Overview and Comparison of Power Converter Stability Metrics

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SPEAKERS

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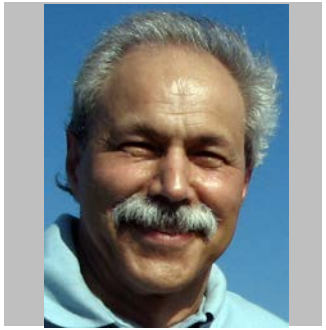

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- Introduction
- Gain-phase plots
  - Traditional gain-phase plots
  - Gain-phase plot approximations and non-invasive measurements
- Nyquist plots and Stability margin
- Other metrics
- What can go wrong?
  - Wrong test signal level
  - Spurious signals
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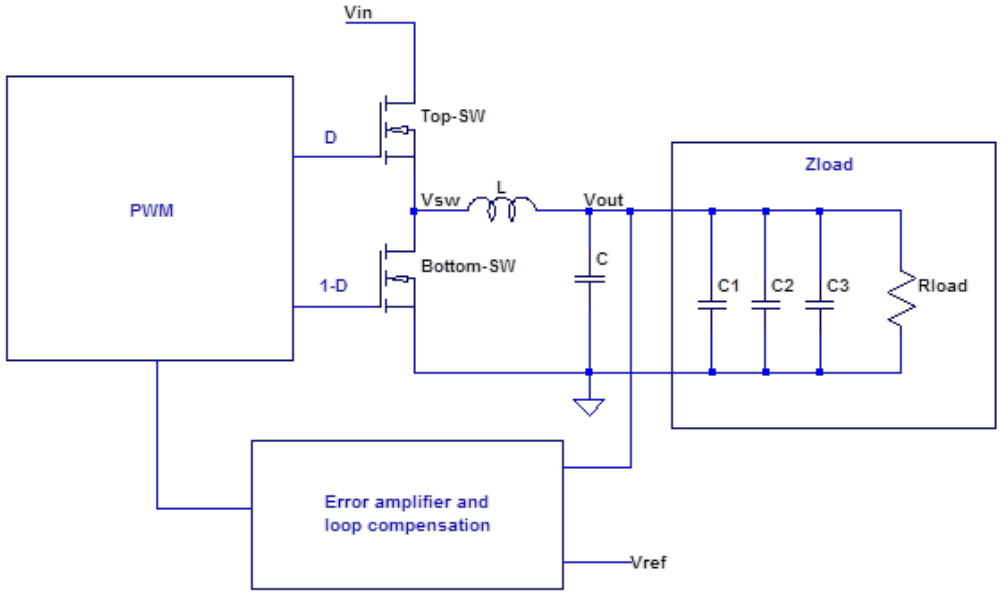
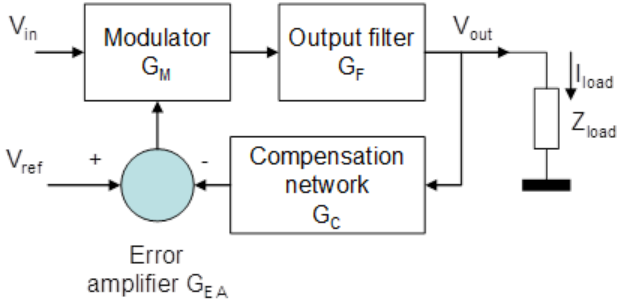
Basic Buck Converter and its Loop Model

Non-isolated buck converter block schematic



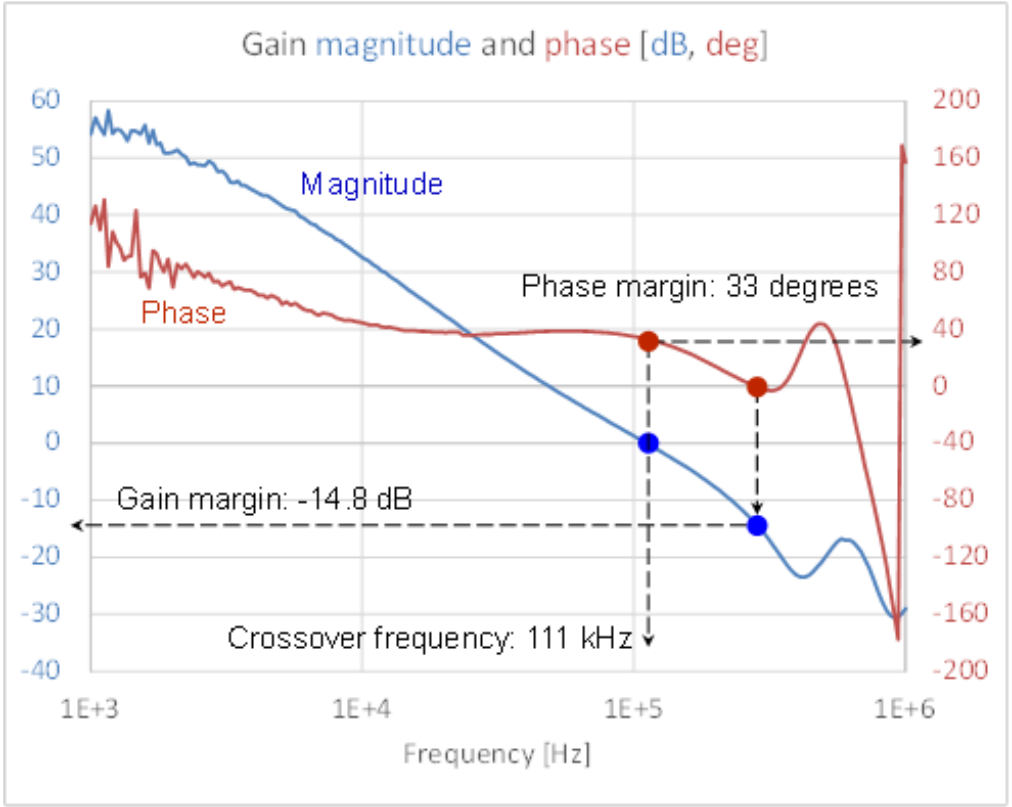
Simplified feedback loop



$$G_{open-loop} = G_M \; G_F \; G_C \; G_{EA}$$

Bode Plot, Phase and Gain Margins

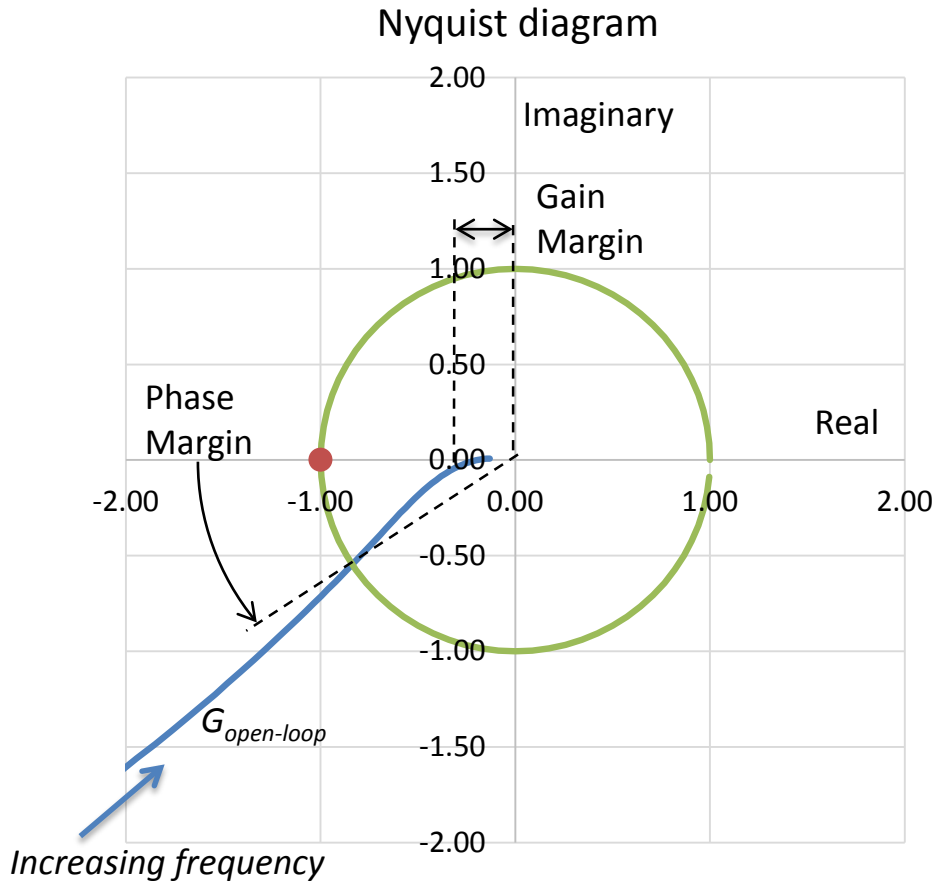
- Crossover Frequency – frequency where gain magnitude equals 0 dB
- Phase Margin – phase at the crossover frequency
- Gain Margin – gain where phase equals 0 degrees



Nyquist Plot

- Plots imaginary vs. real component of loop gain
- Frequency parameter
- Point of instability is -1,0

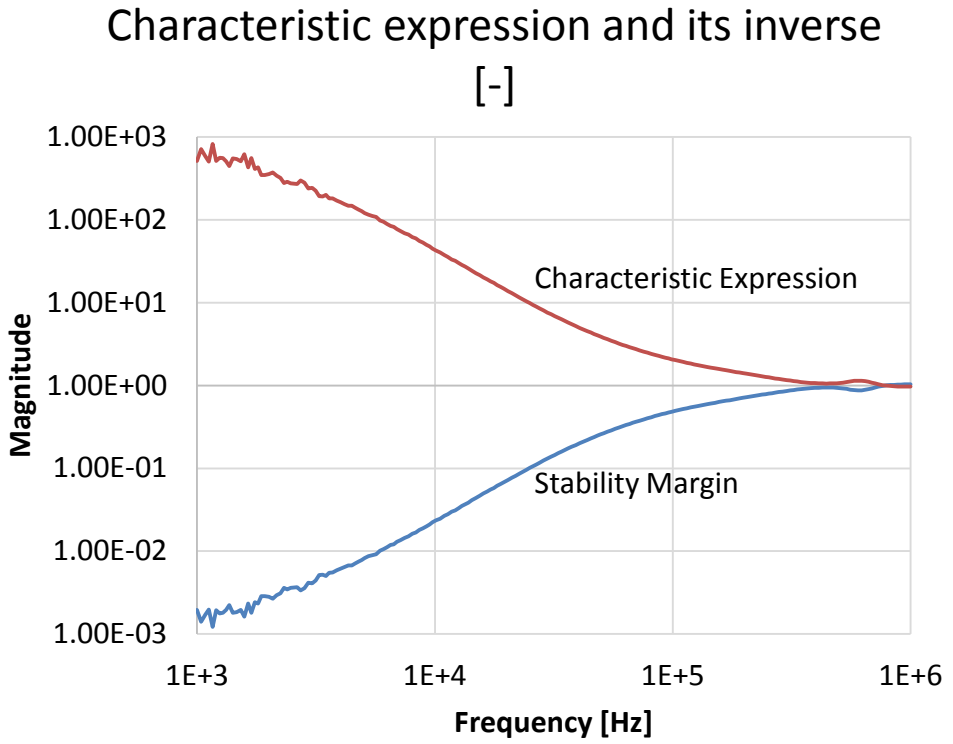
$$\frac{\Delta V_{out}}{\Delta I_{load}} = Z_{out-closed-loop}(f) = \frac{Z_{out-open-loop}(f)}{1 + G_{open-loop}(f)}$$



Characteristic Expression Magnitude and Its Inverse

- Plots $\{1+G_{open\text{-}loop}(f)\}$ and its inverse, the stability margin

  Provides the vector magnitude from the instability point



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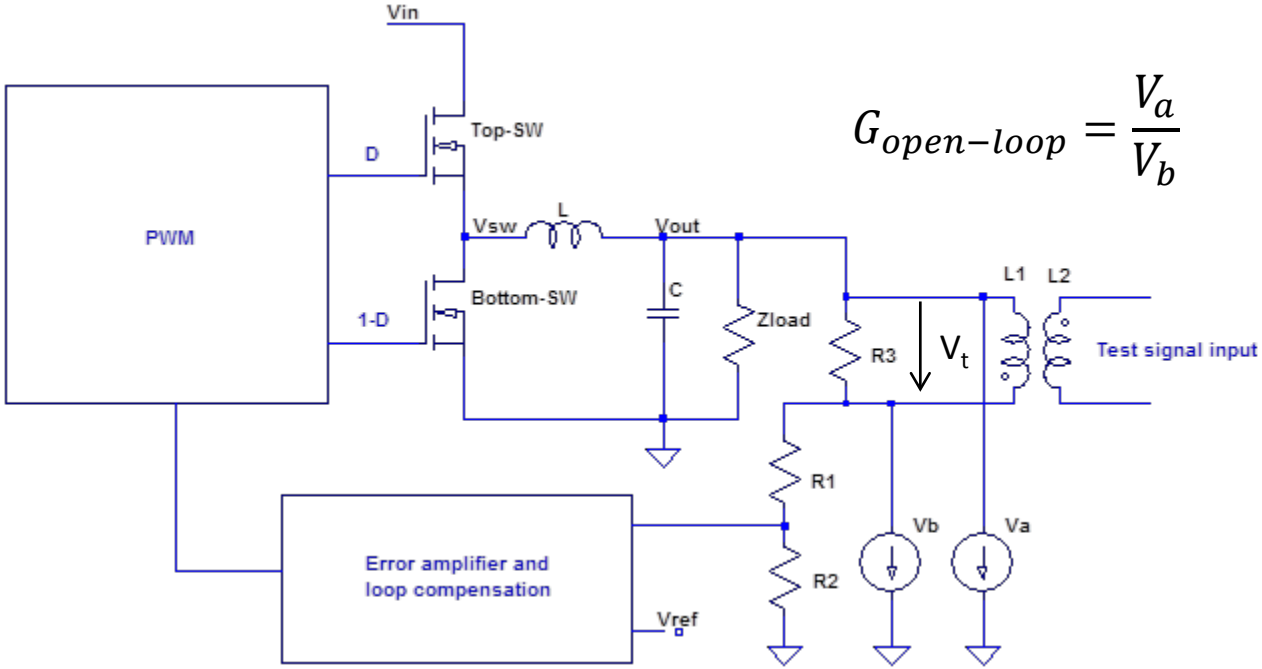
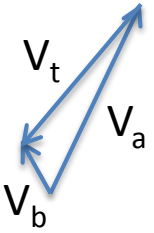
Gain-Phase Measurement Connection



$$G_{open-loop} = \frac{V_a}{V_b}$$

- Requires floating source
- Injection level is important
- Invasive connection



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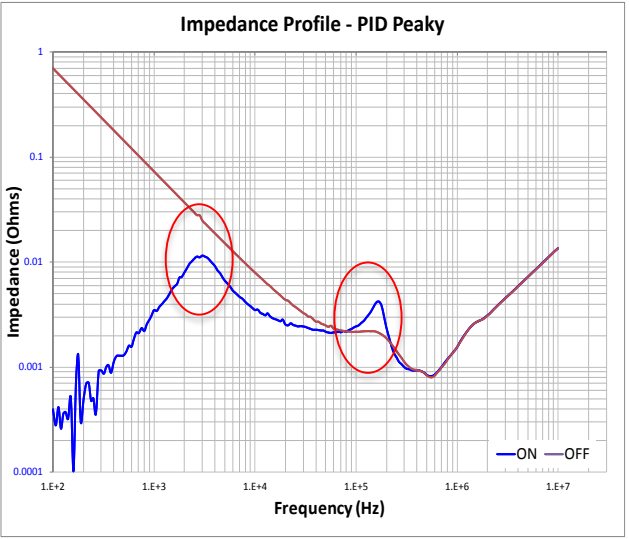
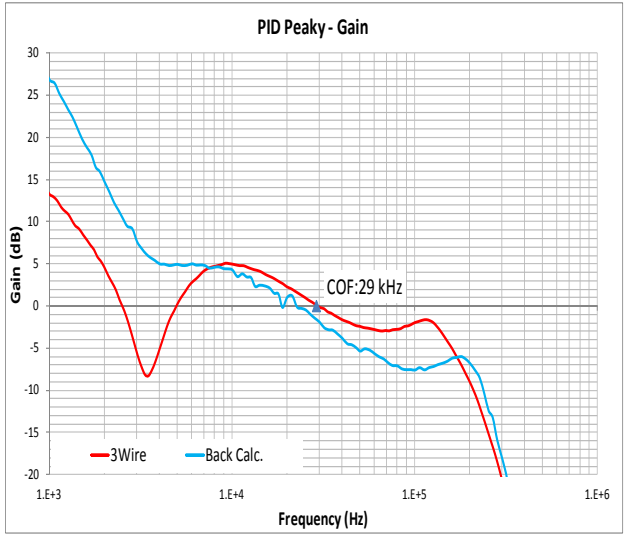
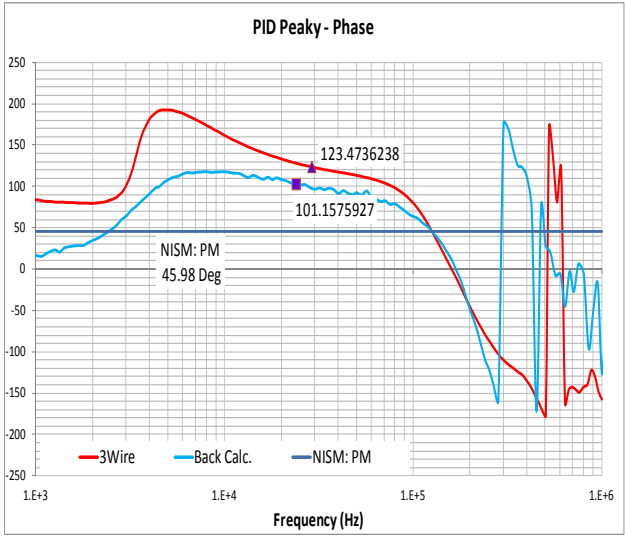
Gain-Phase Measurement Based on Impedance (1)

- Open-loop output impedance can be approximated by OFF impedance
- 'Peaky' example

$$G_{open-loop}(f) = \frac{Z_{out-open-loop}(f)}{Z_{out-closed-loop}(f)} - 1$$





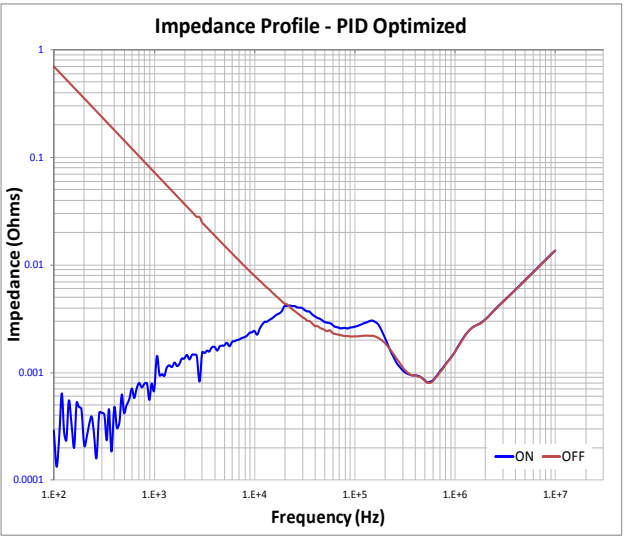


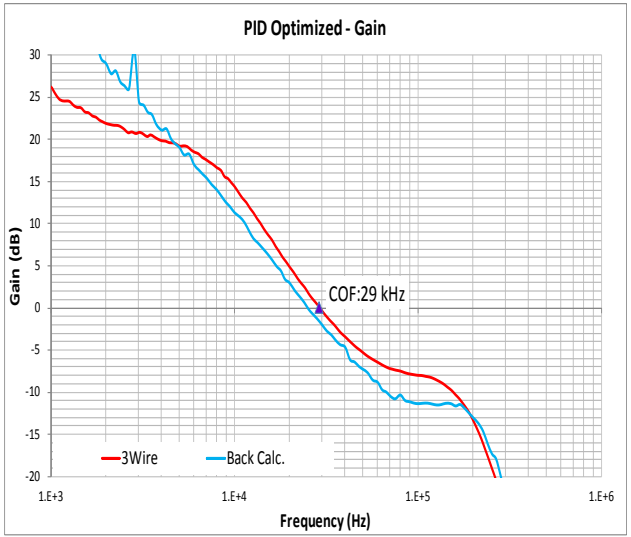
Steve Sandler, "Killing the Bode Plot," DesignCon 2016, January 19-21, 2016, Santa Clara, CA.

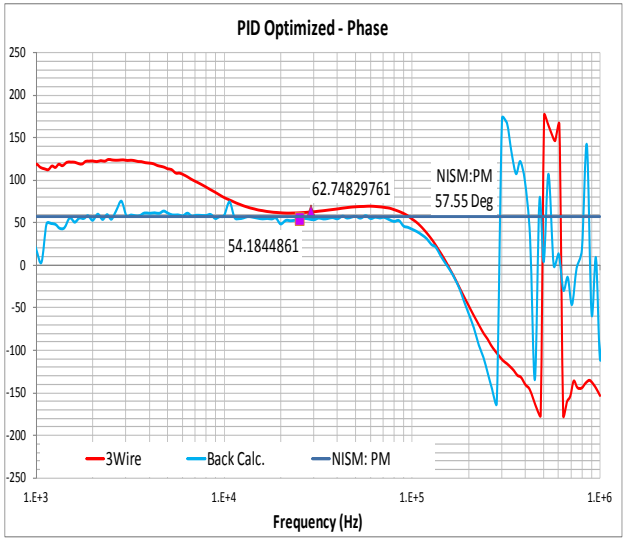
Gain-Phase Measurement Based on Impedance (2)

- Open-loop output impedance can be approximated by OFF impedance
- Optimized example

$$G_{open-loop}(f) = \frac{Z_{out-open-loop}(f)}{Z_{out-closed-loop}(f)} - 1$$







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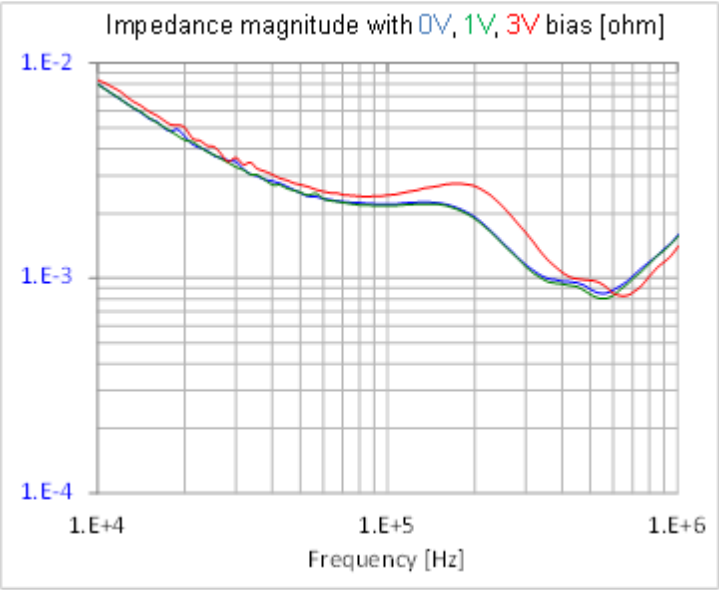
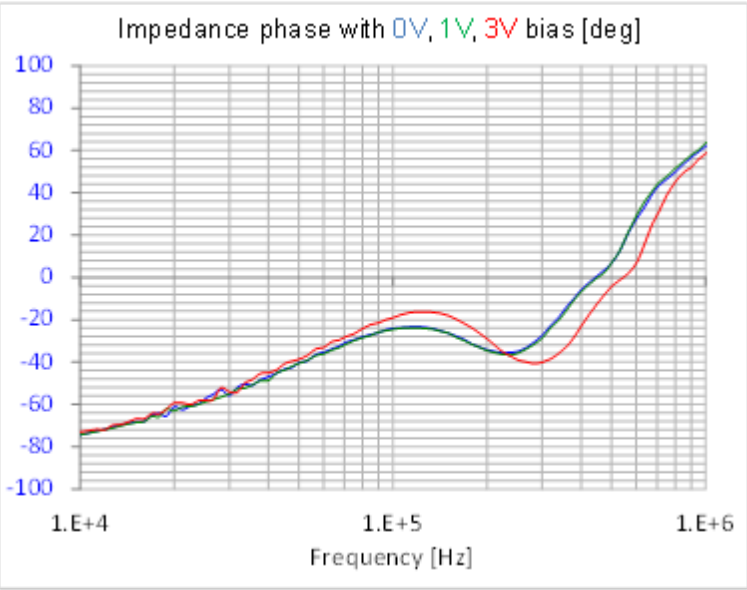
Gain-Phase Measurement Based on Impedance (3)

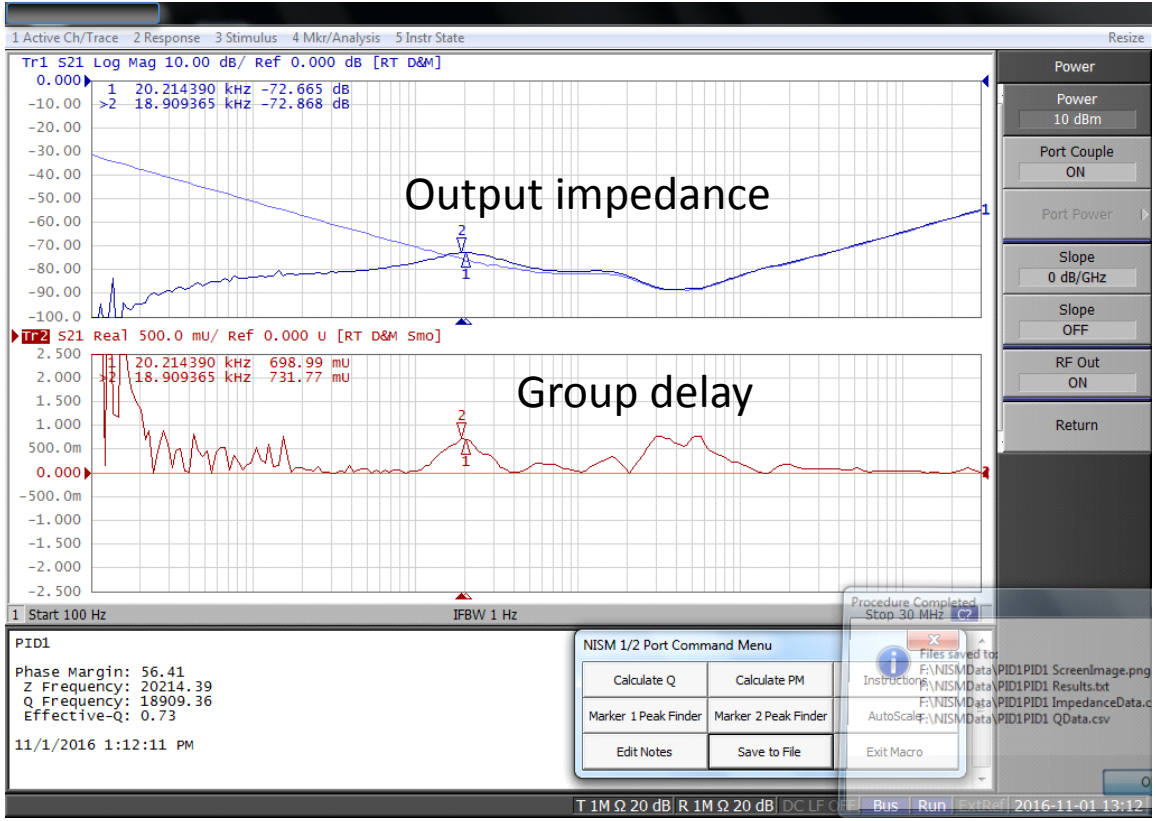
- DC bias for OFF impedance is important





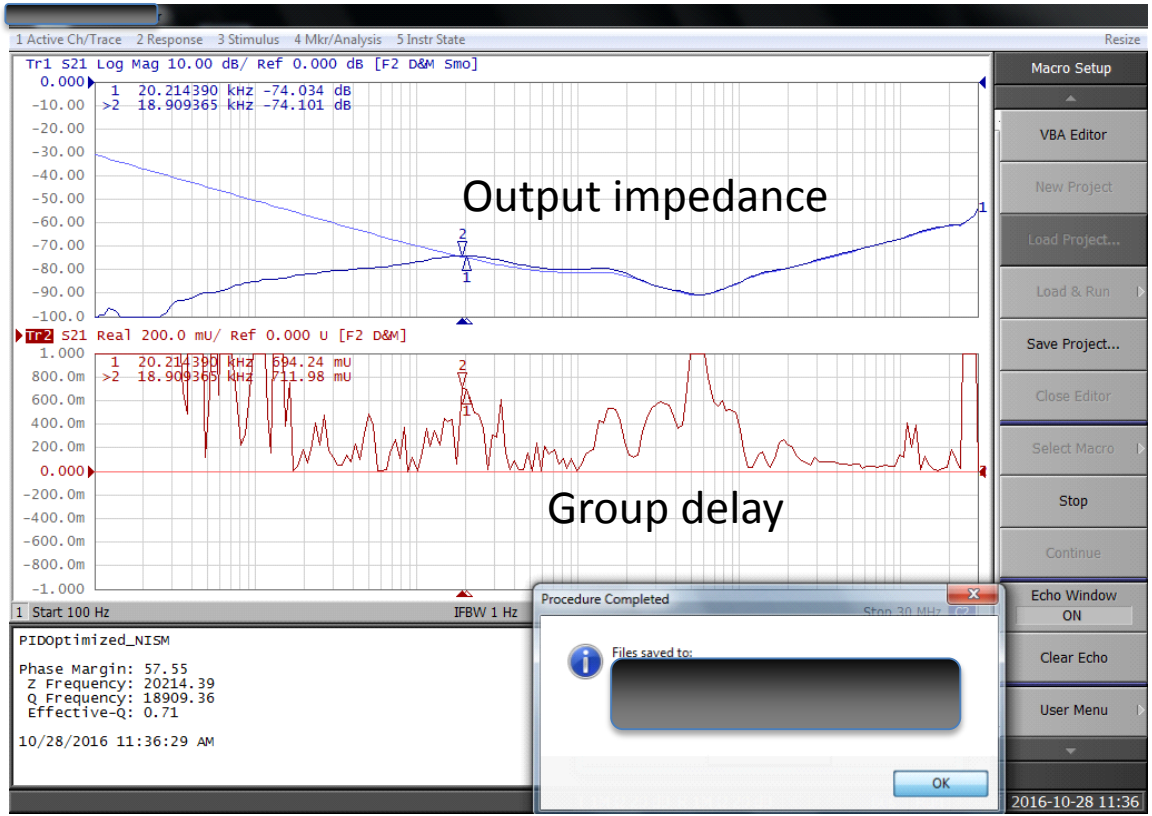
NISM Example on Low-Noise DUT

- NISM is noninvasive
- Estimates phase margin based on second order model of output impedance



Steve Sandler, "Killing the Bode Plot," DesignCon 2016, January 19-21, 2016, Santa Clara, CA.

NISM Example on High-Noise DUT



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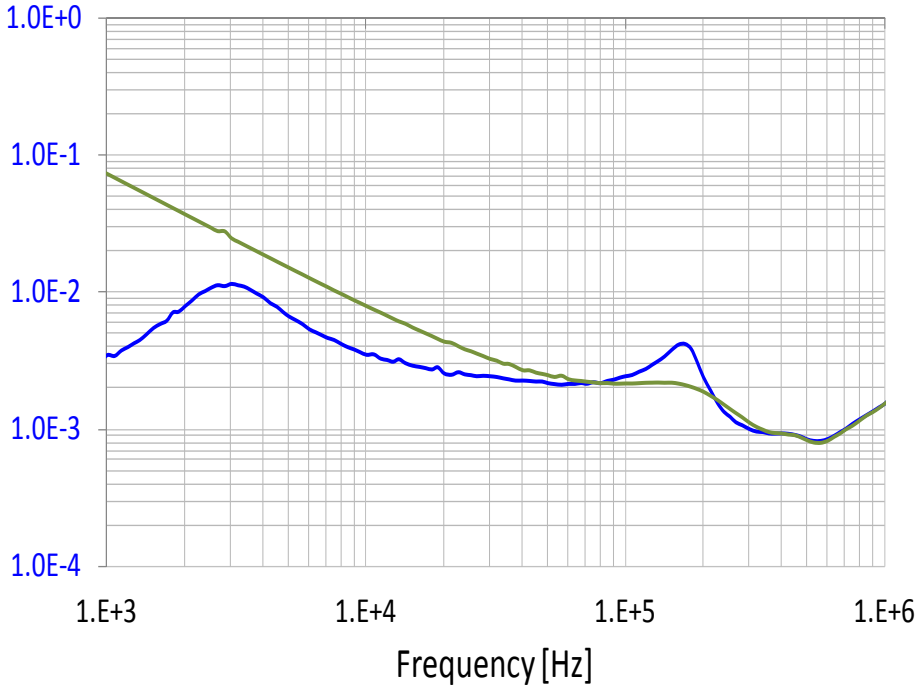
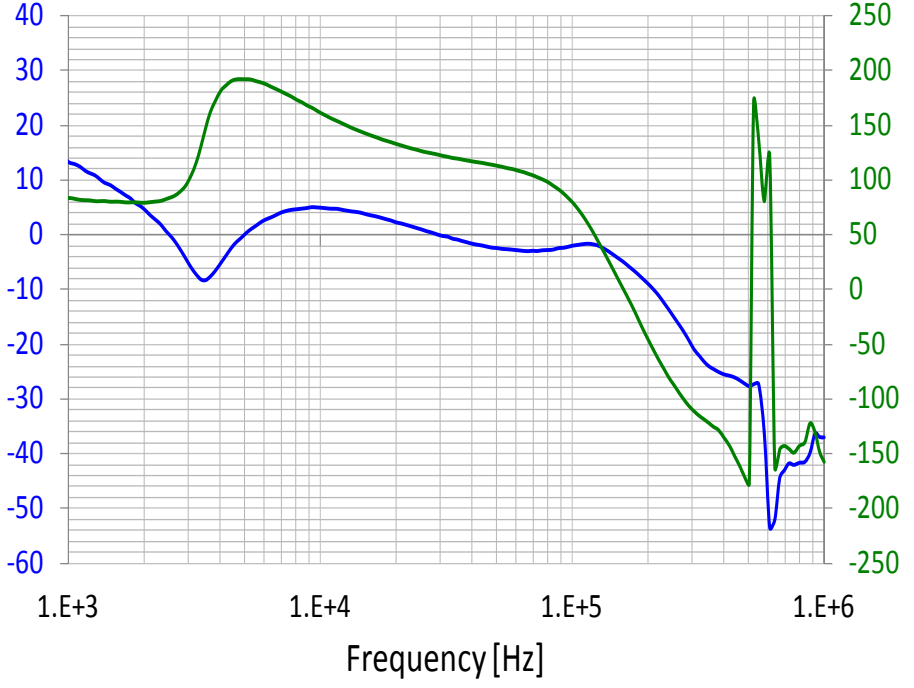
Impedance, Gain-Phase on Unstable Converter

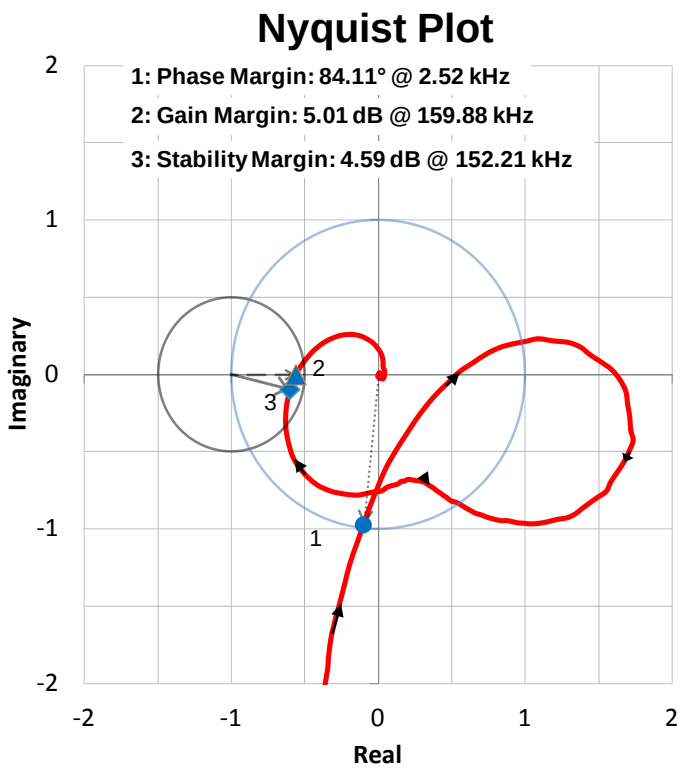
Impedance magnitude ON, OFF [ohm]

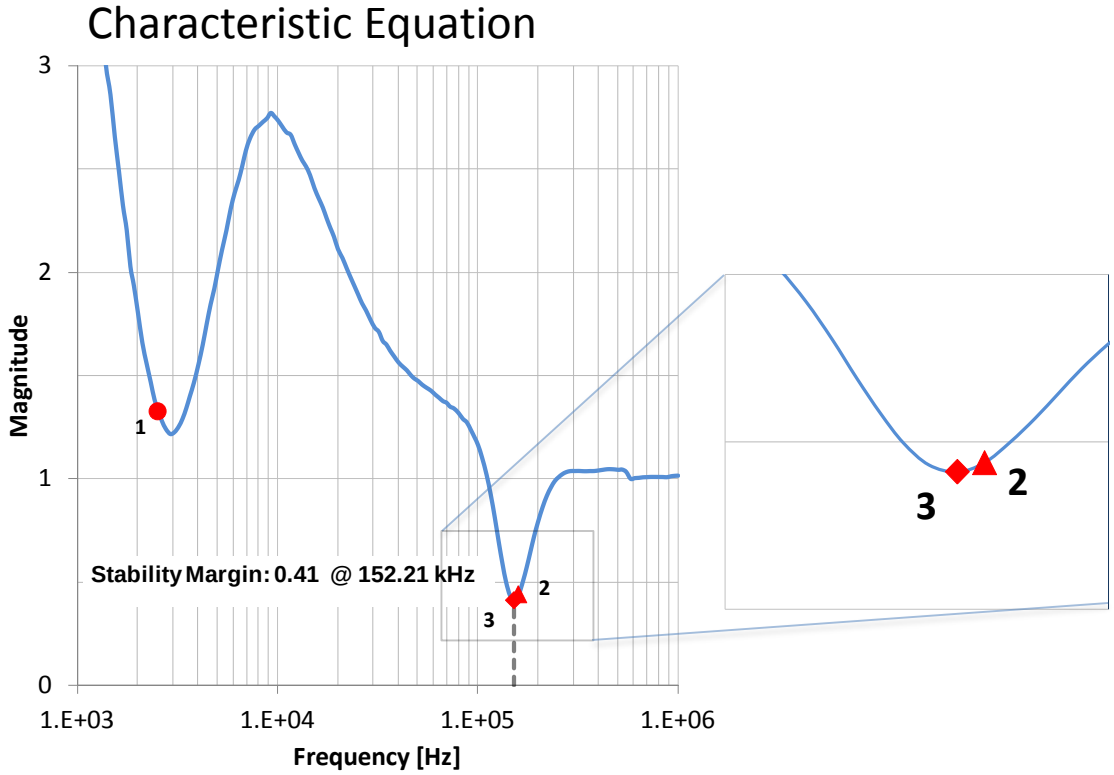


Measured gain magnitude, phase [dB, deg]



Nyquist and Stability Plots on Unstable Converter





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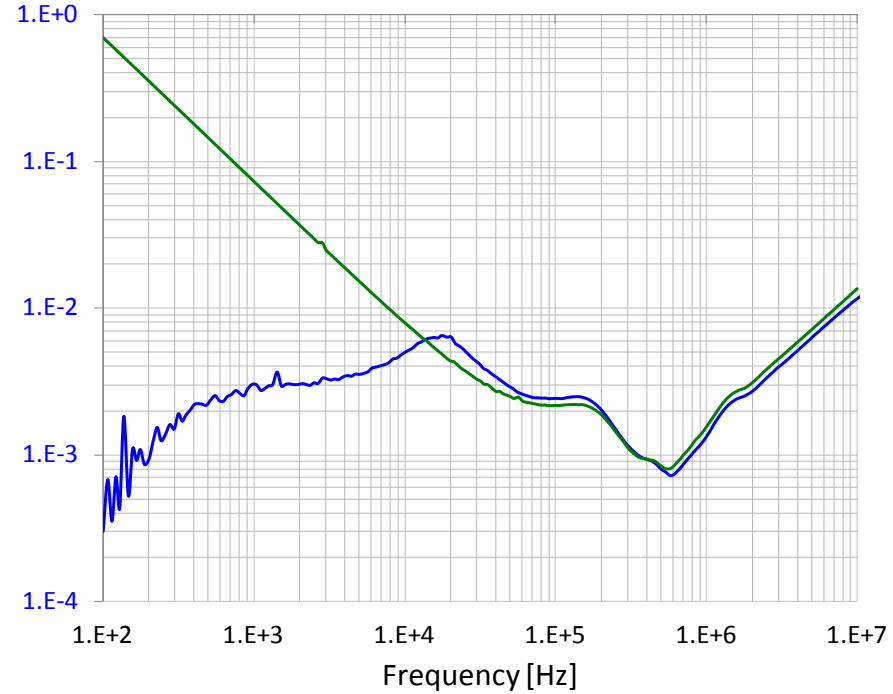

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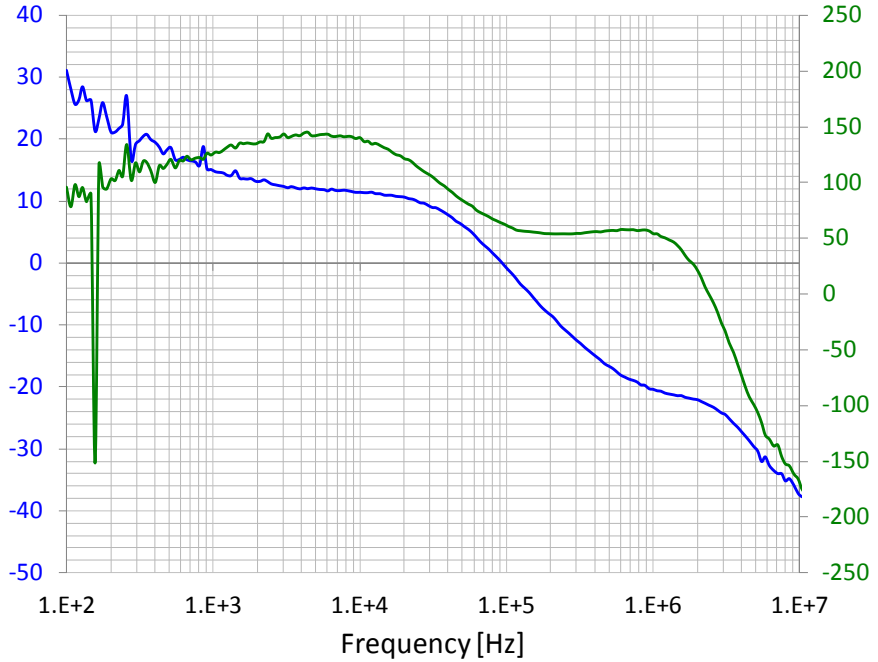

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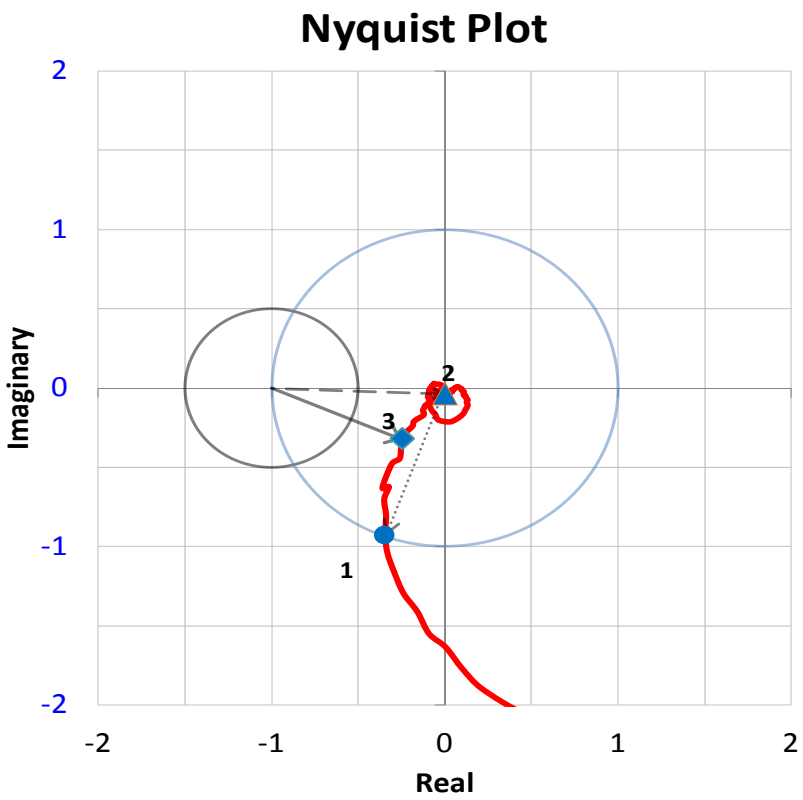

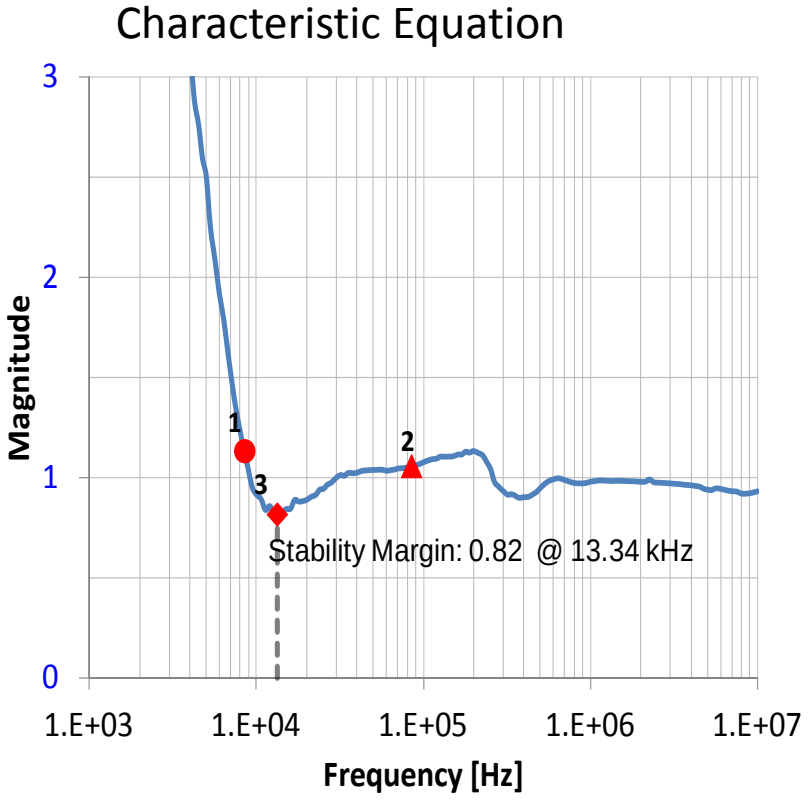

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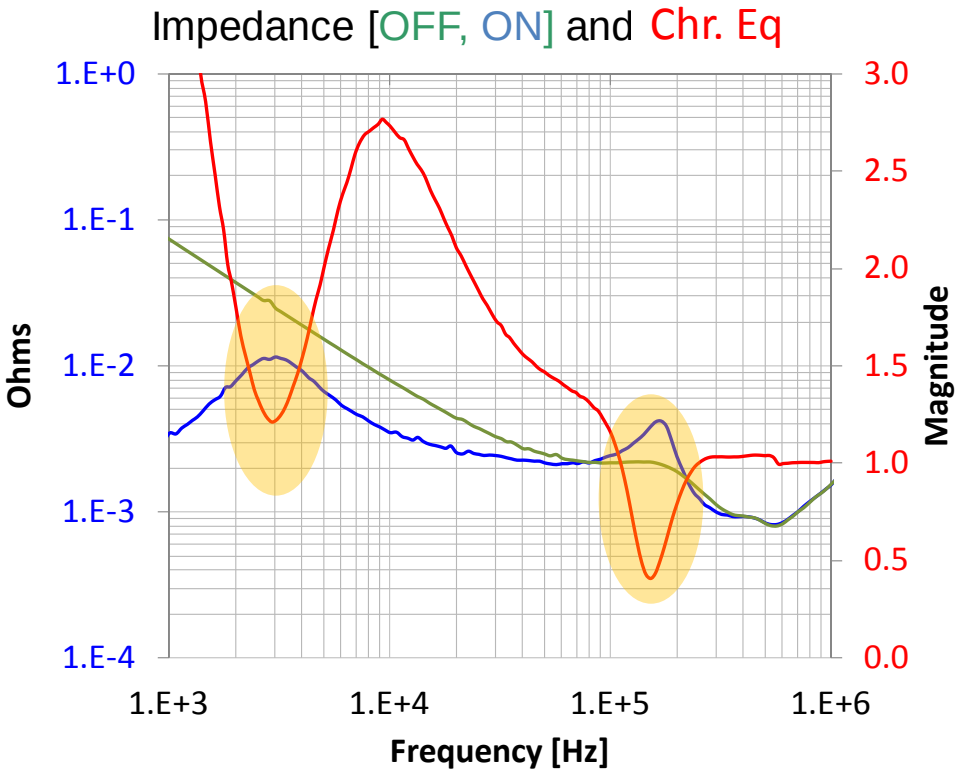
Impedance Profile and Characteristic Expression

- Impedance plot has peaks
- The lows of the Characteristic Expression occur at the same frequency points
- Direct correlation between impedance profile peaks and instability

$$Z_{out-closed-loop}(f) = \frac{Z_{out-open-loop}(f)}{1 + G_{open-loop}(f)}$$



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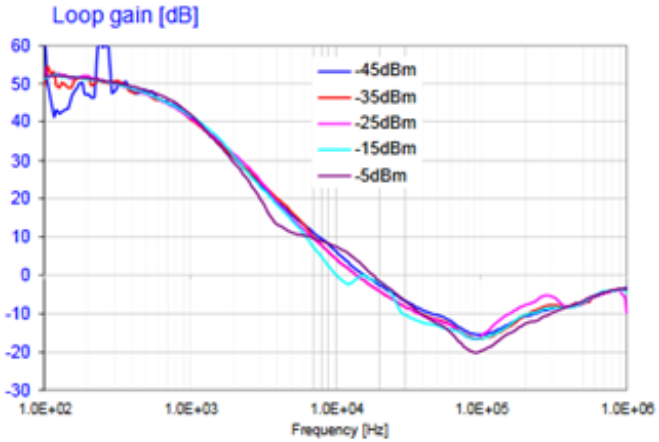
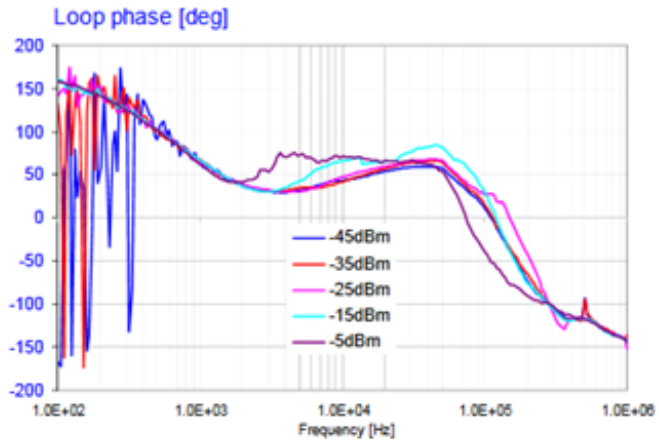
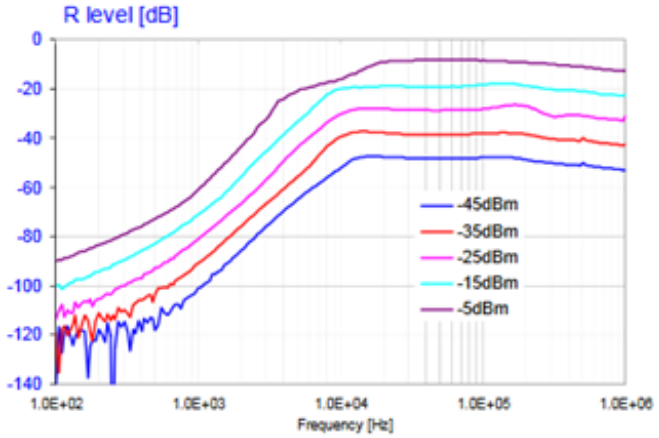
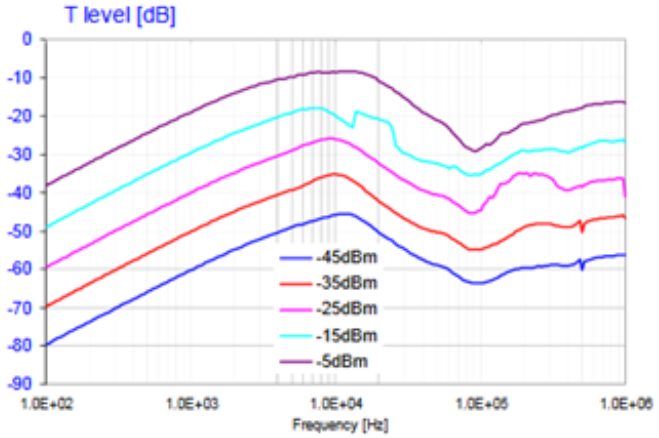
Gain-Phase Curves vs. Injection Level

- Loop gain varies several orders of magnitude over frequency
- Improper signal level can lead to saturation or noisy results









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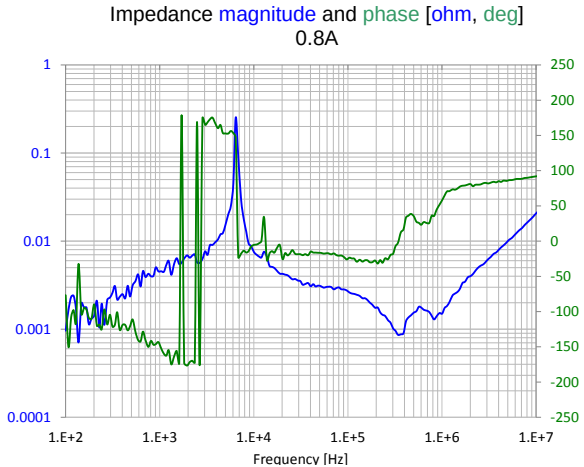
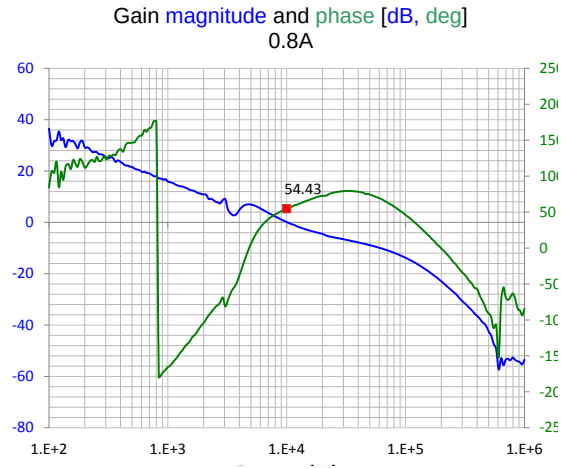
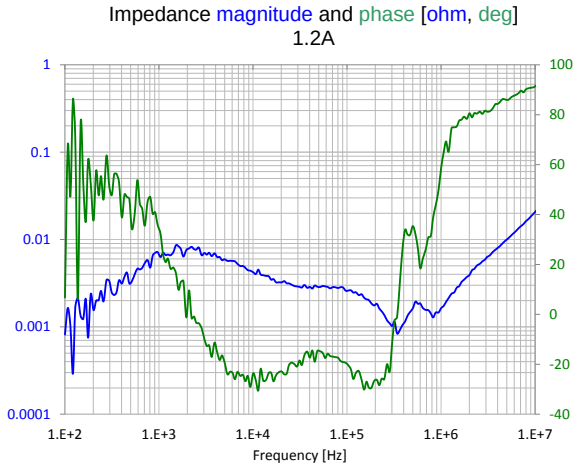
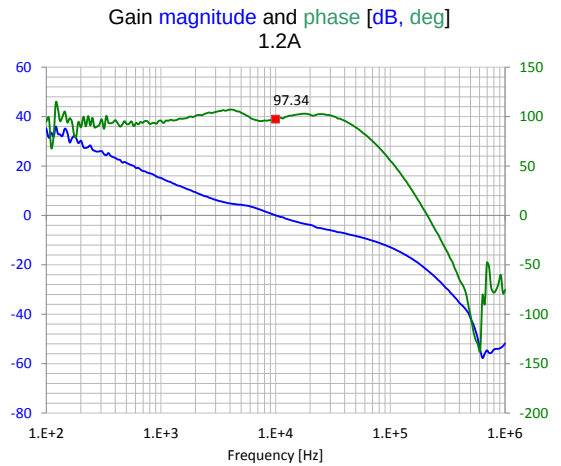
Impedance and Gain-Phase vs. DC Load Current

- Measured small signal output impedance can be a significant function of load current
- At the same time, measured gain-phase also changes



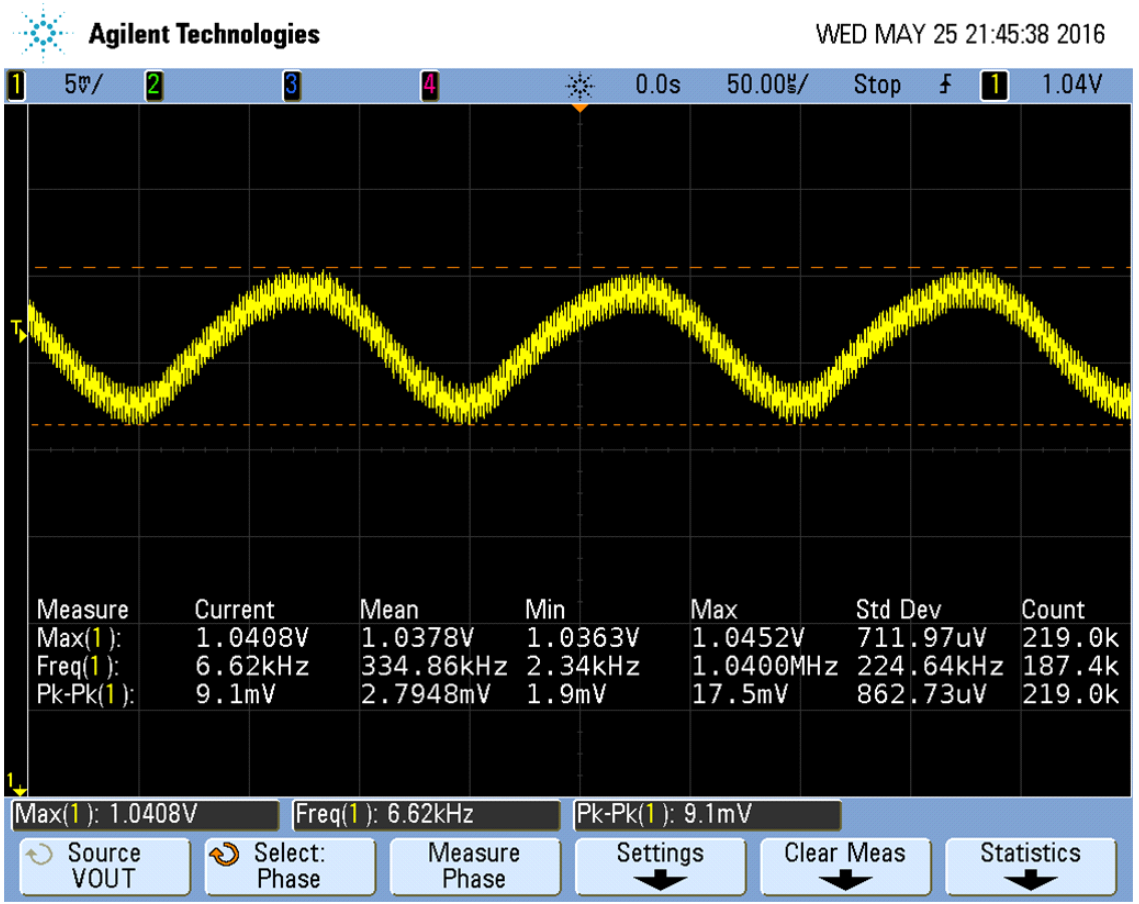






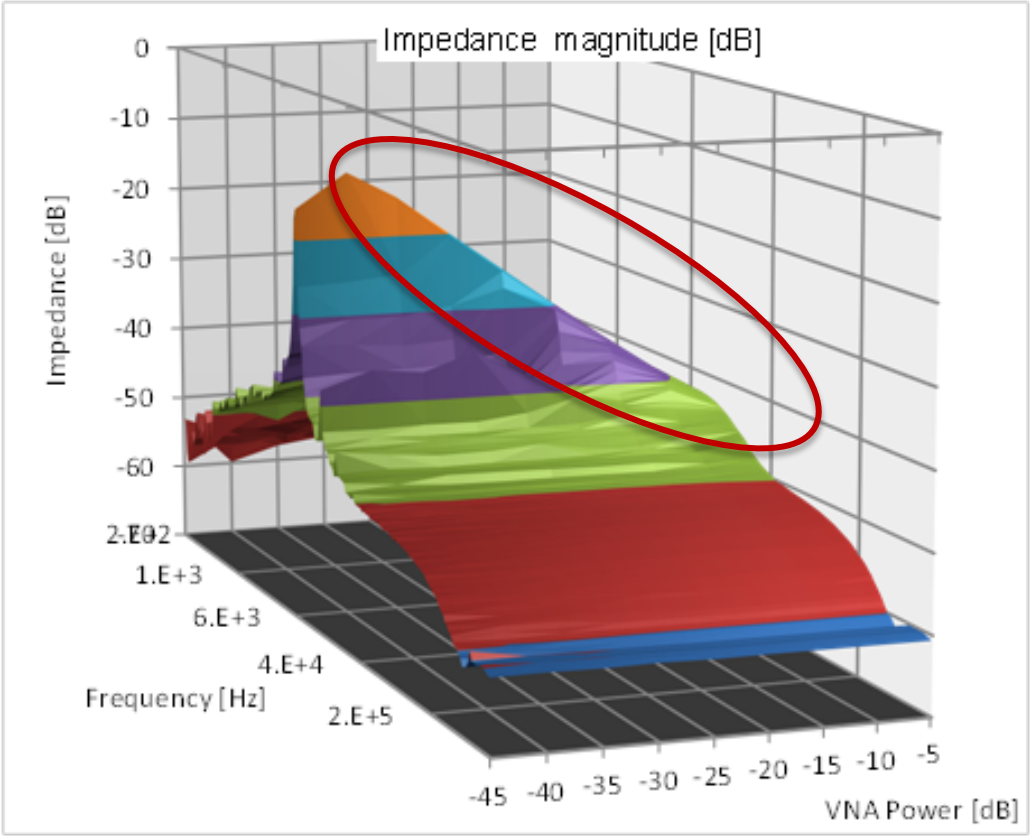
Periodic Output Disturbance

- At the operating point of sudden change, a periodic, uncorrelated ripple appears



Impedance vs. Injection Level

- At the operating point of sudden change, the measured output impedance linearly varies with injection level



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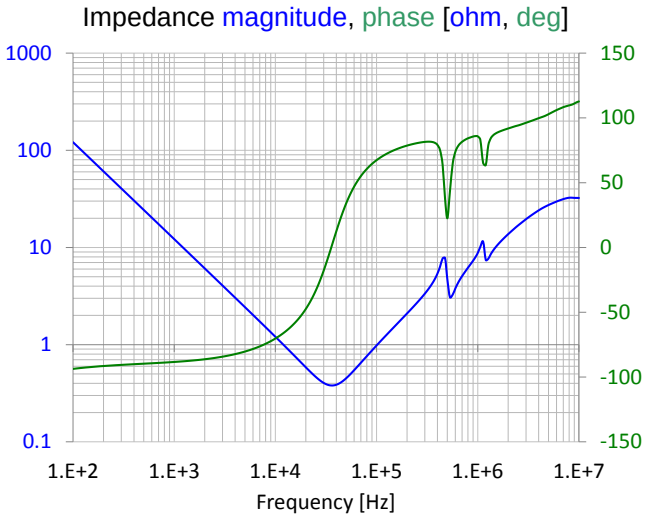
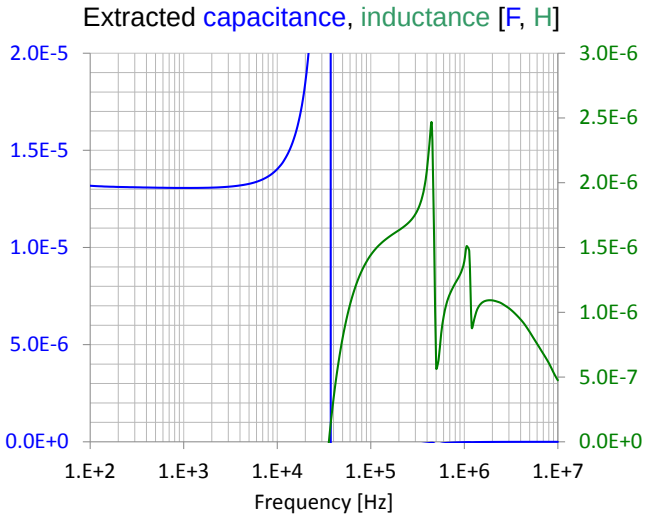
Impedance of Electronic Load

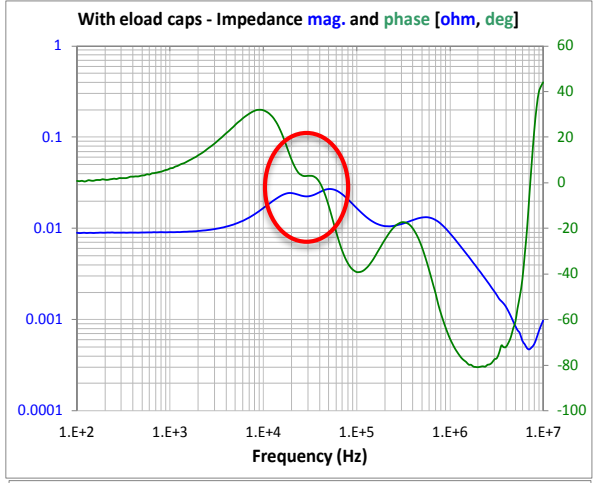
- High current electronic loads have capacitors across their input
- The extra capacitance can change the DUT behavior

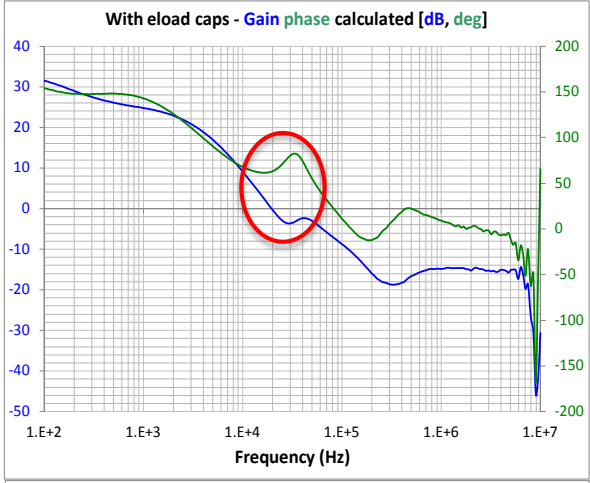


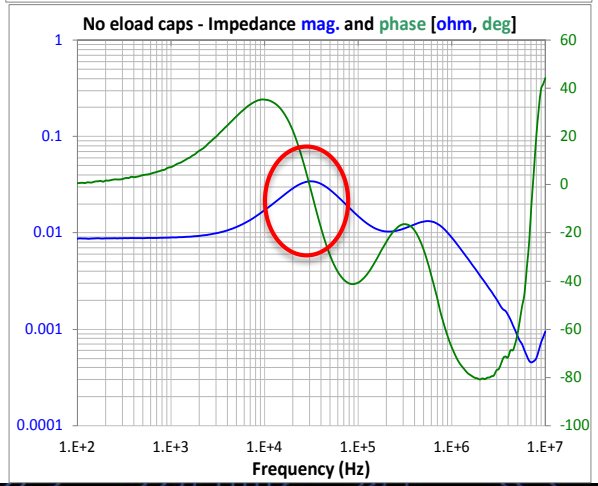


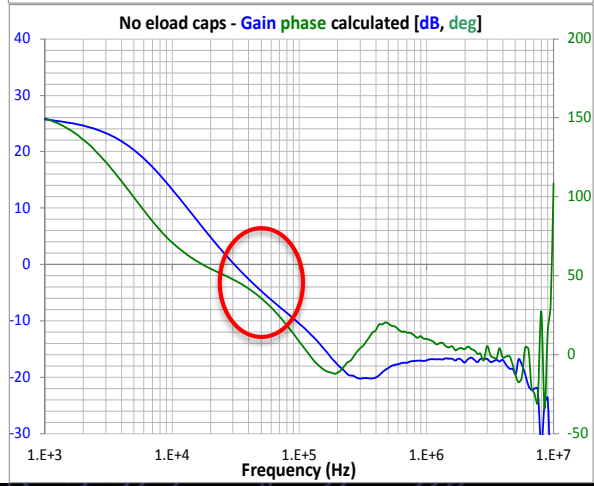
Effect of Electronic Load

- Measured output impedance and gain-phase plots with and without extra capacitance in electronic load

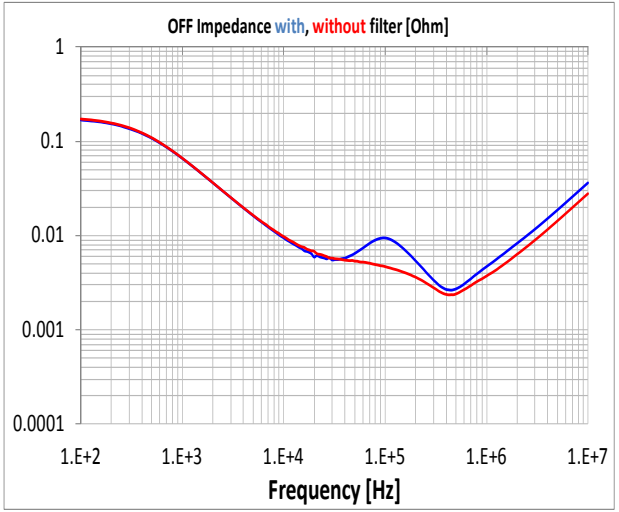


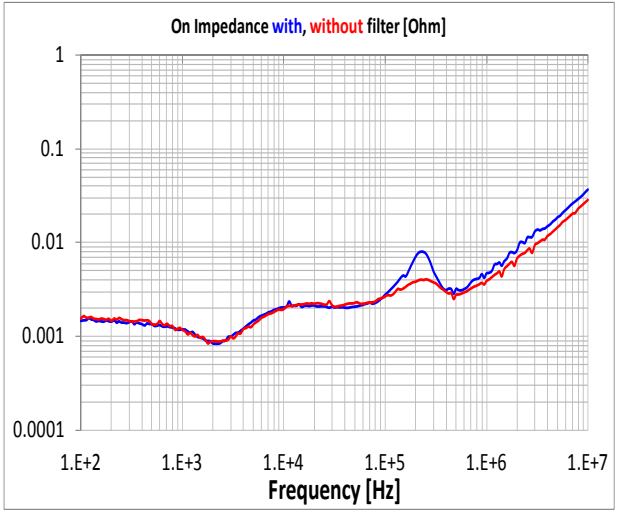


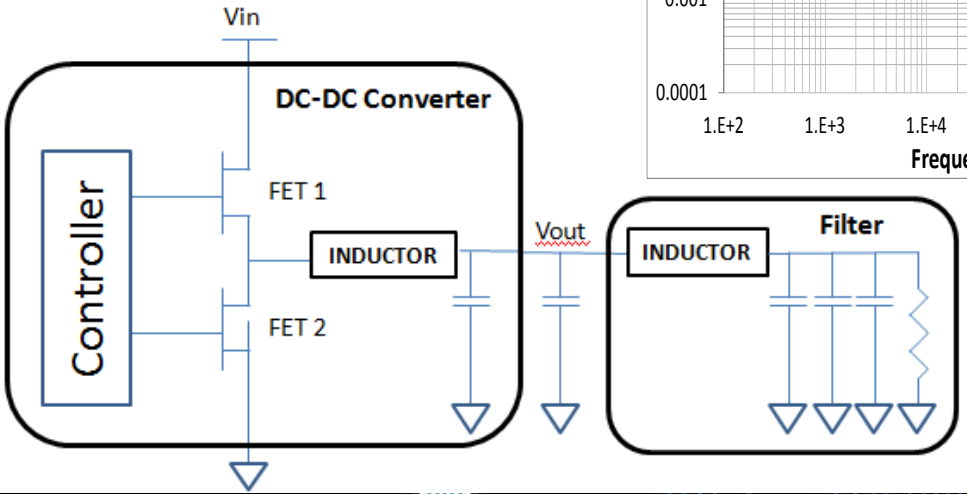




Impact of Secondary Output Filter

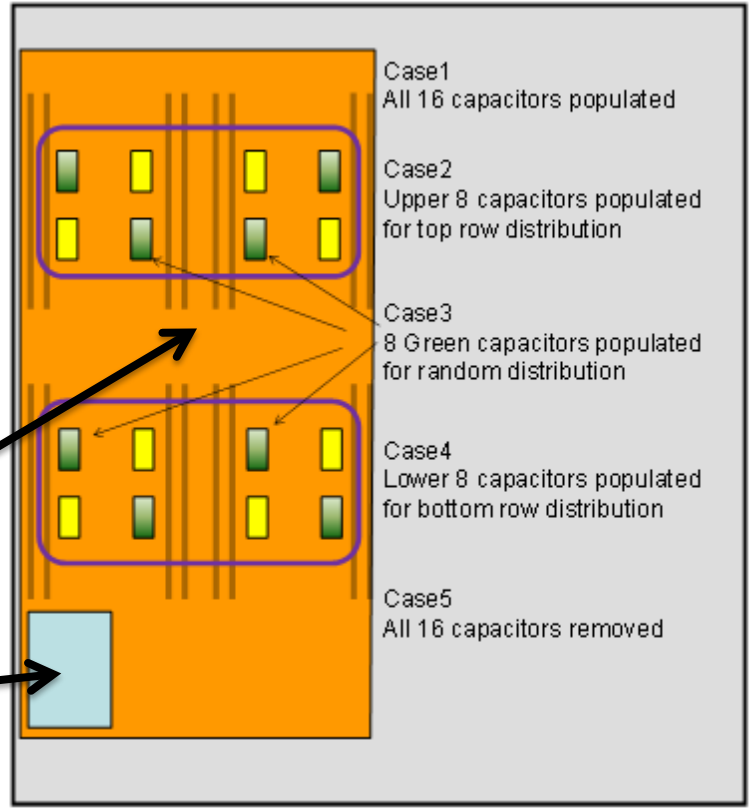






Geometry for Plane R-C Filtering

- 16 - 1000uF D-size bulk capacitors populated
- Configurations target various cases of extra phase shift in voltage transfer function

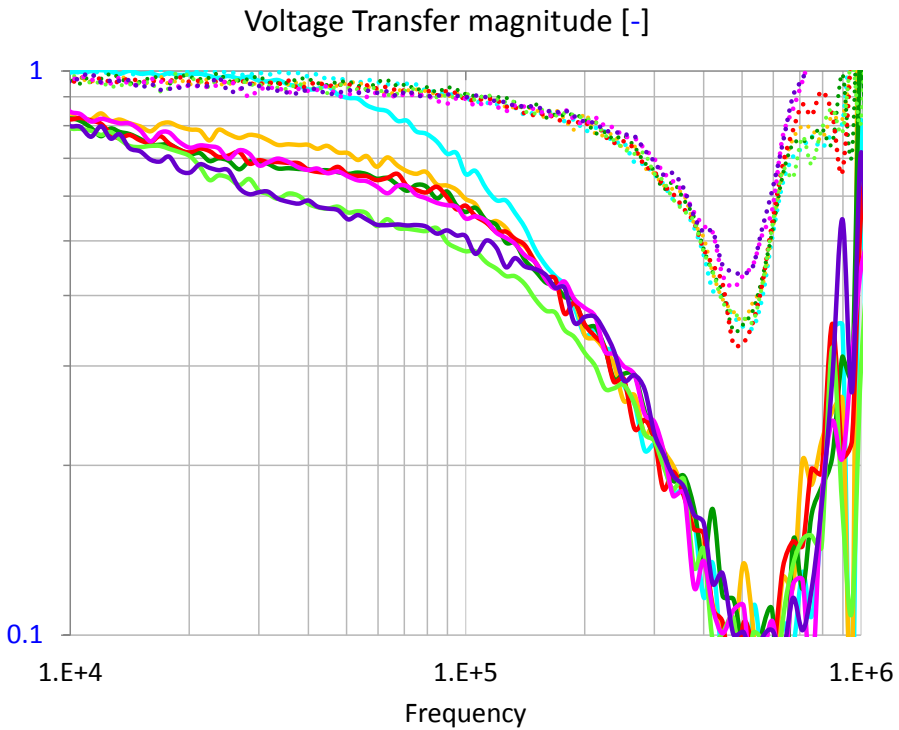


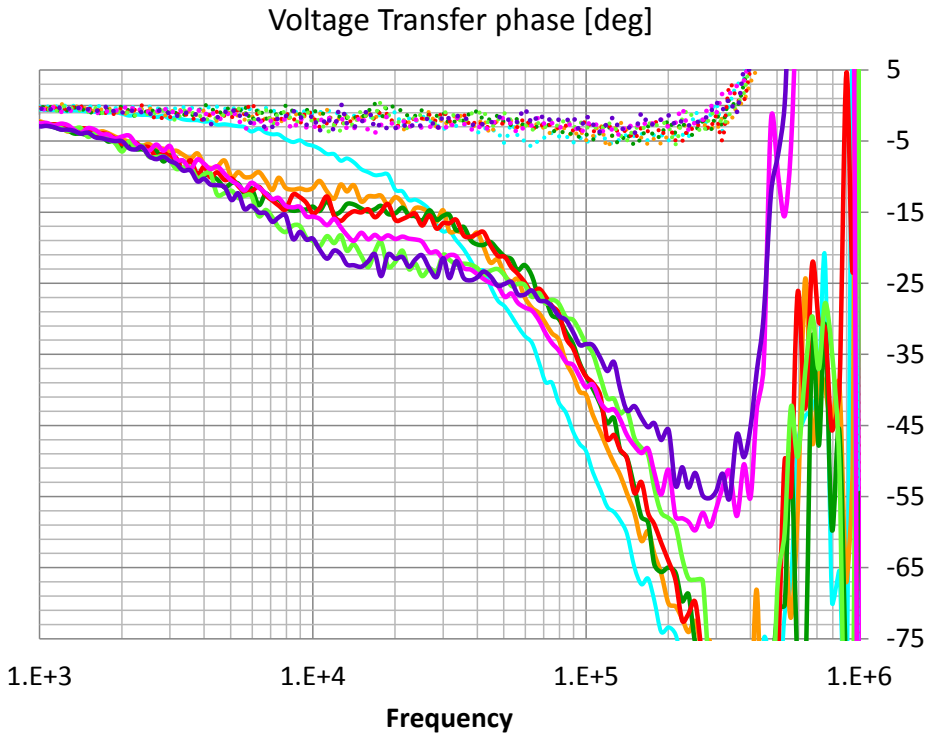
Remote sense connection

DC-DC converter

"Impact of Regulator Sense-point Location on PDN Response," DesignCon 2015, Santa Clara, CA, January 27 - 30, 2015

Plane R-C Filtering





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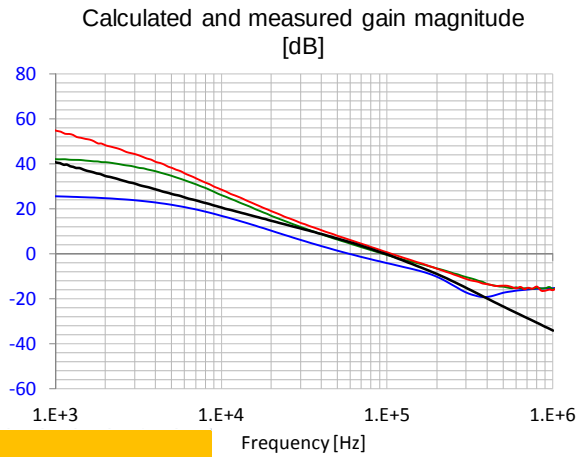
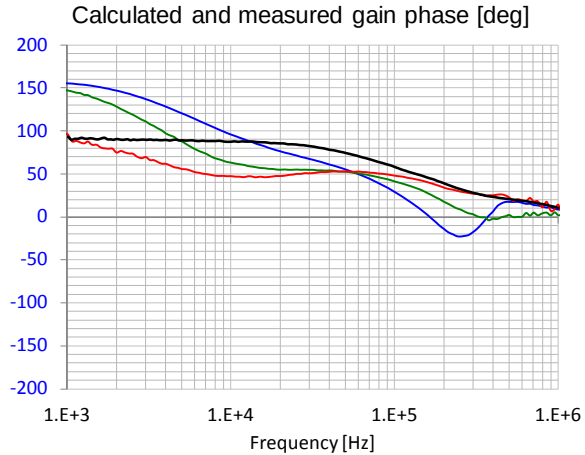
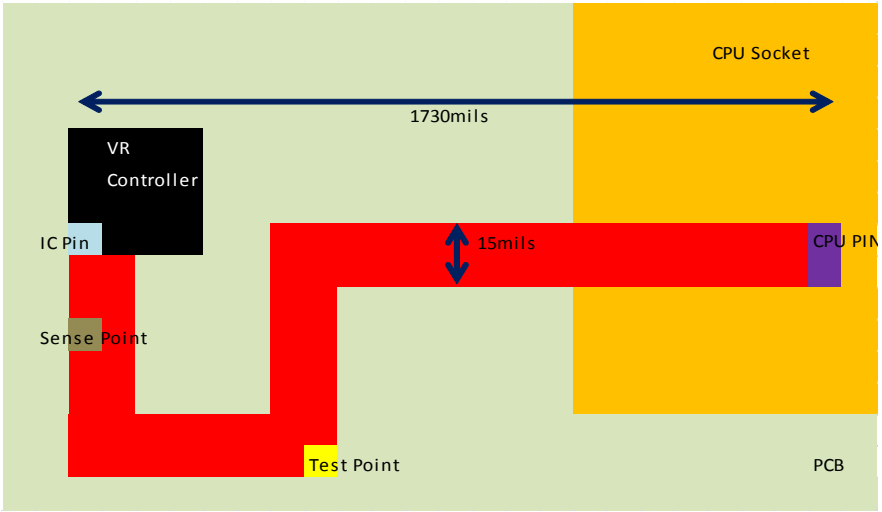
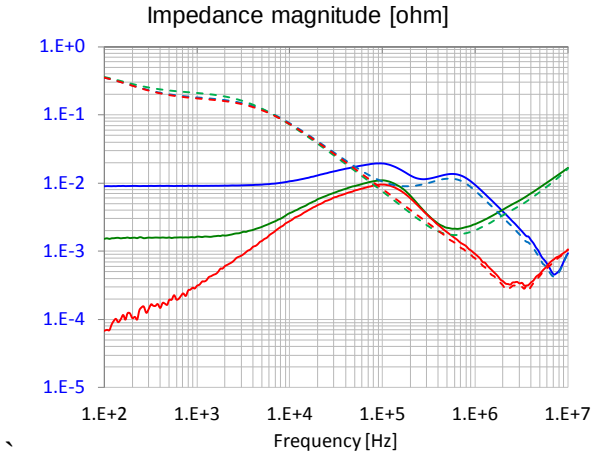
  - Traditional gain-phase plots
  - Gain-phase plot approximations and non-invasive measurements
- Nyquist plots and Stability margin
- Other metrics
- What can go wrong?
  - Wrong test signal level
  - Spurious signals
  - Impact of test equipment and load circuit
  - Measurement location
- Summary and Conclusions

Effect of Measurement Location

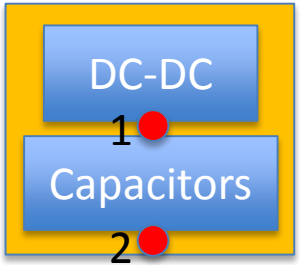








Effect of Measurement Location



Green

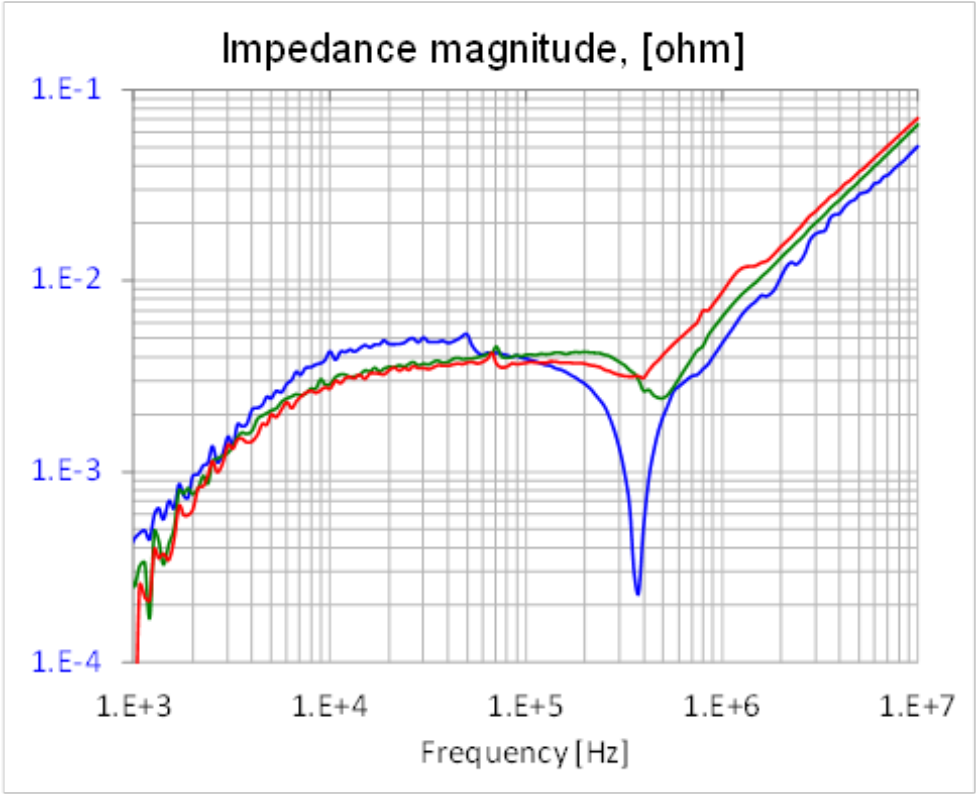
Sense: 1, Measure: 2

Blue

Sense: 2, Measure: 2

Red

Sense: 2, Measure: 1



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Summary and Conclusions

- Phase and gain margins are useful metrics only in special cases
- Nyquist plot, Characteristic expression and Stability margin plots provide specific views of DUT stability conditions
- Direct loop gain measurement is invasive but most robust
- NISM is noninvasive, works well with low-noise peaky impedance profiles
- Loop gain calculated from OFF and ON impedances is minimally invasive, but measurement location matters
- Measuring the loop gain function requires careful setting of injection power
- Frequency-domain measurements are invalid if uncorrelated tracking spurious signals are generated by the DUT

Thank you!

QUESTIONS?