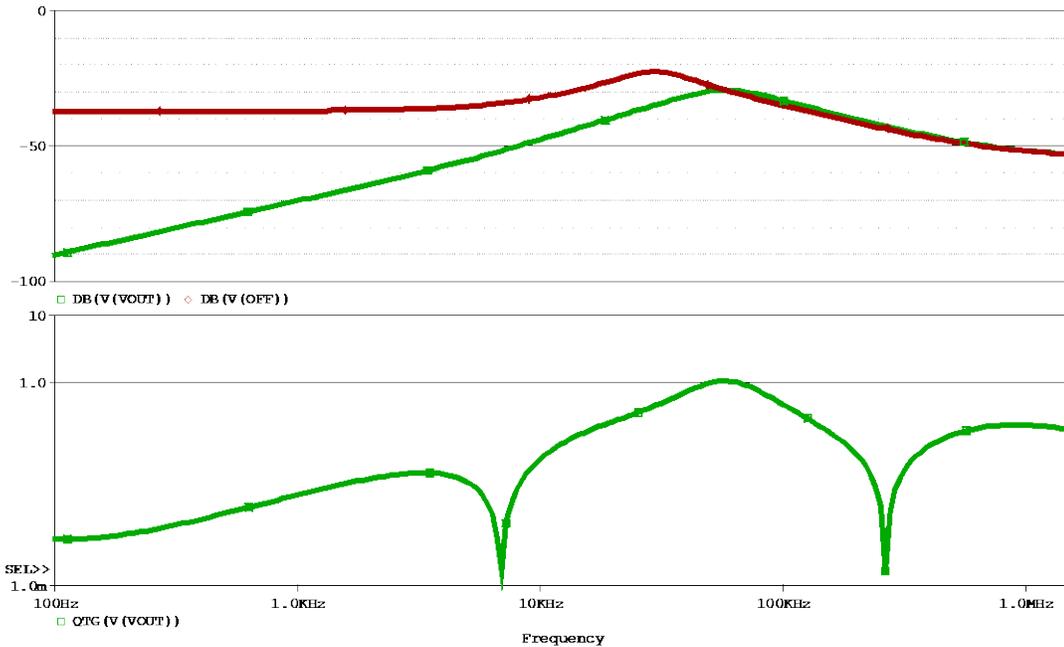


Figure 69: The output impedance and QTG plots of the LM21212-1 Average model. Both the on state and off state output impedances are plotted in the top half.

Deriving a Bode Plot from Output Impedance

As a check, or for curiosity, you can create a Bode plot from the on and off state output impedance.

The loop gain Bode plot can also be derived from the open loop and closed loop output impedances because of the following relationship open loop, closed loop, and the loop gain vector T:

$$Closed\ Loop = \frac{Open\ Loop}{1 + T}$$

T is solved for:

$$T = \frac{Open\ Loop}{Closed\ Loop} - 1$$

Add the following as macros to PSpice A/D. Each line can be copied and then then pasted into the macros window:

```

BODE_FROM_ZOFF_ZON(off,on)           = (1-off/on)
BODE_DB_FROM_ZOFF_ZON(off,on)        = DB(1-off/on)
BODE_PHASE_FROM_ZOFF_ZON(off,on)     = P(1-off/on)
    
```

There is a multiply by -1 in the macros otherwise the derived Bode plot has a 180 degree shift compared to the actual Bode plot.

Then plot the following:

1. `StabilityDistance(BODE_FROM_ZOFF_ZON(V(OFF),V(VOUT)))`
2. `BODE_DB_FROM_ZOFF_ZON(V(OFF),V(VOUT))`
3. `BODE_PHASE_FROM_ZOFF_ZON(V(OFF),V(VOUT))`

Note that the `StabilityDistance` plot uses a log-y scale.

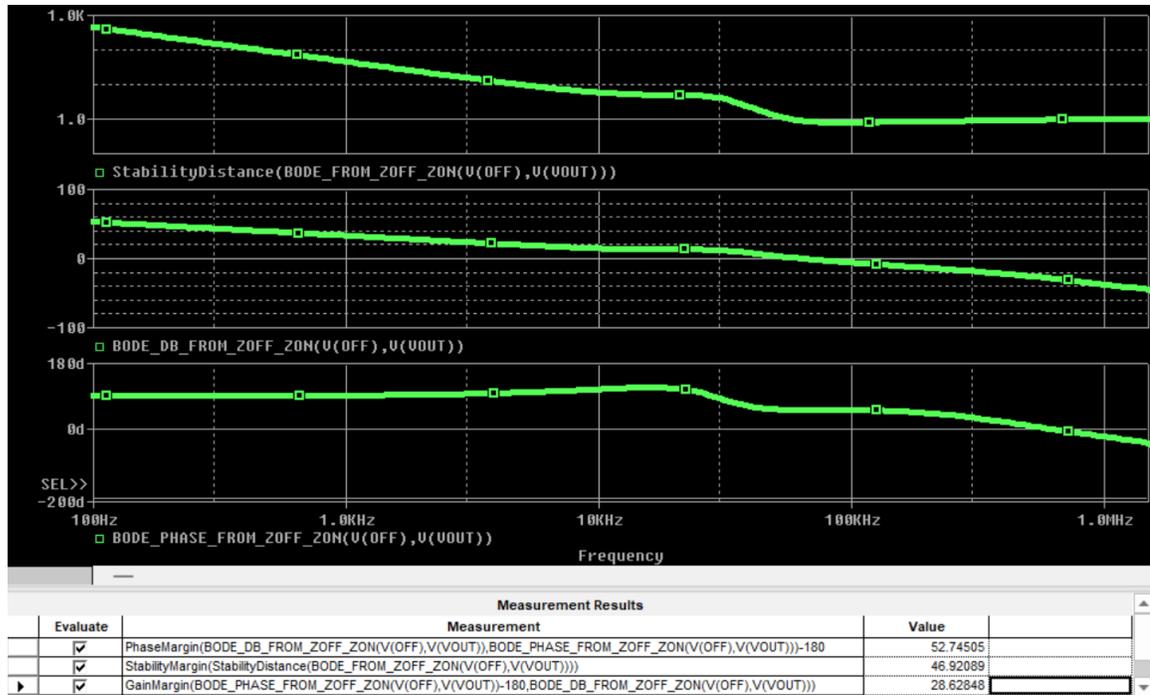


Figure 70: The loop gain Bode plot and stability distance plot derived from the off state and on state output impedances of the LM21212-1 Average model.

The resulting phase margin, gain margin, and stability margin are the same as from the loop gain Bode plot in Figure 66.

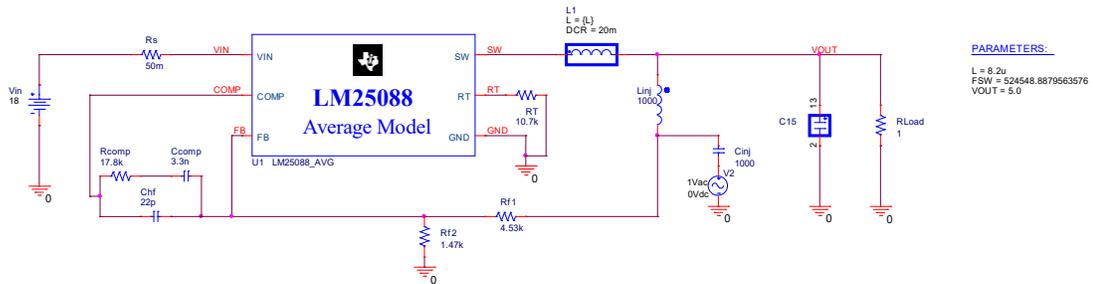
Design #2 - LM25088 PSpice Average Model <https://www.ti.com/lit/zip/snvm388>

If you were following along from the PSpice NISM Examples section, you'll first revert the project so that it simulates the loop gain Bode plot as shown below. Then, click on PSpice > Run to simulate.

LM25088 AVERAGE MODEL



Title			LM25088 Wide Input Range Non-Synchronous Buck Controller
Size	Document Number	Rev	
D	Datasheet :SNVS609G EVM:SNVA383C	1.0	
Date:	Thursday, March 14, 2013	Sheet	1 of 1



Application Notes:

1. The LM25088 Average model is encrypted and will only run in PSPICE Versions 15.7 and above.
2. The testbench has been configured for VIN = 18V, VOUT= 5.0V & IOUT = 5A.
3. Only the required pins for AC analysis have been modelled.
4. Inductor Value L ,Switching Frequency FSW & Vout desired has passed as parameters.
5. Thermal characteristics, operating quiescent current and shutdown current of the part have not been modelled.
6. The AC simulation runs from 10Hz to 200kHz and takes approximately 1 sec to run on a 4 core 2.8GHz machine.

Figure 71: The LM25088 Average model from TI. The test circuit is configured to simulate the loop gain Bode plot.

Please review the steps to add the StabilityDistance macro and StabilityMargin measurement on pages 73 through 75.

Then in the PSpice A/D window plot the following waveforms:

1. StabilityDistance(V(VOUT))
2. DB(V(VOUT))
3. P(V(VOUT))

Note that the StabilityDistance plot uses a log-y scale.

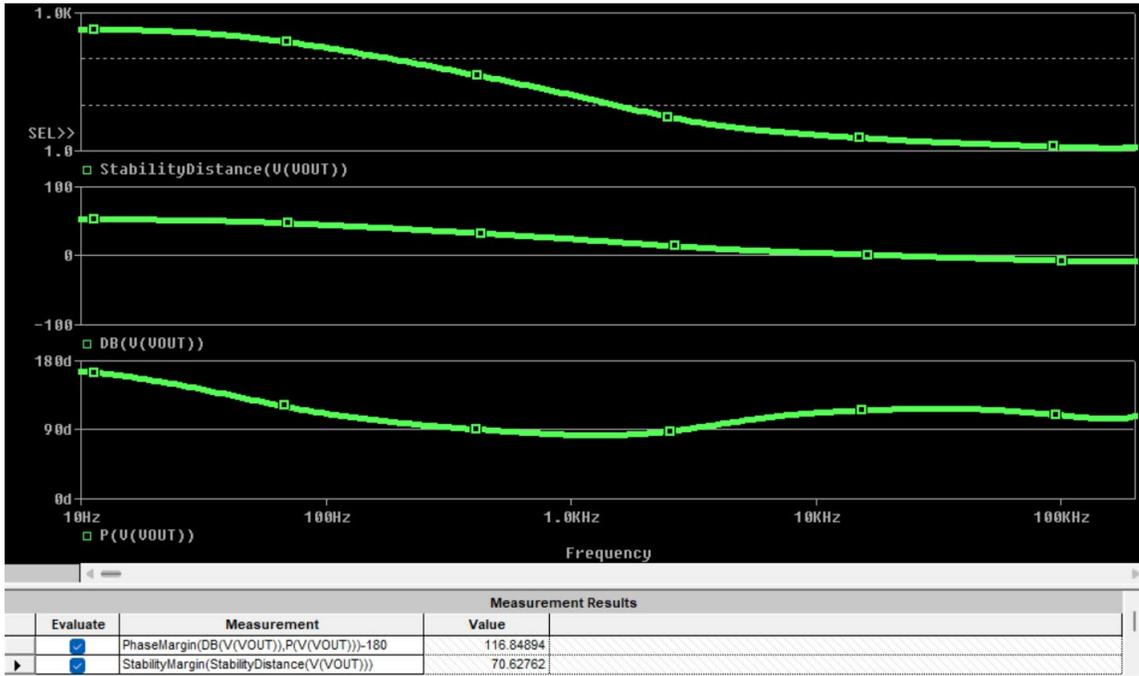


Figure 72: The loop gain Bode plot and stability distance plot of the LM25088 Average model.

The resulting phase margin is 116.8 degrees, and the stability margin is 70.6 degrees. There is no gain margin to report as the phase curve does not cross 0 degrees in the frequency range. Note from Figure 43 that the NISM is greater than 70 degrees.

Then modify the simulation schematic so that it is configured for simulating the output impedance. Do the following:

1. Delete Linj and replace it with a wire.
2. Delete Cinj and V2.
3. Place an AC current source between VOUT and ground. Its polarity is not relevant to what is plotted.

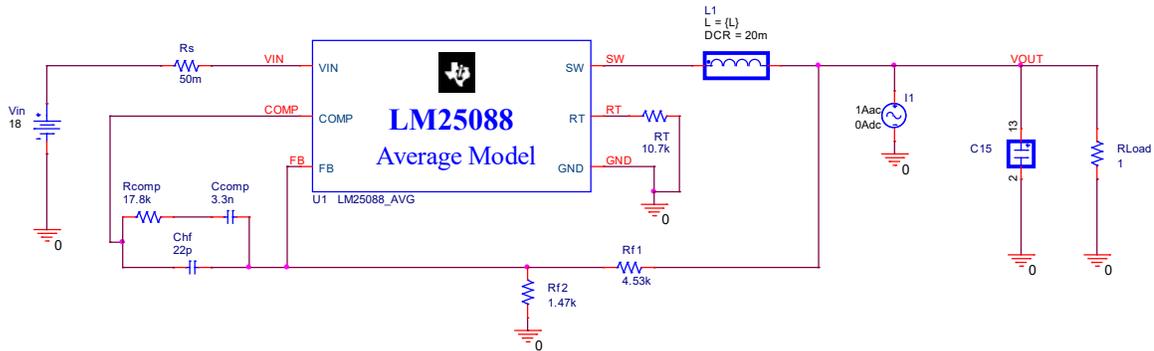


Figure 73: The LM25088 Average model from TI. The test circuit is configured to simulate the closed loop (on state) output impedance plot.

Then copy the AC current, the C15 output capacitor, and the RLoad output resistor, paste this group in the simulation schematic, and rename the VOUT node alias to OFF like so:

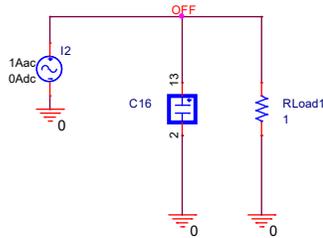


Figure 74: The test circuit is configured to simulate the open loop (off state) output impedance plot.

The test circuit above is the open loop (off state) output impedance of the LM25088 Average model because the open loop impedance looking back towards the LM25088 itself (which is in parallel with the load capacitor and load resistor) is much larger than the load capacitor and load resistor impedance. This contrasts with the first example where the LM21212-1 Average model is included in the open loop (off state) test circuit.

Simulate the circuit and then in the PSpice A/D window plot the following waveforms:

1. In the top plot, plot DB(V(VOUT)) and DB(V(OFF))
2. QTG(V(VOUT))

Note that the QTG plot uses a log-y scale.

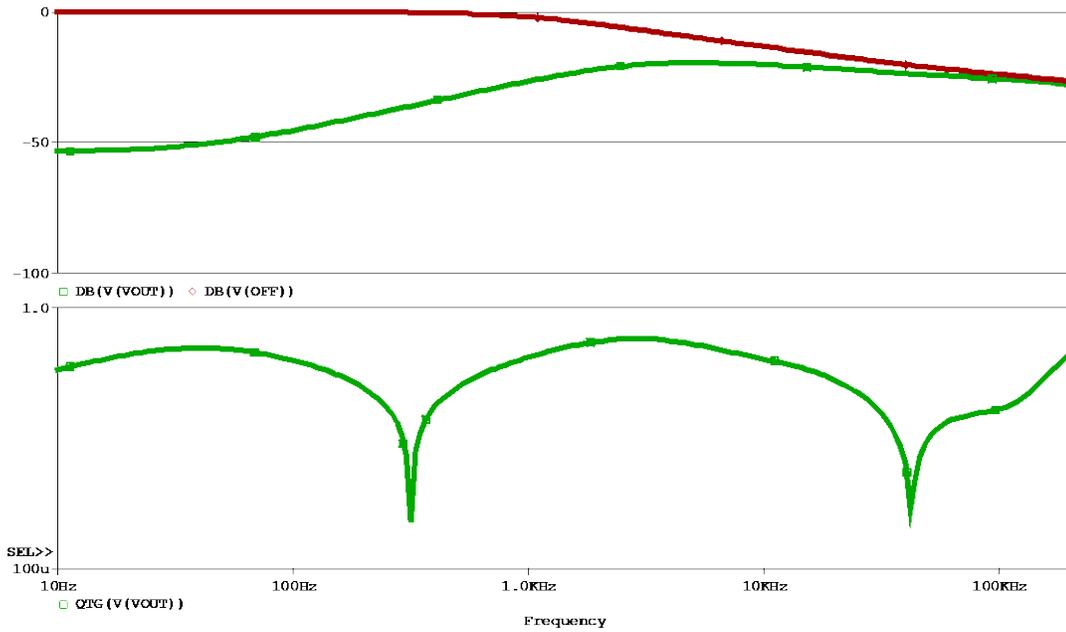


Figure 75: The output impedance and QTG plots of the LM25088 Average model. Both the on state and off state output impedances are plotted in the top half.

Next, the derived Bode plot from the open loop and closed loop output impedances are plotted.

Plot the following:

1. `StabilityDistance(BODE_FROM_ZOFF_ZON(V(OFF),V(VOUT)))`
2. `BODE_DB_FROM_ZOFF_ZON(V(OFF),V(VOUT))`
3. `BODE_PHASE_FROM_ZOFF_ZON(V(OFF),V(VOUT))`

Note that the `StabilityDistance` plot uses a log-y scale.

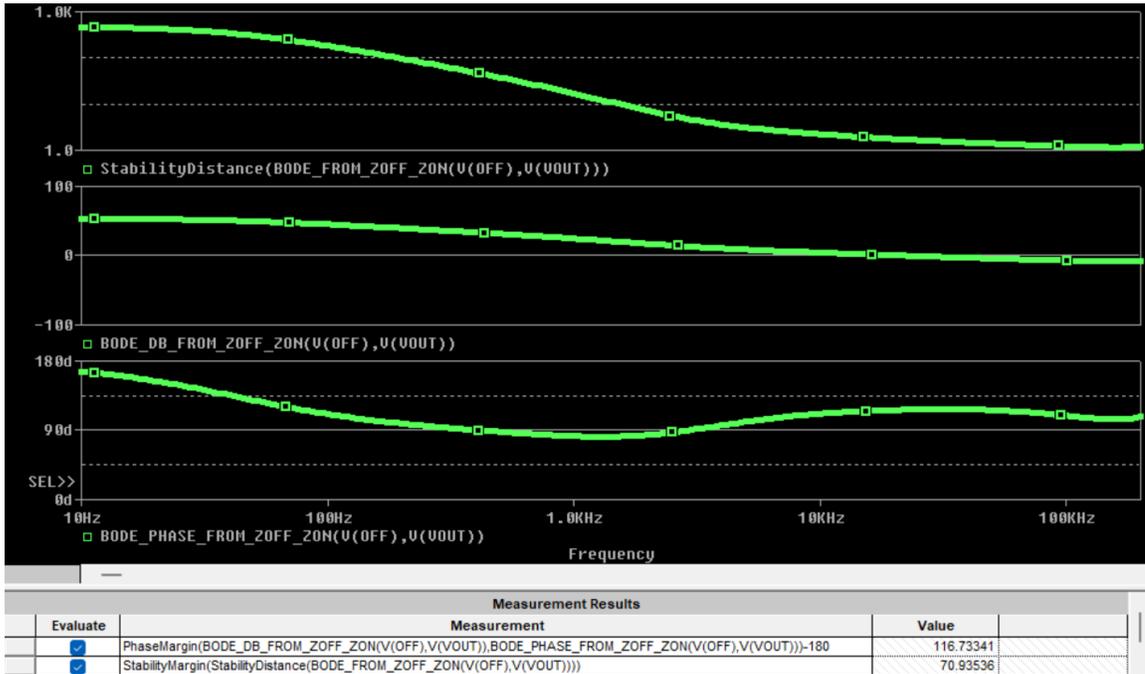


Figure 76: The loop gain Bode plot and stability distance plot derived from the off state and on state output impedances of the LM25088 Average model.

The resulting phase margin and stability margin are the same as the loop gain Bode plot in Figure 72.

Design #3 – HS117 Three-Terminal Linear Regulator

The simulation is setup to plot the loop gain Bode plot. This example illustrates the existence of passive resonances due to the loading which are present in both the on state and off state output impedances.

The HS117 has a floating voltage reference so the loop break circuit is referenced to the output voltage. This is opposed to the previous two examples where the voltage reference is referenced to ground. The node V(Bode) is generated by the E1 source and is the loop gain Bode plot.

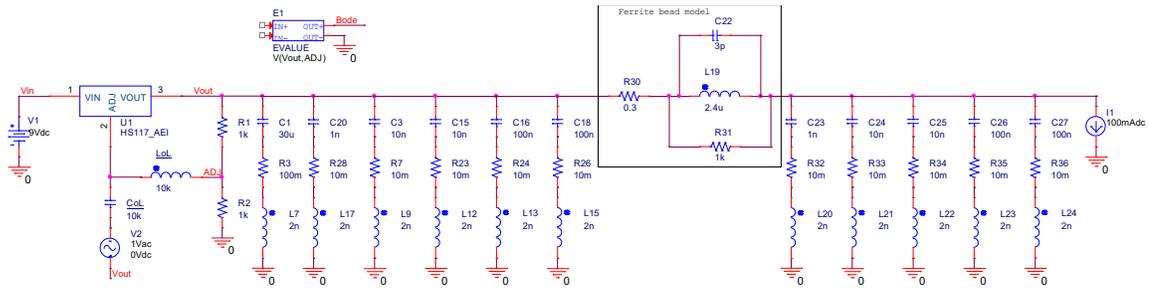


Figure 77: The HS117 three-terminal linear regulator model developed by AEi and available in the Power IC Model Library for PSpice (<https://www.aeng.com/library.htm>). The test circuit is configured to simulate the loop gain Bode plot. Please email info@picotest.com or info@aeng.com for these files.

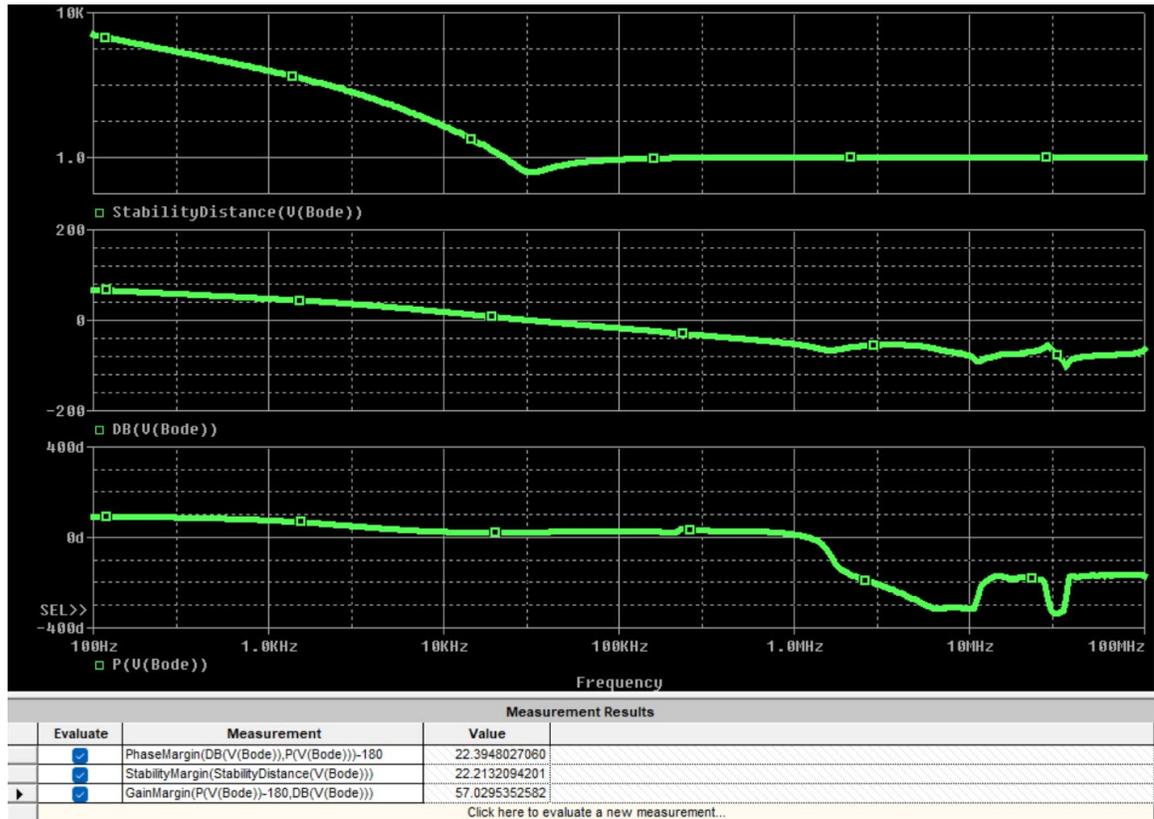


Figure 78: The loop gain Bode plot and stability distance plot of the HS117.

The resulting phase margin is 22.4 degrees, the gain margin is 57.0 dB, and the stability margin is 22.2 degrees. Note that the stability margin is slightly worse than the phase margin. Note from Figure 46 that the NISM is approximately 24.6 degrees.

Then the test circuit is configured to measure the on state and off state output impedances.

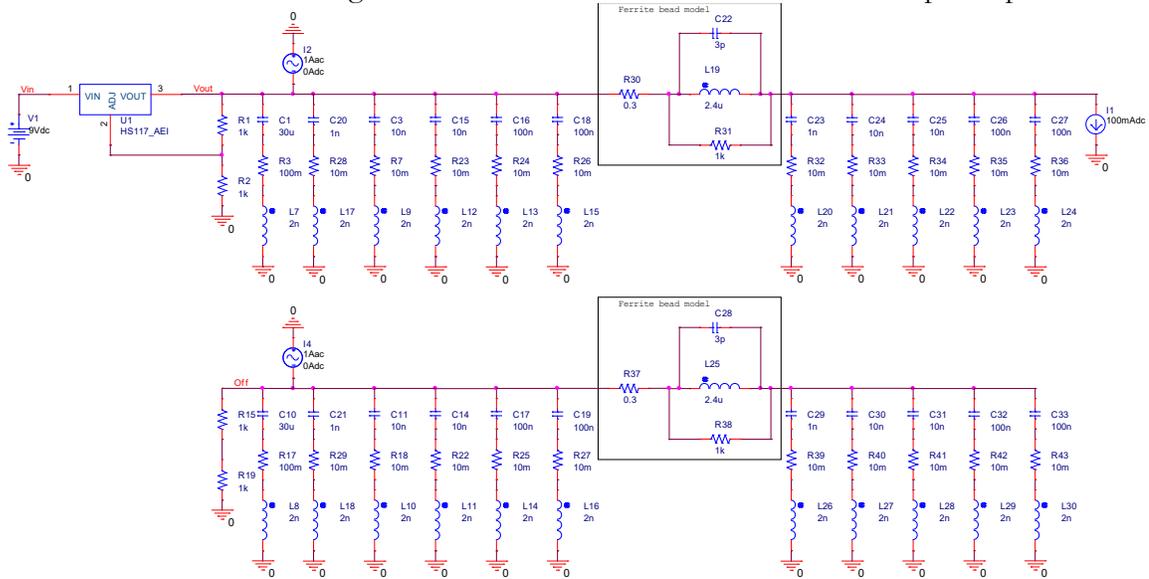


Figure 79: The HS117 test circuit is configured to simulate the on state and off state output impedances.

Next, the derived Bode plot from the open loop and closed loop output impedances are plotted.

Plot the following:

1. `StabilityDistance(BODE_FROM_ZOFF_ZON(V(OFF), V(VOUT)))`
2. `BODE_DB_FROM_ZOFF_ZON(V(OFF), V(VOUT))`
3. `BODE_PHASE_FROM_ZOFF_ZON(V(OFF), V(VOUT))`

Note that the `StabilityDistance` plot uses a log-y scale.

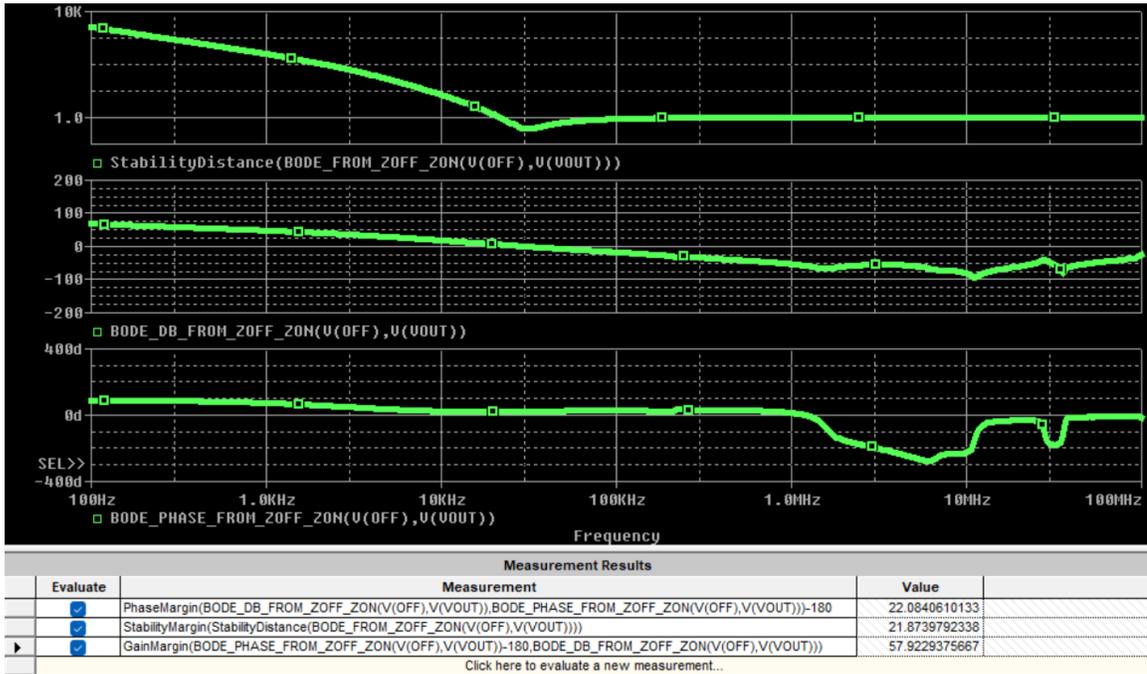


Figure 80: The loop gain Bode plot and stability distance plot derived from the off state and on state output impedances of the HS117 three-terminal linear regulator.

The margins are close to those as the loop gain Bode plot in Figure 78.

This ends the set of NISM examples for PSpice.

Chapter 5 - Installing and Running the NISM on Keysight ADS

This document contains the instructions on how to setup ADS to perform a NISM data display measurement.

1. How to Enable NISM in a Local ADS Workspace

After downloading the files from the Picotest website, place the compiled “Sandler_NISM_M1Z_M2Q.atp” function and “**workspace_auto_load_files.ael**” file into the desired ADS workspace directory. When ADS loads the workspace, it looks at the “**workspace_auto_load_files.ael**” file to see what custom functions to load from the local workspace.

Note: This step needs to be repeated for each local ADS workspace. Refer to **Section IV** to enable NISM globally for all ADS workspaces.

2. How to Enable NISM Globally for All ADS Workspaces

1. Go to the following directory within the default folder for saving ADS workspaces created during ADS installation:

<User-specific file path> \hpeesof\expressions\ael

Note: If your PC has more than one version of ADS installed, ensure your path is in the correct “hpeesof” folder for that install version. New versions of ADS can be

installed to keep using the same workspace directory with the same “hpeesof” folder so that local user customization like this NISM function is not lost. The path shown above is for Windows OS and may be different for Linux.

2. Place the compiled “**Sandler_NISM_M1Z_M2Q.atf**” function into the directory from the previous step as shown in Figure 1.

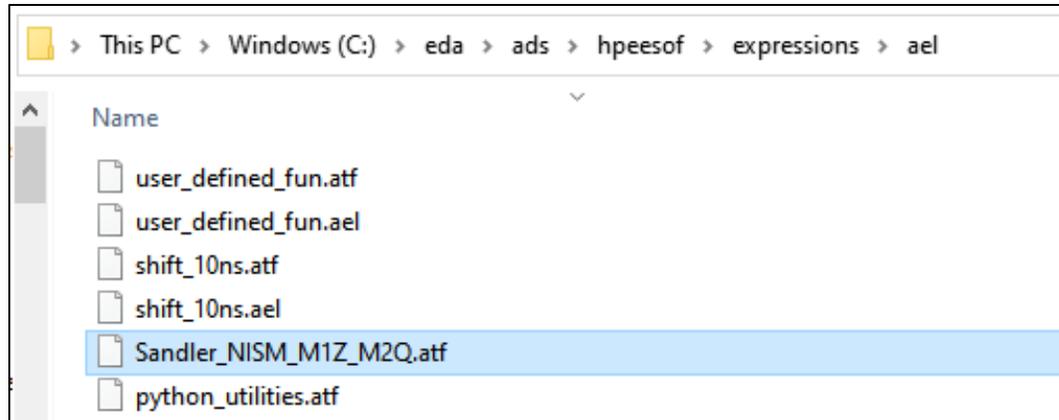
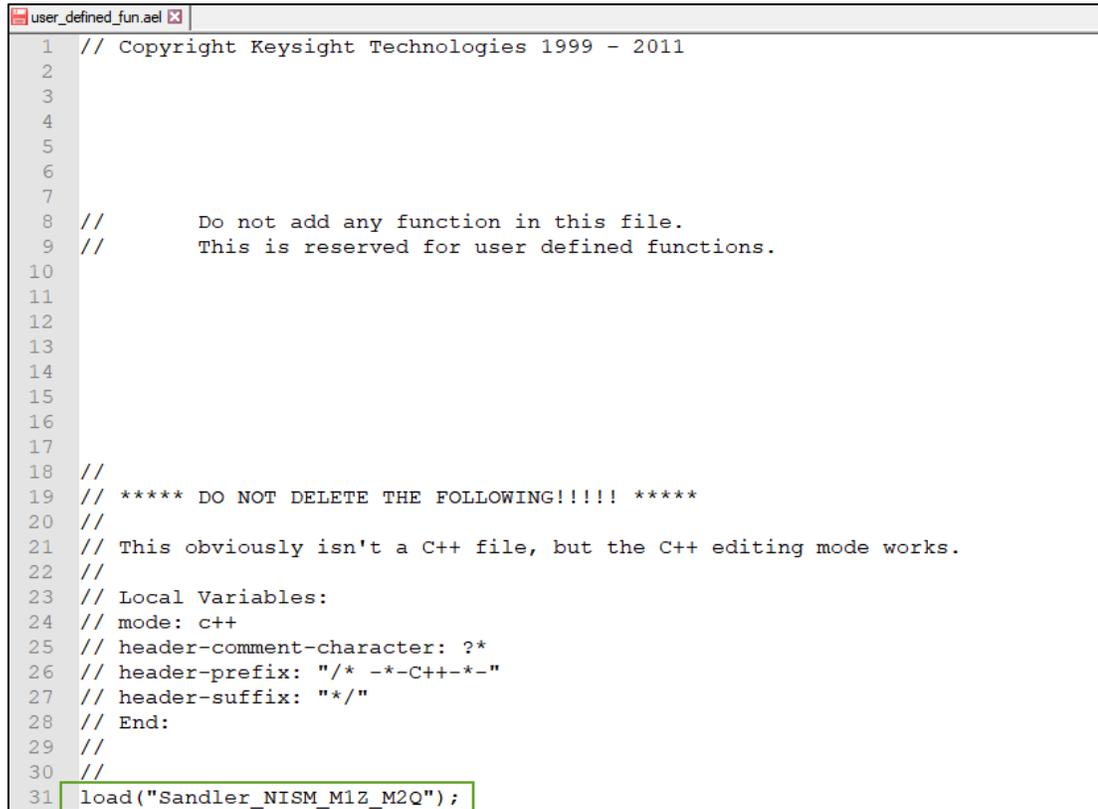


Figure 81: Compiled "Sandler_NISM_M1Z_M2Q.atf" function placed within the proper directory.

3. Within the same directory, open the “**user_defined_fun.ael**” file in a text editor and add the following line as shown in Figure 2:

```
load("Sandler_NISM_M1Z_M2Q");
```



```
1 // Copyright Keysight Technologies 1999 - 2011
2
3
4
5
6
7
8 //      Do not add any function in this file.
9 //      This is reserved for user defined functions.
10
11
12
13
14
15
16
17
18 //
19 // ***** DO NOT DELETE THE FOLLOWING!!!!!! *****
20 //
21 // This obviously isn't a C++ file, but the C++ editing mode works.
22 //
23 // Local Variables:
24 // mode: c++
25 // header-comment-character: ?*
26 // header-prefix: "/* -*-C++-*/"
27 // header-suffix: "*/"
28 // End:
29 //
30 //
31 load("Sandler_NISM_M1Z_M2Q");
```

Figure 82: Properly modified “user_defined_fun.ael” file with the load () added.

4. Save and close the “user_defined_fun.ael” file.
 5. If ADS is open, restart the program.
- 3. Configuring an S-Parameter Simulation for NISM**
1. Place an S-Parameter simulation controller into your ADS schematic, and then double click on it to open the S-Parameter configuration dialog box.
 2. Under the Frequency tab shown in Figure 3, select “Log” as the frequency sweep type. Then enter the start and stop points for the logarithmic frequency sweep, as well as the number of points per decade.

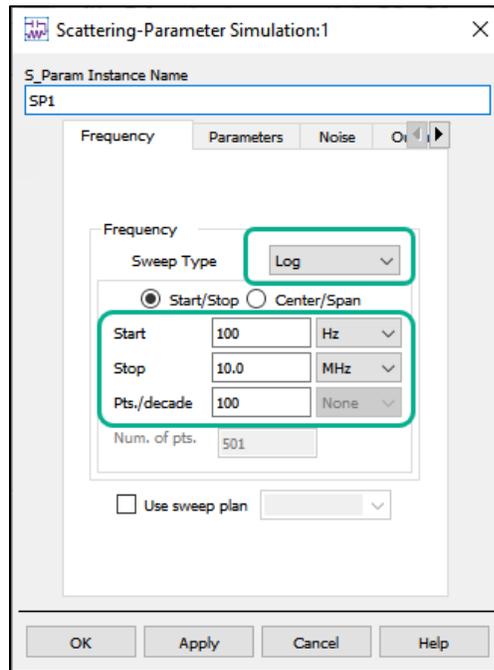


Figure 83: Frequency tab of the S-Parameter configuration dialog box.

3. Under the Parameters tab, as shown in Figure 4, verify that the “Z-parameters” and “Group delay” check boxes are both checked, and then click “OK.”

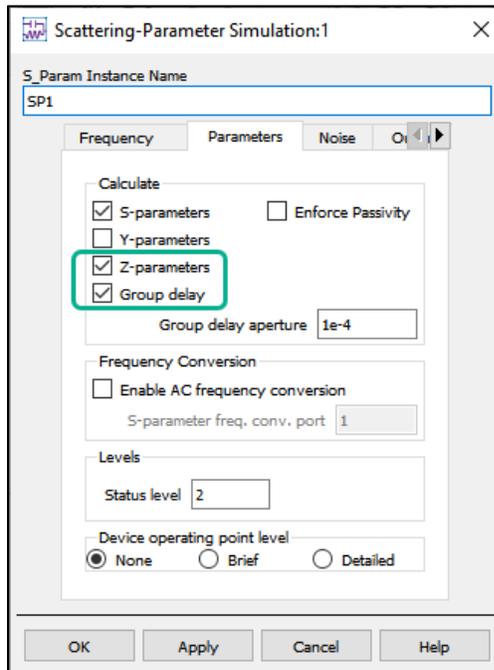


Figure 84: Parameters tab of the S-Parameter configuration dialog box.

4. After importing the VRM model into your ADS schematic, run the S-Parameter simulation.

4. Adding NISM Equations to an ADS Data Display

1. Add the following equations anywhere in the data display, either on an existing page or on a new page.

Note: The first equation assumes that the VRM output port termination number is set to 1.

Eqn Sandler_NISM_Zout = Z(1,1)

Eqn QTg_freq=QTg_freq_function(Sandler_NISM_Zout)

Eqn Sandler_NISM_QTg=Sandler_NISM_QTg_function(Sandler_NISM_Zout)

Eqn Sandler_NISM_PM=Sandler_NISM_M1Z_M2Q_function(M1,M2)

Eqn Z_Frequency=indep(M1)

Eqn Q_Frequency=indep(M2)

Eqn Effective_Q=M2

Eqn Time_Stamp=date_time()

5. Plotting Zout and QTg Data

1. Add a new rectangular plot to your data display.
2. In the Plot Traces & Attributes window, add the trace “mag(Sandler_NISM_Zout)” to your plot.
3. Type the trace expression “plot_vs(Sandler_NISM_QTg, QTg_freq)” into the Plot Traces & Attributes window, and click “>> Add >>” as shown in Figure 5:

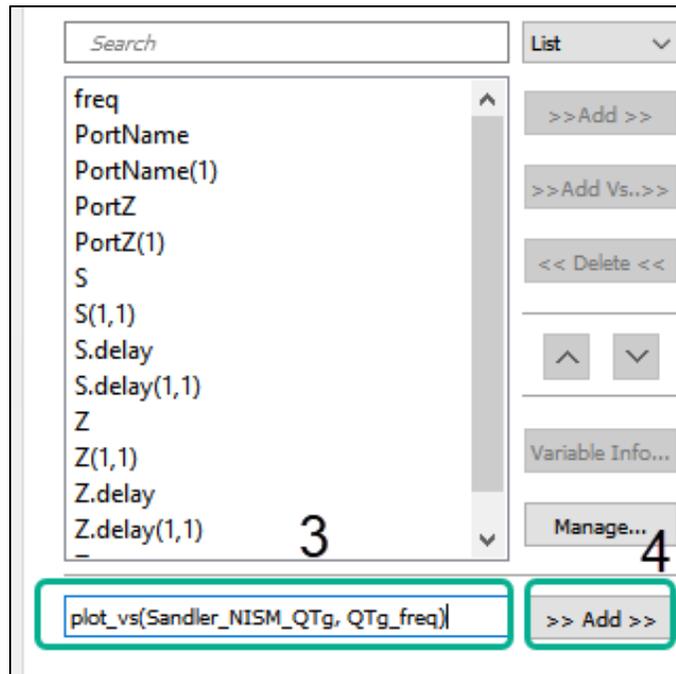


Figure 85: Adding “Sandler_NISM_QTg, QTg_freq” trace to your plot.

4. Double click on the “plot_vs(Sandler_NISM_QTg, QTg_freq)” trace.
5. In the Trace Options window, go to the Plot Axes tab and select “Right Y Axis” in the Y axis dropdown, and then click “OK.”
6. In the Plot Traces & Attributes window, go to the Plot Options tab and set the X Axis, Y Axis, and Right Y Axis scales to logarithmic, and then click “OK.”
7. Add marker ‘m1’ on the “mag(Sandler_NISM_Zout)” trace at the active resonance impedance peak.
8. Add marker ‘m2’ on the “Sandler_NISM_QTg, QTg_freq” trace at the peak nearest in frequency to the active resonance impedance peak.
9. Rename markers ‘m1’ and ‘m2’ to ‘M1’ and ‘M2,’ respectively.
10. Add a text box to the data display with the following details:

Sandler_NISM_PM: @Sandler_NISM_PM degrees
 Z Frequency: @Z_Frequency Hz
 Q Frequency: @Q_Frequency Hz
 Effective Q: @M2

@Time_Stamp

11. Figure 6 illustrates a correctly implemented NISM plot and results text box:

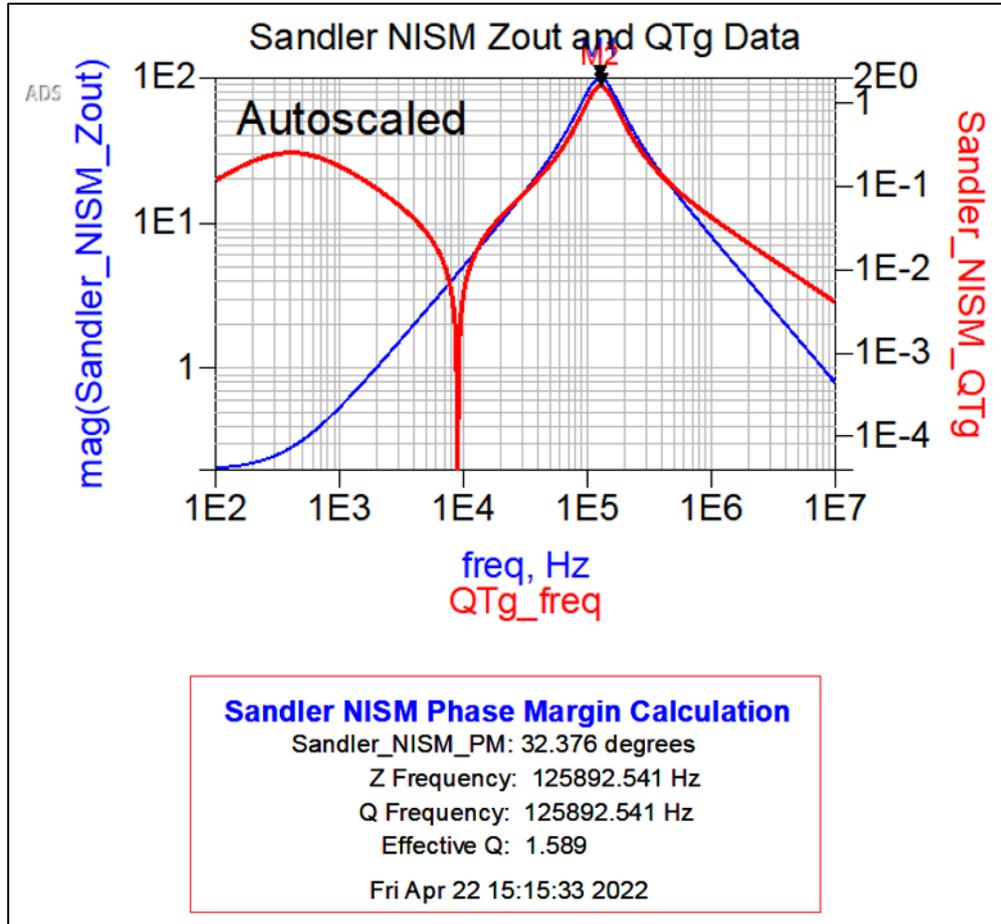


Figure 86: Correctly implemented NISM plot and results text box. Plotting the impedance in the OFF state (power off), can help differentiate passive resonances from the active, control loop resonances. It can also help identify the control loop bandwidth which is where the NISM cursor measurement should be made.

Chapter 6 - References

NISM Technical Information

- **Main NISM Technical page**
<https://www.picotest.com/non-invasive-stability-measurement.html>
- **Introduction to NISM**
<https://www.picotest.com/non-invasive-stability-measurement.html>
- **NISM Solution Page**
<https://www.picotest.com/measurements/NISM.html>
- **NISM Software**
https://www.picotest.com/products_NISM_software.html
- **Many application notes and articles discussing and using NISM**
<https://www.picotest.com/blog/category/nism/> (this will require registration)

Videos Covering NISM

- **Introduction to NISM, June 2017**
<https://www.youtube.com/watch?v=cxeulMcvYR8>
- **Webinar: Non-invasive Stability Measurement of Power Supplies with Bode 100**
<https://www.youtube.com/watch?v=i4gOrdZS9Kg>
- **Webinar: Stability Analysis of Power Supplies, March 2018**
<https://www.youtube.com/watch?v=0kZOG7sNuik>
- **Webinar: Output Impedance of Power Supplies, May 2020**
<https://www.youtube.com/watch?v=YpAWwylArwk>

- **Robert Bolanos Video on NISM, Oct. 2022**
<https://www.youtube.com/watch?v=ErpU3jSQPgY>

Papers and Some Background and Theory about why NISM works

- **NISM using the P2102A Probe and the Keysight E5061B, Picotest 4/29**
https://www.picotest.com/images/download/ApplicationNote-NISM_using_P2102A_Probe_and_E5061B_VNA.pdf
- **ZOUT to NISM: Output Impedance to Non-Invasive Stability Measurement**
<https://www.microwavejournal.com/blogs/32-rf-signal-integrity-to-power-integrity/post/41276-zout-to-nism-output-impedance-to-non-invasive-stability-measurement>
- **Overview and Comparison of Power Converter Stability Metrics, DesignCon 2017**
http://electrical-integrity.com/Paper_download_files/DC17_PAPER_11_OverviewComparisonPowerConverterStability_Hartman.pdf
- **Output Impedance for Stability Analysis, 2020**
https://www.picotest.com/images/download/AppNote_OutputImpedance_Stability_V1.0.pdf
- **Output impedance - an important design parameter for power supplies, Power Analysis and Design Symposium April 2018**
https://www.picotest.com/images/download/Florian%20Hammerle_OutputImpedance.pdf
- **Paper: Fundamentals of Linear Stability - NASA Engineering**
<https://nescacademy.nasa.gov/review/downloadfile.php?file=LinearStability091414.pdf&id=274&distr=Public>
- **Video: Fundamentals of Linear Stability - NASA Engineering, NASA Nov. 2014**
<https://nescacademy.nasa.gov/video/f753628f4d934668b14fb559d71f5ae81d>
- **A Bode Plot Without Access to the Control Loop**
<https://www.signalintegrityjournal.com/blogs/15-extreme-measurements/post/2307-a-bode-plot-without-access-to-the-control-loop>
- **Impedance measurements stabilize op-amp buffers**
<https://www.edn.com/impedance-measurements-stabilize-op-amp-buffers/>
- **Software Enables Accurate Stability Test, Improves Non-Invasive Phase Margin Measurement Accuracy**
<https://www.electronicdesign.com/technologies/power-electronics-systems/article/21196953/software-enables-accurate-stability-test-improves-noninvasive-phase-margin-measurement-accuracy>
- **Assessing Point-Of-Load Regulators Using Non-Invasive Techniques**
<https://www.electronicdesign.com/technologies/power/power->

[supply/regulators/article/21195167/assessing-pointofload-regulators-using-noninvasive-techniques](https://www.electronicdesign.com/technologies/power/power-supply/power-electronics-systems/article/21195167/assessing-pointofload-regulators-using-noninvasive-techniques)

- **So how does this non-invasive measurement relate to phase margin and gain margin?**
<https://www.picotest.com/articles/Non-invasive%20FAQ%2022.pdf>
- **Evaluate Feedback Stability When There's No Test Point**
<https://www.electronicdesign.com/technologies/test-measurement/article/21796507/evaluate-feedback-stability-when-theres-no-test-point>
- **New Technique for Non-Invasive Testing of Regulator Stability**
<https://www.electronicdesign.com/technologies/power/power-supply/power-electronics-systems/article/21193660/new-technique-for-noninvasive-testing-of-regulator-stability>

Issues with Bode Plots

- **Non-Invasively Assess Your Multiple-Loop LDO's Stability**
<https://www.electronicdesign.com/power-management/article/21798898/noninvasively-assess-your-multipleloop-ldos-stability>
- **The 5-Minute Method for Stabilizing Any Control Loop**
<https://www.signalintegrityjournal.com/articles/1546-the-5-minute-method-for-stabilizing-any-control-loop>
- **Five Things Every Engineer Should Know About Bode Plots**
<https://www.powerselectronics.com/technologies/power-electronics-systems/article/21861083/five-things-every-engineer-should-know-about-bode-plots>
- **Killing the Bode Plot**
<https://www.dropbox.com/s/l8hsv1a9k77jvn5/Killing%20the%20Bode%20Plot%20Final.pdf?dl=0>
- **Bode Plots are Overrated**
<https://www.signalintegrityjournal.com/articles/585-bode-plots-are-overrated>
- **When Bode Plots Fail Us**
<https://www.electronicdesign.com/technologies/power/power-supply/power-electronics-systems/article/21194594/when-bode-plots-fail-us>

VRM Modeling

- **Video - How To Simulate Your Power Supply**
<https://www.youtube.com/watch?v=8RlP2BsPwPM>
- **Video - DesignCon 2023 - VRM Modeling and Stability Analysis for the Power Integrity Engineer**
<https://www.youtube.com/watch?v=rnd0CG9wlvQ>

- **VRM Modeling and Stability Analysis for the Power Integrity Engineer**
<https://www.signalintegrityjournal.com/articles/3355-vm-modeling-and-stability-analysis-for-the-power-integrity-engineer>
- **VRM Modeling: A Strategy to Survive the Collision of Three Worlds, SIJ, November 21, 2018**
<https://www.signalintegrityjournal.com/articles/1017-vm-modeling-a-strategy-to-survive-the-collision-of-three-worlds>
- **Measurement Based VRM Modeling, 2017 IEEE 21st Workshop on Signal and Power Integrity (SPI), IEEE, May 2017 IEEE 21st Workshop on Signal and Power Integrity (SPI)**
<https://ieeexplore.ieee.org/document/7944009>
<https://www.picotest.com/downloads/Measurement-Base-VRM-Model-Tutorial-Final-2017.pdf>
- **Video: Measurement-Based, Harmonic Balance VRM Model, DGCon April 2020, A unified, fast-simulating, Harmonic Balance VRM simulation model is introduced. it supports discontinuous, continuous, and forced continuous conduction modes for voltage mode, voltage mode feed-forward and current mode control.**
<https://youtu.be/QtPCyiR4QmY>
<https://www.picotest.com/blog/video-measurement-based-harmonic-balance-vm-model/>
- **Characterizing and Selecting the VRM, SIJ, April 25, 2018**
<https://www.signalintegrityjournal.com/articles/831-characterizing-and-selecting-the-vm>
- **Characterizing the VRM, EDIcon Online, Sept. 2019**
Email Info@picotest.com or Info@aeng.com for this article
- **The Inductive Nature of Voltage Control Loops**
<https://www.edn.com/the-inductive-nature-of-voltage-control-loops/>
- **Measurement Based VRM Model Tutorial Handout Final.pdf, Picotest, May 2017**
Picotest Power Integrity Training Course Material, email info@picotest.com
- **Measuring and Interpreting Impedance Data, SIJ August, 2019**
<https://event.on24.com/eventRegistration/EventLobbyServlet?target=reg20.jsp&referrer=https%3A%2F%2Fwww.signalintegrityjournal.com%2Fevents%2F99-measuring-and-interpreting-impedance-data&eventid=2049545&sessionid=1&key=DA37B34BE8615E5EA7FEB1101C3D0BF8®Tag=&sourcepage=register>
- **Stability and Performance Improvement with Feedback in VRM Transconductance Error Amplifiers**
A Case Study using the Sandler State Space Average VRM Model, EDIcon Online, October 2022
<https://edicononline.com/session/stability-and-performance-improvement-with-feedback-in-vm-transconductance-error-amplifiers-a-case-study-using-the-sandler-state-space-average-vm-model/>
- **Small Signal Models Small Signal Problems SIJ, NOV 2022**
<https://www.signalintegrityjournal.com/articles/2898-small-signal-models-small-signal->

problems

- **VRM Modeling and Stability Analysis for the Power Integrity Engineer, DesignCon Feb 2023 - Ballroom F, Ben Dannan (NGC), Heidi Barnes (Keysight Technologies), Christian Yots (TI), Steve Sandler (Picotest) 2023**
<https://www.picotestonline.com/designcon2023>
<https://www.signalintegrityjournal.com/articles/3355-vrm-modeling-and-stability-analysis-for-the-power-integrity-engineer>
- **TPS7H4003 SSA Workspace in ADS VRM ADS workspace.**
https://ef6487b8-0ffb-4eed-96ad-999884d5d72f.filesusr.com/archives/b3f48a_c453744a2bbf41768ef56872e0092fcb.zip?dn=TPS7H4003_SSA_Model_v2_wrk.zip