ABSTRACT

This application report discusses a new method of doing stability Analysis testing by using basic lab equipment, while not requiring any specific instruments.

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1 Introduction

In today's market, there are many expensive instruments available for conducting stability analysis. This Application Report provides a new and easy method to generate Bode plots for stability Analysis by using basic lab instruments. This same technique can be further employed to do a frequency response Analysis of any system.

2 TOP Level Block Diagram

![System Level Block Diagram]

Figure 1. System Level Block Diagram
Calculating the Frequency Response

As seen in Figure 2, using the Signal Generator, a single tone is injected into the loop coupling through the Injection Isolator. It is captured using an oscilloscope at both the ends of the 50 Ω resistance. By using drivers on the host computers, data is captured from the oscilloscope and as a result, the frequency response is calculated at the injected frequency.

As demonstrated in Figure 2, the voltage probed at both the nodes of 50 Ω can be given as:

\[
V_{\text{OUT}1}(f) = V_{\text{OUT}2}(f) \times (-A) \times (B) \times \left[ \frac{FB2}{FB1 + FB2} \right] \tag{1}
\]
\[
V_{\text{OUT}2}(f) = V_{\text{OUT}1}(f) - V_{\text{IN}} \times \left( \frac{N1}{N2} \right) \tag{2}
\]

Here \( \frac{N1}{N2} = 1 \), thus we ignore it for further discussion.

From Equation 1 and Equation 2, we have:

\[
V_{\text{OUT}2}(f) = V_{\text{OUT}2}(f) \times (-A) \times (B) \times \left[ \frac{FB2}{FB1 + FB2} \right] - V_{\text{IN}} \tag{3}
\]

From Equation 3, we have:

\[
V_{\text{OUT}2}(f) \times \left[ 1 + A \times B \times \left( \frac{FB2}{FB1 + FB2} \right) \right] = -V_{\text{IN}}(f) \tag{4}
\]

From Equation 4, we have:

\[
V_{\text{OUT}2}(f) = -\frac{V_{\text{IN}}(f)}{1 + A \times B \times \left( \frac{FB2}{FB1 + FB2} \right)} \tag{5}
\]

From Equation 1 we have:

\[
V_{\text{OUT}1}(f) = \frac{-V_{\text{IN}}(f) \times A \times B \times \left( \frac{FB2}{FB1 + FB2} \right)}{1 + A \times B \times \left( \frac{FB2}{FB1 + FB2} \right)} \tag{6}
\]

From Equation 5 and Equation 6, we have:

\[
H(f) = \frac{V_{\text{OUT}1}(f)}{V_{\text{OUT}2}(f)} = A \times B \times \left( \frac{FB2}{FB1 + FB2} \right) \tag{7}
\]

where \( A \times B \times \left( \frac{FB2}{FB1 + FB2} \right) \) is the loop gain.

Figure 2. Signal Injection and Capturing

Both the nodes of the 50 ohm resistance (Vout1, Vout2) are captured using channels of the Oscilloscope. Most of the present day Digital Oscilloscopes have capability to transfer captured raw data to the computer. The device specific drivers would be required to capture the raw data from the oscilloscope.

Here, we have used National Instruments' LabVIEW™ to capture the data from the Oscilloscope and to do further processing.
The Flow chart below explains the Signal Flow and processing steps.

4 Signal Flow: Data Capturing Module

Signal Generator Characterization
(Waveform, Amplitude, Offset)

Oscilloscope channels
Characterization

User Inputs: No of per points decade (K)
Starting Frequency/Stop Frequency (fin/fstop)
No of times data averaged (A)
No of readings trashed after each frequency change (R)

K=1

Set Signal generator:
freq=fin; Output ON

Temp-gain=0, Temp-phase=0

Oscilloscope data is captured inside Lab-view

Increment k

YES

K<R

Digital Processing Block
Gain Margin
Phase Margin

Temp-gain=Temp-gain +Gain Margin
Temp-phase=Temp-phase +Phase Margin

YES

K<R+A

NO

Increment fin to next frequency
Store the averaged Values

NO

freq <fstop

STOP

Figure 3. Signal Flow
Digital Signal Processing Block

From the above signal flow graph, the digital processing block is explained here.

As demonstrated in Equation 7, the two node voltages $V_{\text{OUT}1}(t)$ and $V_{\text{OUT}2}(t)$ can be treated as a system in time domain with Input $V_{\text{OUT}1}(t)$ and Output $V_{\text{OUT}2}(t)$.

Where $H(t)$ as derived from Equation 7 can be given in frequency domain as:

$$H(f) = A \times B \times \left[ \frac{FB2}{FB1 + FB2} \right].$$

$H(f)$ can also be expressed as:

$$H(f) = K(f)e^{i\theta(f)}$$

where:

$$K(f) = \text{modulus}\left[ A \times B \times \left( \frac{FB2}{FB1 + FB2} \right) \right] = \text{modulus}\left[ V_{\text{OUT}2} \right] / \text{modulus}\left[ V_{\text{OUT}1} \right]$$

and:

$$\theta(f) = \text{arg}\left[ A \times B \times \left( \frac{FB2}{FB1 + FB2} \right) \right] = \text{arg}\left[ V_{\text{OUT}2} \right] - \text{arg}\left[ V_{\text{OUT}1} \right]$$

where $K(f)$ is the Magnitude Response and $\theta(f)$ is the phase response.

The Digital Processing Block is used to calculate the frequency response as per the two time domain signals $V_{\text{OUT}1}(t)$ and $V_{\text{OUT}2}(t)$.

To calculate the frequency response ($H(f)$) of the system, the FFT of both the signals $V_{\text{OUT}1}(t)$ and $V_{\text{OUT}2}(t)$ is calculated with a starting frequency of zero hertz and a frequency step size equal to Bin width.

$$\text{Bin Width} = \frac{\text{Sampling Frequency}}{\text{Number of samples taken to calculate FFT}}$$

The FFT of the time domain signals will be a vector with both magnitude and phase information present inside it.

As demonstrated in Equation 10, the magnitude and phase of both the signals $V_{\text{OUT}1}(f)$ and $V_{\text{OUT}2}(f)$ is divided at the respective frequencies and thereby $K(f)$ and $\theta(f)$ are calculated. They are both arrays with each array element representing each bin.

The Bin corresponding to the injected frequency gives you Gain Margin and Phase Margin at the desired injected frequency.

From Equation 9 and Equation 10:

Gain Margin $G(f) = K(\text{Inj. bin})$ and Phase Margin $P(f) = \theta(\text{Inj. bin})$

where Injected bin = Injected Frequency / Bin Width
The data was captured inside the laptop by writing a code in LabVIEW™ using the signal flow Graph given under Heading 4. Online libraries from LabVIEW™ were used and automated setup was made to run for the user entered frequency range.

One needs to input different parameters for signal generator, oscilloscope, and Digital Signal Processing block.

![Figure 5. GUI Front Panel Using LabVIEW™](image-url)
Characterization of Oscilloscope Channels

Before running the stability Analysis for a given device, both the channels of Oscilloscope need to be characterized to compensate for inherent sampling phase and gain error present in the channels.

7.1 Experiment Setup

![Test Setup Diagram]

Test Setup Conditions:
1. Waveform Used: Sine Waveform
2. Amplitude: 300 mV
3. Frequency: 1 KHz to 500 KHz with 20 steps per decade
4. Offset value: 0 V
5. Oscilloscope Channels used: 1 and 4
6. Frequency Resolution used in FFT calculation(Bin width): 1 Hz
7.2 Observed Test Data (Experiment No.1)

GUI mentioned in column 5 was used to capture the three parameters.

1. Frequency of the Injected Signal from Signal Generator.
2. Gain Margin = G(f) at the injected frequency as demonstrated in Equation 12
3. Phase Margin = P(f) at the injected frequency as demonstrated in Equation 12

![Figure 7. Observed Data (Oscilloscope Characterization)](image)

Figure 7 shows that the maximum phase error observed is 0.000726 at 450 Khz which is equal to 0.0416 degrees. We can neglect this error. Similar is the case with gain error between two channels.

Therefore, the Oscilloscope itself doesn't introduce any gain and phase errors between both of the channels.
8 Concept Validation: TPS40200

To prove the concept tps40200 was used to calculate the loop stability and hence validate the concept. Test setup used was.

Figure 8. Concept Validation (System Setup)
Experiment No.1 was repeated for above system set-up.

### Figure 9. Observed Data (TPS40200)

<table>
<thead>
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<th>Frequency</th>
<th>Magnitude (V/V)</th>
<th>Phase (radians)</th>
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</thead>
<tbody>
<tr>
<td>1000.000000</td>
<td>9.242310</td>
<td>2.017085</td>
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<tr>
<td>1500.000000</td>
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<td>1.709123</td>
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<td>2000.000000</td>
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<td>2500.000000</td>
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<td>3000.000000</td>
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<tr>
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<td>0.081595</td>
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</tr>
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</table>
10 Loop Gain Plot

The captured data is finally stored inside an Excel template where the Loop Gain Margin (V/V) and Phase Margin values (radians) are converted into dB and degrees scale respectively. After which they are plotted in the same template.

Figure 10. Loop Gain Magnitude Plot: LabVIEW™

Figure 11. Loop Gain Phase Plot: LabVIEW™
Figure 12. TINA-TI Average Model

Figure 13. TINA-TI Loop Gain Plot
12 Concept Validation: TPS40210

To validate the concept with a boost EVM TPS40210 was used in the same system setup as Figure 8 with TPS40200 replaced with TPS40210.

13 Observed Data Using LabVIEW™

Experiment No.1 was repeated for above mentioned system set-up.

![Figure 14. Observed Data Using LabVIEW™](image-url)
14 Loop Gain Magnitude Plot

![Loop Gain Magnitude Plot](image1)

**Figure 15. Loop Gain Magnitude Plot: LabVIEW™**

15 Loop Gain Phase Plot

![Loop Gain Phase Plot](image2)

**Figure 16. Loop Gain Phase Plot: LabVIEW™**
16 Loop Gain Plot under Similar Conditions Given in the TPS40210 User Guide

![Figure 17. Loop Gain Response Given in User Guide](image)

17 Comparison

<table>
<thead>
<tr>
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<th>Using Automated Lab Test Set-up</th>
<th>User Guide/TINA-TI</th>
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</thead>
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<tr>
<td>TPS40200 Phase Margin(degrees)</td>
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<td>TPS40200 Crossover Frequency(Hz)</td>
<td>7.12k</td>
<td>7.26k</td>
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<tr>
<td>TPS40210 Phase Margin(degrees)</td>
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<td>TPS40210 Crossover Frequency(Hz)</td>
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<td>8.6k</td>
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</table>

18 Conclusion

We can conclude that the procedure described above yields results that are close to the expected results. Therefore, the procedure can be used to do stability Analysis testing for different DC-DC converters and LDO’s. The scope of this concept is broad, as it can be used for the PSRR calculation for LDO’s, small signal response calculations for op-amps, and more.

The major advantage found with the above automated system was much less variability. The present test-setup was tested for 1000’s readings and the variability found in the results was less than 0.1%.

Only basic lab equipment was needed for the above Automated Frequency Response Analyzer. Therefore, no individual lab instruments are required for the above characterizations.

This could potentially save a lot of money for the characterizations mentioned above as well as many more, since the individual instruments for these characterizations are quite costly in the market.
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- Reorient or relocate the receiving antenna.
- Increase the separation between the equipment and receiver.
- Connect the equipment into an outlet on a circuit different from that to which the receiver is connected.
- Consult the dealer or an experienced radio/TV technician for help.

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Concerning EVMs including detachable antennas
Under Industry Canada regulations, this radio transmitter may only operate using an antenna of a type and maximum (or lesser) gain approved for the transmitter by Industry Canada. To reduce potential radio interference to other users, the antenna type and its gain should be so chosen that the equivalent isotropically radiated power (e.i.r.p.) is not more than that necessary for successful communication.

This radio transmitter has been approved by Industry Canada to operate with the antenna types listed in the user guide with the maximum permissible gain and required antenna impedance for each antenna type indicated. Antenna types not included in this list, having a gain greater than the maximum gain indicated for that type, are strictly prohibited for use with this device.

Cet appareil numérique de la classe A ou B est conforme à la norme NMB-003 du Canada.
Les changements ou les modifications pas expressément approuvés par la partie responsable de la conformité ont pu vider l’autorité de l’utilisateur pour actionner l’équipement.

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Le présent appareil est conforme aux CNR d’Industrie Canada applicables aux appareils radio exempts de licence. L’exploitation est autorisée aux deux conditions suivantes : (1) l’appareil ne doit pas produire de brouillage, et (2) l’utilisateur de l’appareil doit accepter tout brouillage radioélectrique subi, même si le brouillage est susceptible d’en compromettre le fonctionnement.

Concernant les EVMs avec antennes détaçables
Conformément à la réglementation d'Industrie Canada, le présent émetteur radio peut fonctionner avec une antenne d'un type et d'un gain maximal (ou inférieur) approuvé pour l'émetteur par Industrie Canada. Dans le but de réduire les risques de brouillage radioélectrique à l'intention des autres utilisateurs, il faut choisir le type d'antenne et son gain de sorte que la puissance isotope rayonnée équivalente (p.i.r.e.) ne dépasse pas l'intensité nécessaire à l'établissement d'une communication satisfaisante.

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If you use this product in Japan, you are required by Radio Law of Japan to follow the instructions below with respect to this product:

1. Use this product in a shielded room or any other test facility as defined in the notification #173 issued by Ministry of Internal Affairs and Communications on March 28, 2006, based on Sub-section 1.1 of Article 6 of the Ministry’s Rule for Enforcement of Radio Law of Japan,
2. Use this product only after you obtained the license of Test Radio Station as provided in Radio Law of Japan with respect to this product, or
3. Use of this product only after you obtained the Technical Regulations Conformity Certification as provided in Radio Law of Japan with respect to this product. Also, please do not transfer this product, unless you give the same notice above to the transferee. Please note that if you could not follow the instructions above, you will be subject to penalties of Radio Law of Japan.

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3. Since the EVM is not a completed product, it may not meet all applicable regulatory and safety compliance standards (such as UL, CSA, VDE, CE, RoHS and WEEE) which may normally be associated with similar items. You assume full responsibility to determine and/or assure compliance with any such standards and related certifications as may be applicable. You will employ reasonable safeguards to ensure that your use of the EVM will not result in any property damage, injury or death, even if the EVM should fail to perform as described or expected.
4. You will take care of proper disposal and recycling of the EVM’s electronic components and packing materials.

Certain Instructions. It is important to operate this EVM within TI’s recommended specifications and environmental considerations per the user guidelines. Exceeding the specified EVM ratings (including but not limited to input and output voltage, current, power, and environmental ranges) may cause property damage, personal injury or death. If there are questions concerning these ratings please contact a TI field representative prior to connecting interface electronics including input power and intended loads. Any loads applied outside of the specified output range may result in unintended and/or inaccurate operation and/or possible permanent damage to the EVM and/or interface electronics. Please consult the EVM User's Guide prior to connecting any load to the EVM output. If there is uncertainty as to the load specification, please contact a TI field representative. During normal operation, some circuit components may have case temperatures greater than 60°C as long as the input and output are maintained at a normal ambient operating temperature. These components include but are not limited to linear regulators, switching transistors, pass transistors, and current sense resistors which can be identified using the EVM schematic located in the EVM User's Guide. When placing measurement probes near these devices during normal operation, please be aware that these devices may be very warm to the touch. As with all electronic evaluation tools, only qualified personnel knowledgeable in electronic measurement and diagnostics normally found in development environments should use these EVMs.

Agreement to Defend, Indemnify and Hold Harmless. You agree to defend, indemnify and hold TI, its licensors and their representatives harmless from and against any and all claims, damages, losses, expenses, costs and liabilities (collectively, "Claims") arising out of or in connection with any use of the EVM that is not in accordance with the terms of the agreement. This obligation shall apply whether Claims arise under law of tort or contract or any other legal theory, and even if the EVM fails to perform as described or expected.

Safety-Critical or Life-Critical Applications. If you intend to evaluate the components for possible use in safety critical applications (such as life support) where a failure of the TI product would reasonably be expected to cause severe personal injury or death, such as devices which are classified as FDA Class III or similar classification, then you must specifically notify TI of such intent and enter into a separate Assurance and Indemnity Agreement.

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