

# **Automated Frequency Response Analyzer**

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## **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

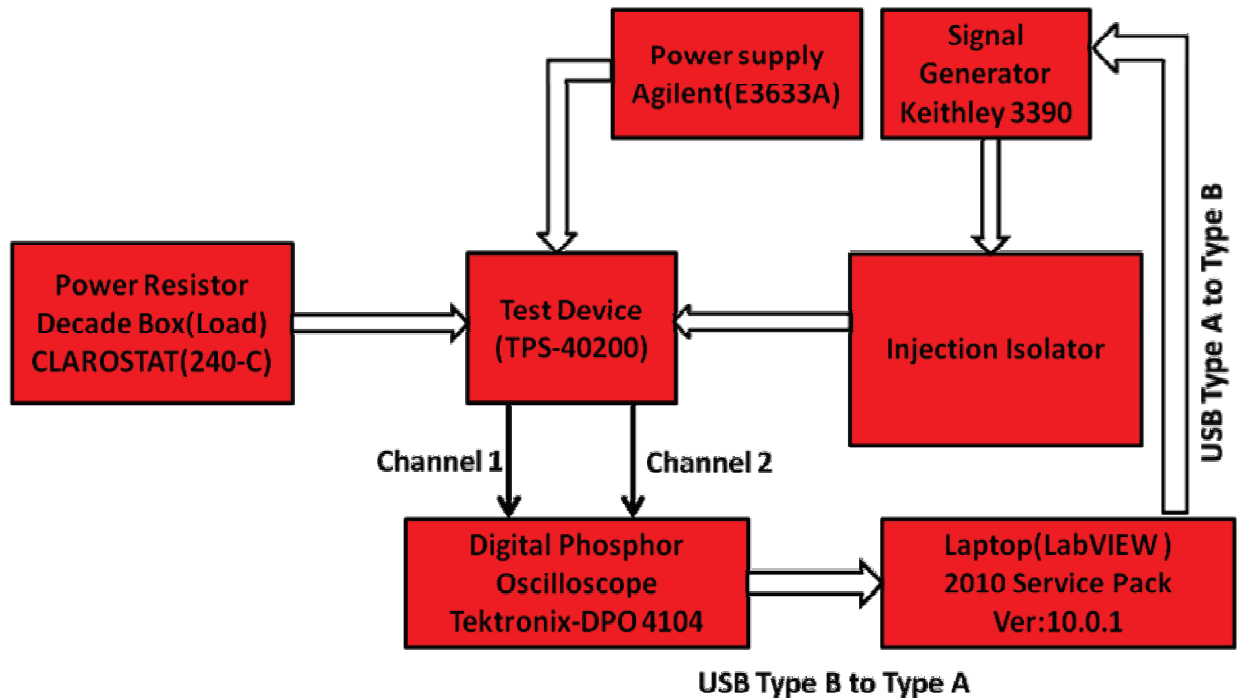


Figure 1. System Level Block Diagram

### 3 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:

$$V_{OUT1}(f) = V_{OUT2}(f) \times (-A) \times (B) \times [FB2 / (FB1 + FB2)] \tag{1}$$

$$V_{OUT2}(f) = V_{OUT1}(f) - V_{IN} \times (N1 / N2) \tag{2}$$

Here (N1 / N2) = 1, thus we ignore it for further discussion.

From Equation 1 and Equation 2, we have:

$$V_{OUT2}(f) = V_{OUT2}(f) \times (-A) \times (B) \times [FB2 / (FB1 + FB2)] - V_{IN} \tag{3}$$

From Equation 3, we have:

$$V_{OUT2}(f) \times [1 + A \times B \times (FB2 / (FB1 + FB2))] = -V_{IN}(f) \tag{4}$$

From Equation 4, we have:

$$V_{OUT2}(f) = -V_{IN}(f) / [1 + A \times B \times (FB2 / (FB1 + FB2))] \tag{5}$$

From Equation 1 we have:

$$V_{OUT1}(f) = [-V_{IN}(f) \times A \times B \times (FB2 / (FB1 + FB2))] / [(1 + A \times B \times (FB2 / (FB1+FB2)))] \tag{6}$$

From Equation 5 and Equation 6, we have:

$$H(f) = V_{OUT1}(f) / V_{OUT2}(f) = A \times B \times (FB2 / (FB1 + FB2)) \tag{7}$$

where  $A \times B \times (FB2 / (FB1+FB2))$  is the loop gain.

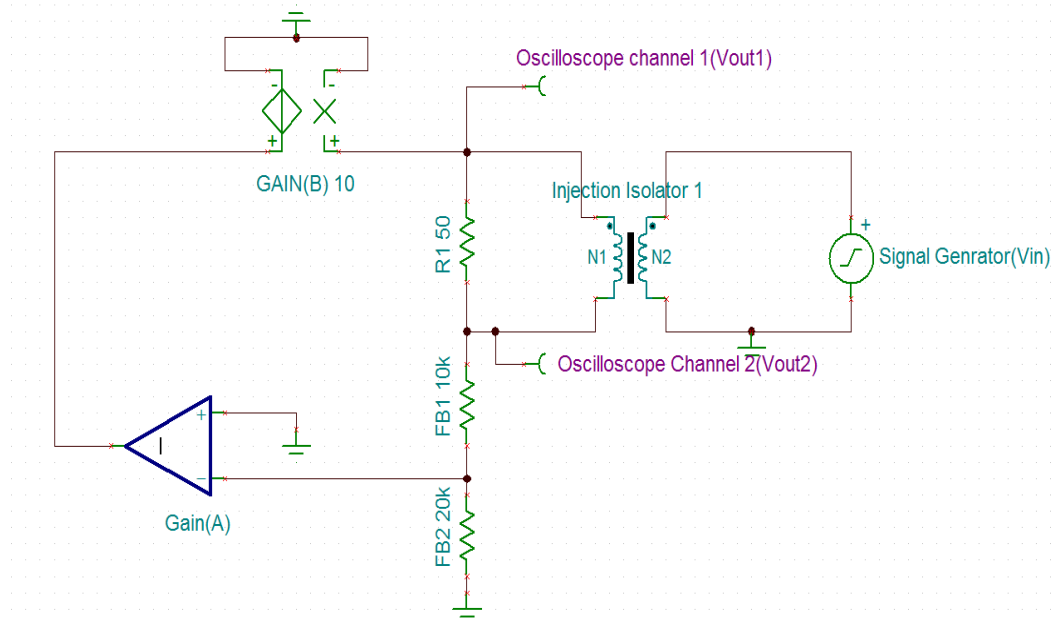


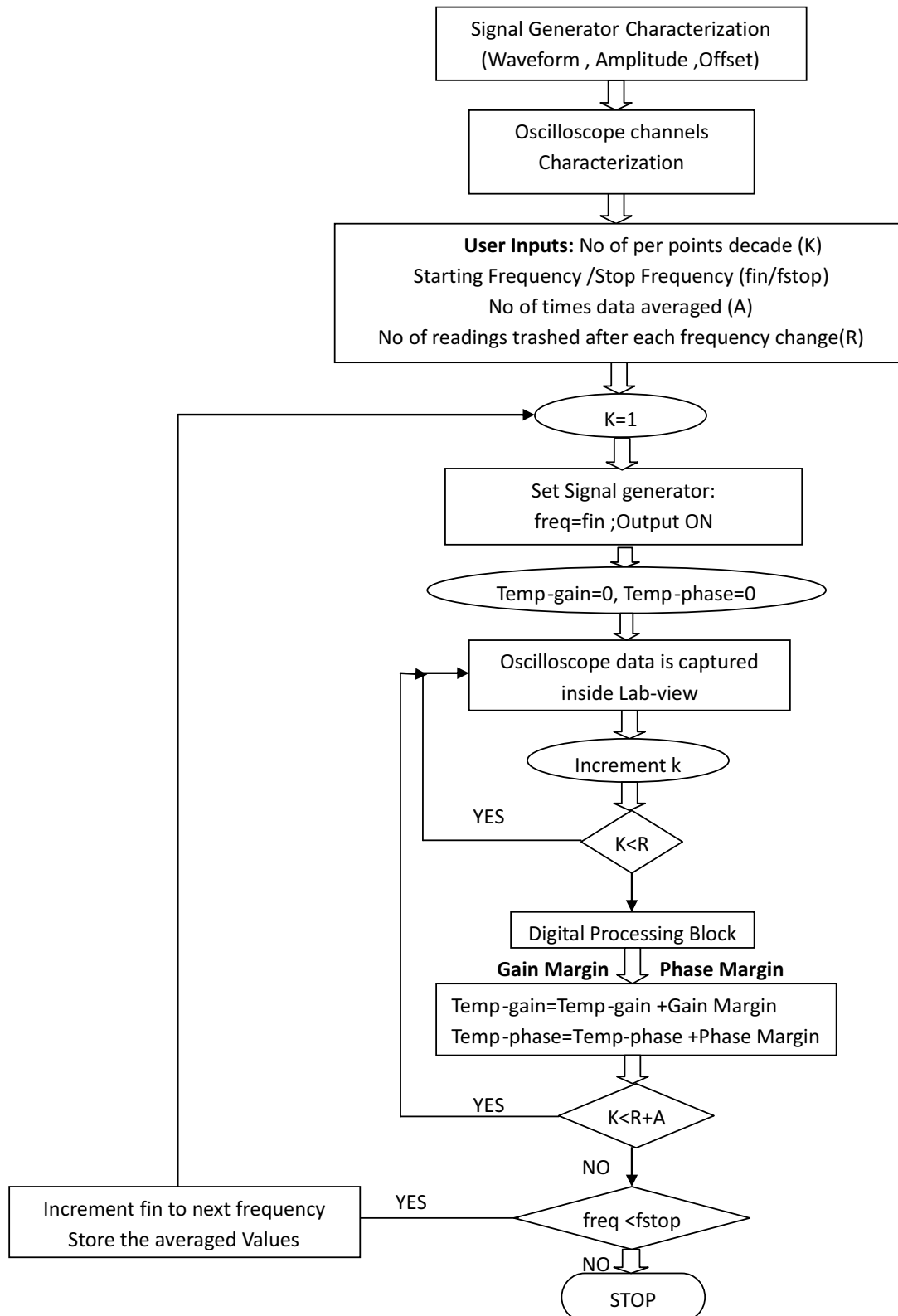
Figure 2. Signal Injection and Capturing

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



**Figure 3. Signal Flow**

## 5 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  $V_{OUT1}(f)$  and  $V_{OUT2}(f)$  can be treated as a system in time domain with Input  $V_{OUT1}(t)$  and Output  $V_{OUT2}(t)$ .

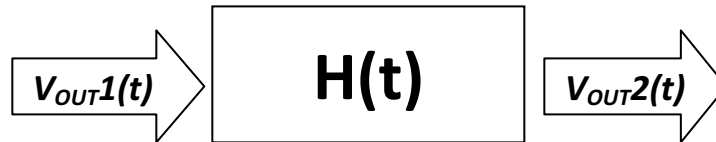


Figure 4.

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

$$H(f) = A \times B \times [FB2 / (FB1 + FB2)].$$

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

$$H(f) = K(f)e^{i\theta(f)} \quad (8)$$

where:

$$K(f) = \text{modulus}[A \times B \times (FB2 / (FB1 + FB2))] = \text{modulus}[V_{OUT2}] / \text{modulus}[V_{OUT1}] \quad (9)$$

and:

$$\theta(f) = \text{arg}[A \times B \times (FB2 / (FB1 + FB2))] = \text{arg}[V_{OUT2}] - \text{arg}[V_{OUT1}] \quad (10)$$

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  $V_{OUT1}(t)$  and  $V_{OUT2}(t)$ .

To calculate the frequency response ( $H(f)$ ) of the system, the FFT of both the signals  $V_{OUT1}(t)$  and  $V_{OUT2}(t)$  is calculated with a starting frequency of zero hertz and a frequency step size equal to Bin width.

$$\text{Bin Width} = \text{Sampling Frequency} / \text{Number of samples taken to calculate FFT} \quad (11)$$

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  $V_{OUT1}(f)$  and  $V_{OUT2}(f)$  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:

$$\text{Gain Margin } G(f) = K(\text{Injected bin}) \text{ and Phase Margin } P(f) = \theta(\text{Injected Bin}) \quad (12)$$

where Injected bin = Injected Frequency / Bin Width



## 7 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

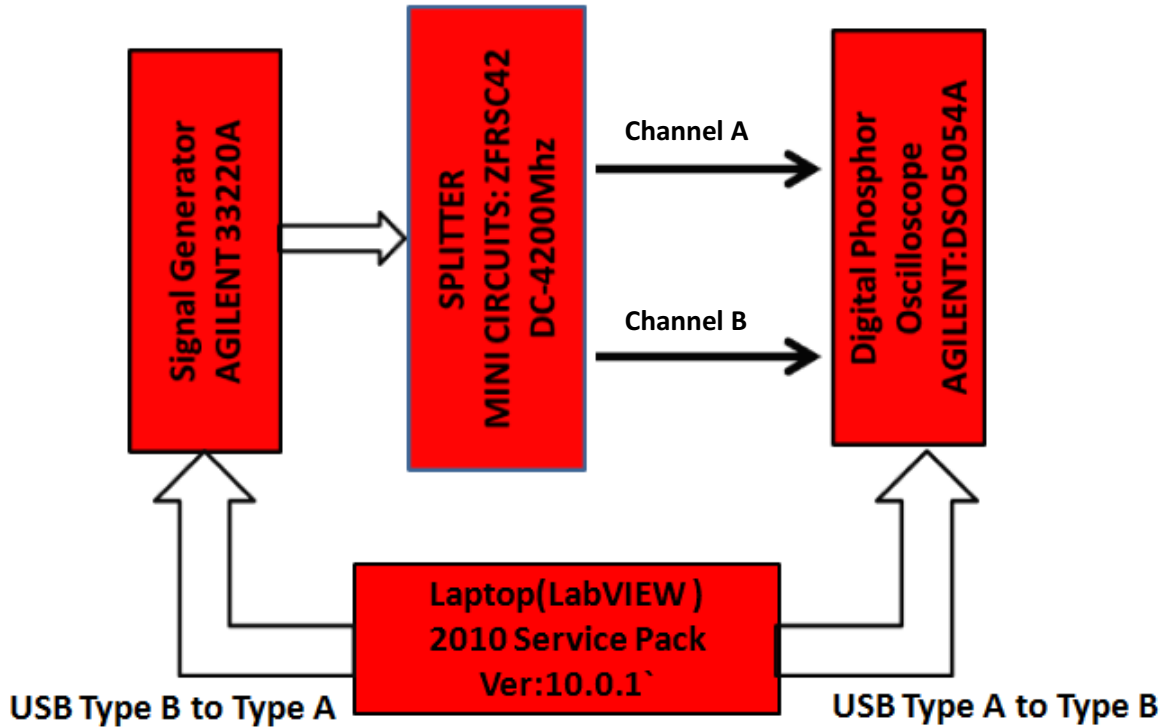


Figure 6. Oscilloscope Characterization (Test Setup)

#### 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 column5 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](#)

loop gain	Frequency	Magnitude(V/V)	Phase(radians)
	1000.000000	0.993686	-0.000247
	1500.000000	0.993260	-0.000208
	2000.000000	0.993176	-0.000194
	2500.000000	0.993153	-0.000183
	3000.000000	0.993011	-0.000177
	3500.000000	0.992954	-0.000165
	4000.000000	0.992838	-0.000135
	4500.000000	0.992935	-0.000135
	5000.000000	0.992614	-0.000133
	5500.000000	0.992708	-0.000132
	6000.000000	0.992924	-0.000109
	6500.000000	0.993197	-0.000113
	7000.000000	0.993059	-9.530545E-5
	7500.000000	0.993019	-9.842494E-5
	8000.000000	0.993032	-8.874914E-5
	8500.000000	0.992952	-7.933237E-5
	9000.000000	0.992931	-7.149700E-5
	9500.000000	0.993170	-7.991691E-5
	10000.000000	0.993127	-7.223340E-5
	10000.000000	0.993072	-7.178877E-5
	15000.000000	0.993094	-4.236375E-5
	20000.000000	0.993158	-4.423788E-5
	25000.000000	0.993041	-2.702333E-5
	30000.000000	0.993279	-3.306150E-5
	35000.000000	0.993172	-4.476817E-5
	40000.000000	0.993326	-2.158555E-5
	45000.000000	0.993286	-1.584008E-5
	50000.000000	0.993240	-3.107281E-5
	55000.000000	0.993380	1.049506E-5
	60000.000000	0.993450	2.722643E-6
	65000.000000	0.993615	1.333673E-5
	70000.000000	0.993290	-8.360867E-6
	75000.000000	0.993240	9.404218E-6
	80000.000000	0.993494	-8.342550E-6
	85000.000000	0.993528	7.851100E-6
	90000.000000	0.993413	-3.160025E-6
	95000.000000	0.993435	4.186047E-5
	100000.000000	0.993342	1.703381E-5
	100000.000000	0.993579	1.827475E-5
	150000.000000	0.993641	0.000107
	200000.000000	0.993922	0.001408
	250000.000000	0.993604	0.000410
	300000.000000	0.991771	-0.000504
	350000.000000	0.992693	0.000135
	400000.000000	0.992775	-0.005296
	450000.000000	0.995206	0.000726

**Figure 7. Observed Data (Oscilloscope Characterization)**

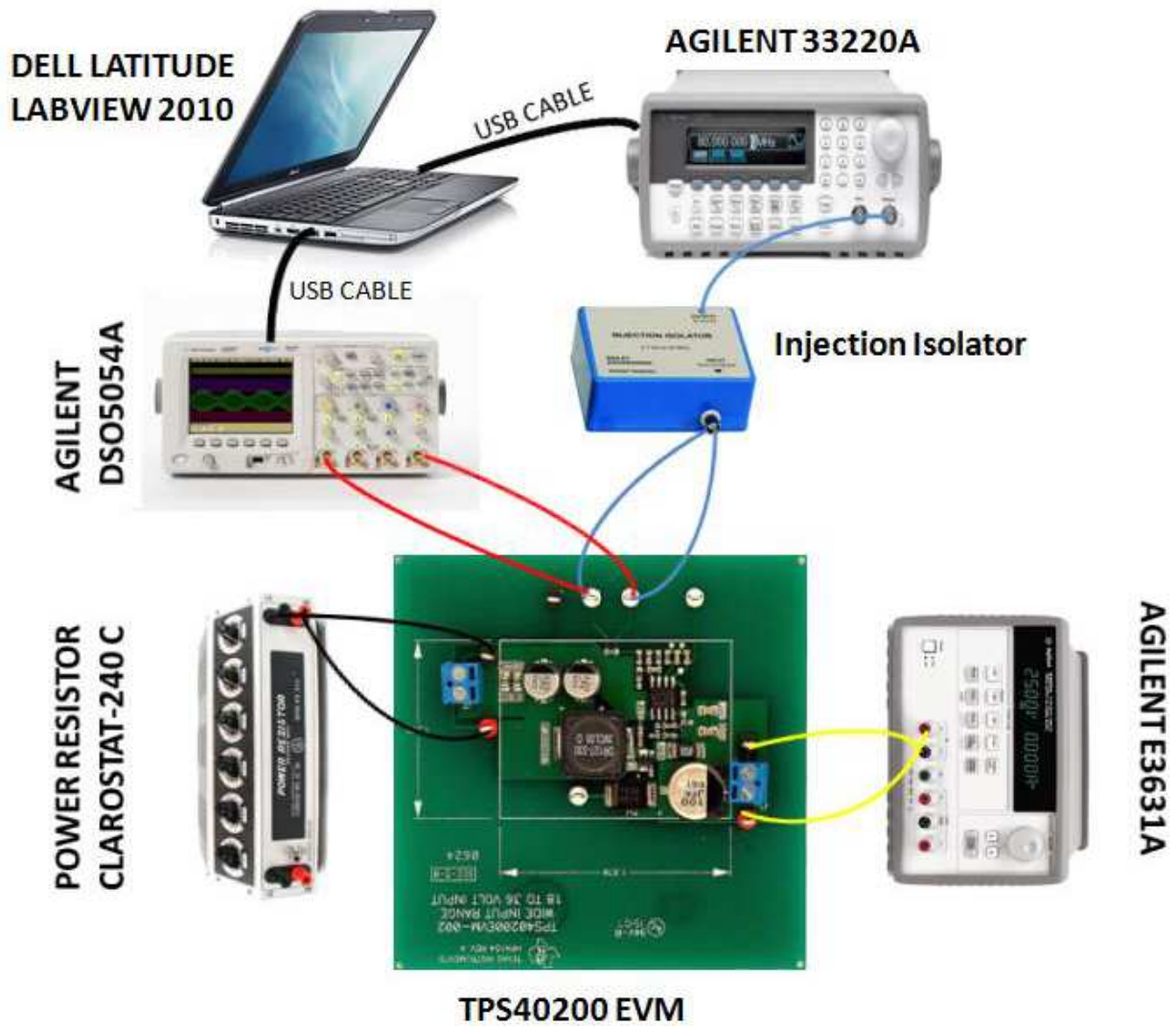
Figure 7 shows that the maximum phase error observed is 0.000726 at 450 KHz which is equal to 0.0416 degrees. We can neglect this error. Similar is the case with gain error between two channels.

Therefore, the Oscilloscope itself doesn't introduce any gain and phase errors between both of the channels.



**8 Concept Validation: TPS40200**

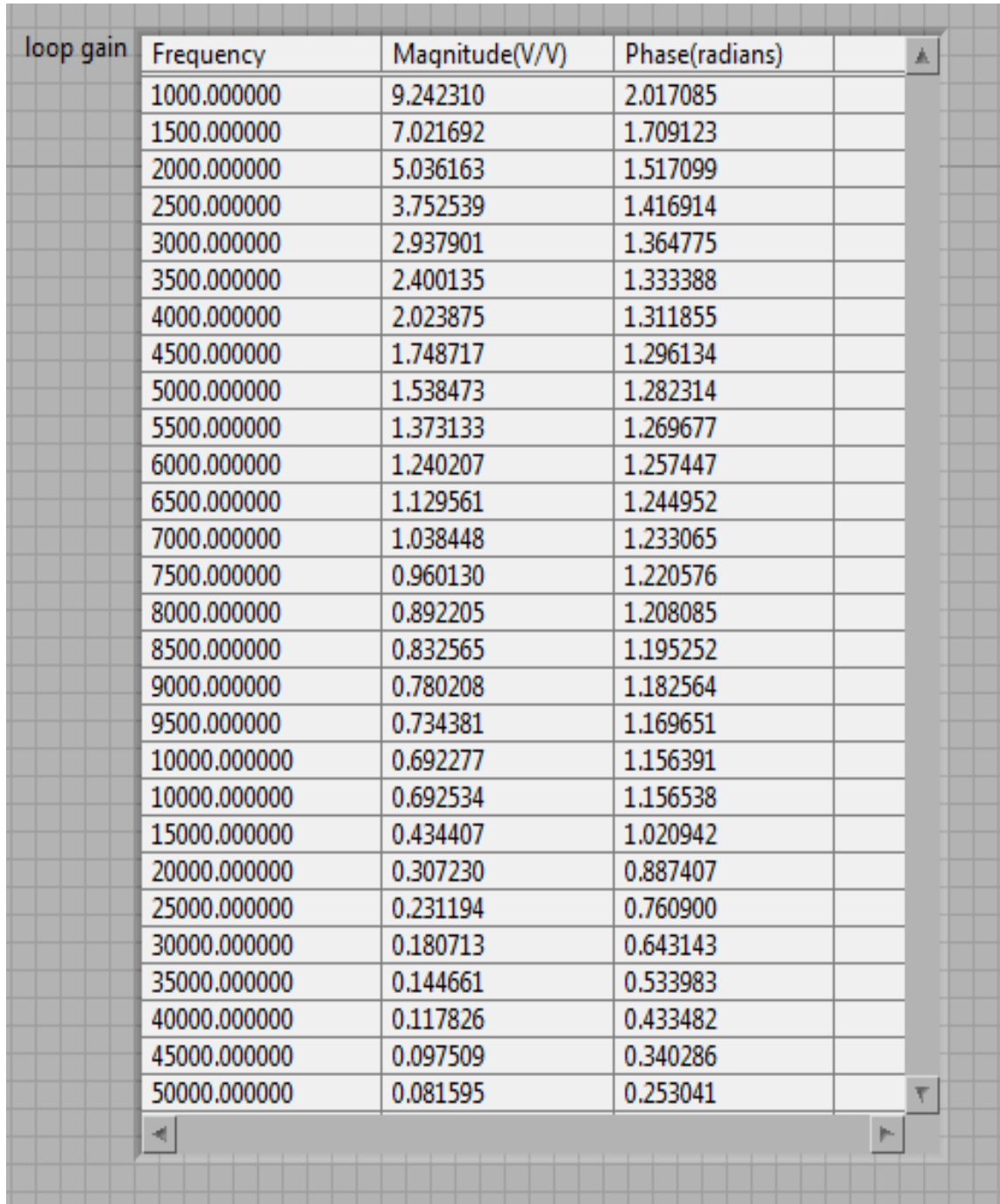
To prove the concept tps40200 was used to calculate the loop stability and hence validate the concept. Test setup used was.



**Figure 8. Concept Validation (System Setup)**

## 9 Observed Data Using LabVIEW™

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



loop gain	Frequency	Magnitude(V/V)	Phase(radians)
	1000.000000	9.242310	2.017085
	1500.000000	7.021692	1.709123
	2000.000000	5.036163	1.517099
	2500.000000	3.752539	1.416914
	3000.000000	2.937901	1.364775
	3500.000000	2.400135	1.333388
	4000.000000	2.023875	1.311855
	4500.000000	1.748717	1.296134
	5000.000000	1.538473	1.282314
	5500.000000	1.373133	1.269677
	6000.000000	1.240207	1.257447
	6500.000000	1.129561	1.244952
	7000.000000	1.038448	1.233065
	7500.000000	0.960130	1.220576
	8000.000000	0.892205	1.208085
	8500.000000	0.832565	1.195252
	9000.000000	0.780208	1.182564
	9500.000000	0.734381	1.169651
	10000.000000	0.692277	1.156391
	10000.000000	0.692534	1.156538
	15000.000000	0.434407	1.020942
	20000.000000	0.307230	0.887407
	25000.000000	0.231194	0.760900
	30000.000000	0.180713	0.643143
	35000.000000	0.144661	0.533983
	40000.000000	0.117826	0.433482
	45000.000000	0.097509	0.340286
	50000.000000	0.081595	0.253041

**Figure 9. Observed Data (TPS40200)**

## 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.

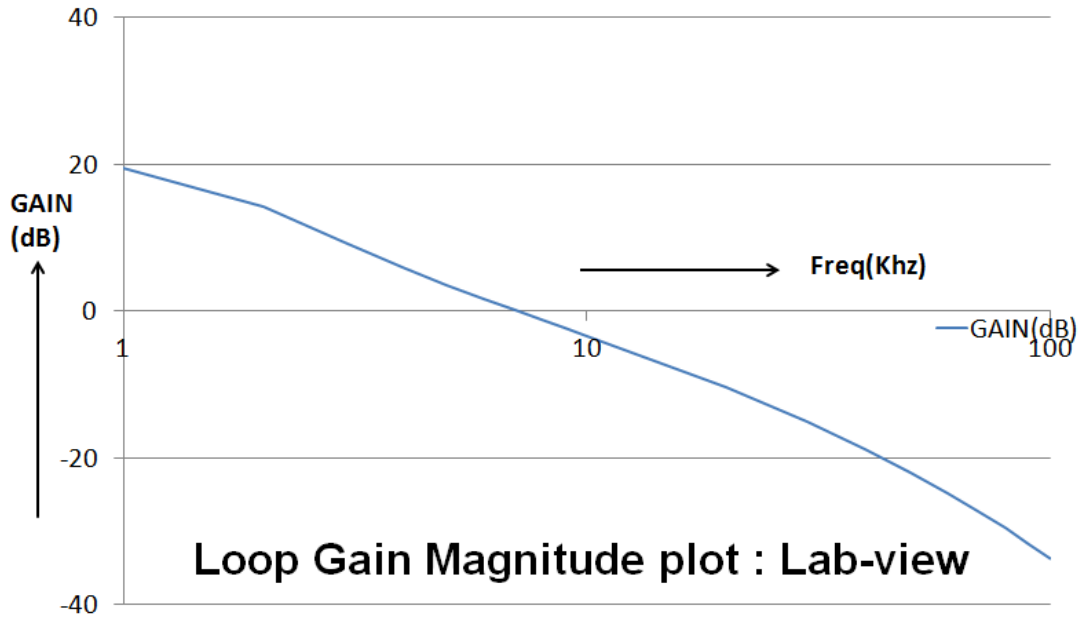


Figure 10. Loop Gain Magnitude Plot: LabVIEW™

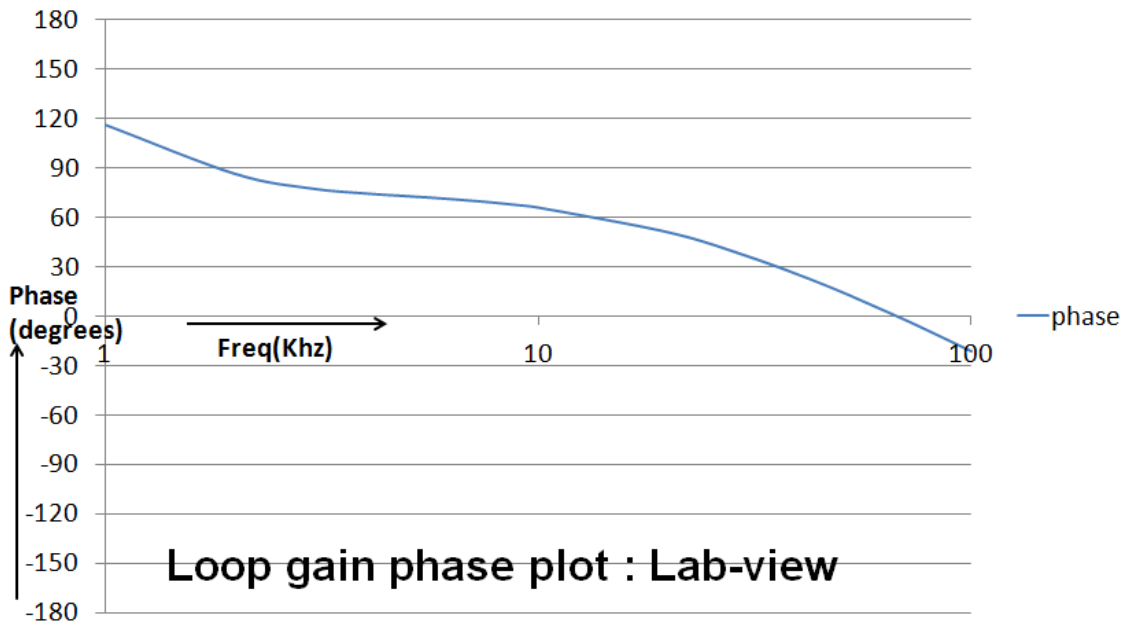


Figure 11. Loop Gain Phase Plot: LabVIEW™

### 11 TINA-TI Average MODEL for the TPS40200-002 EVM Setup

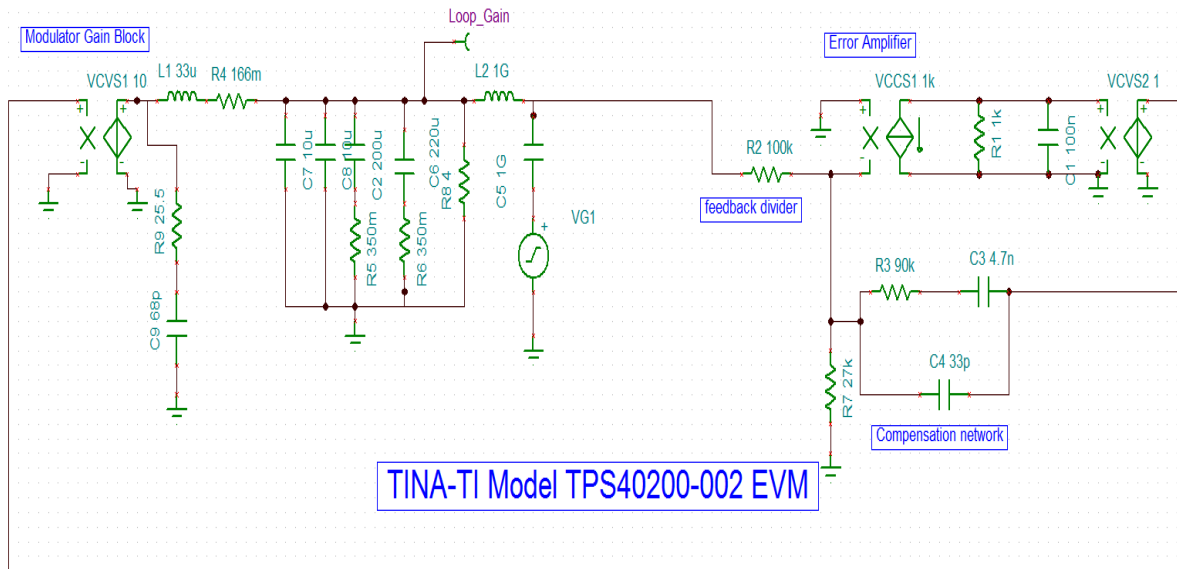


Figure 12. TINA-TI Average Model

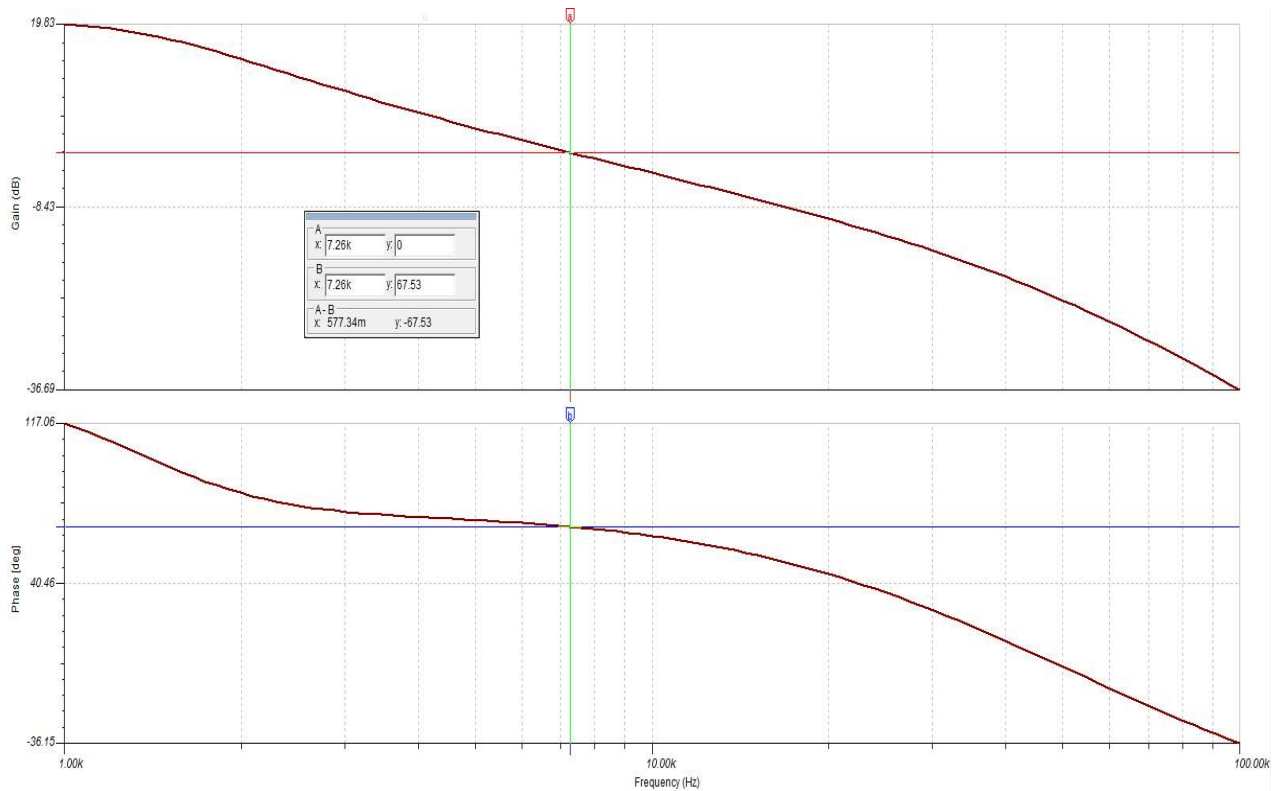


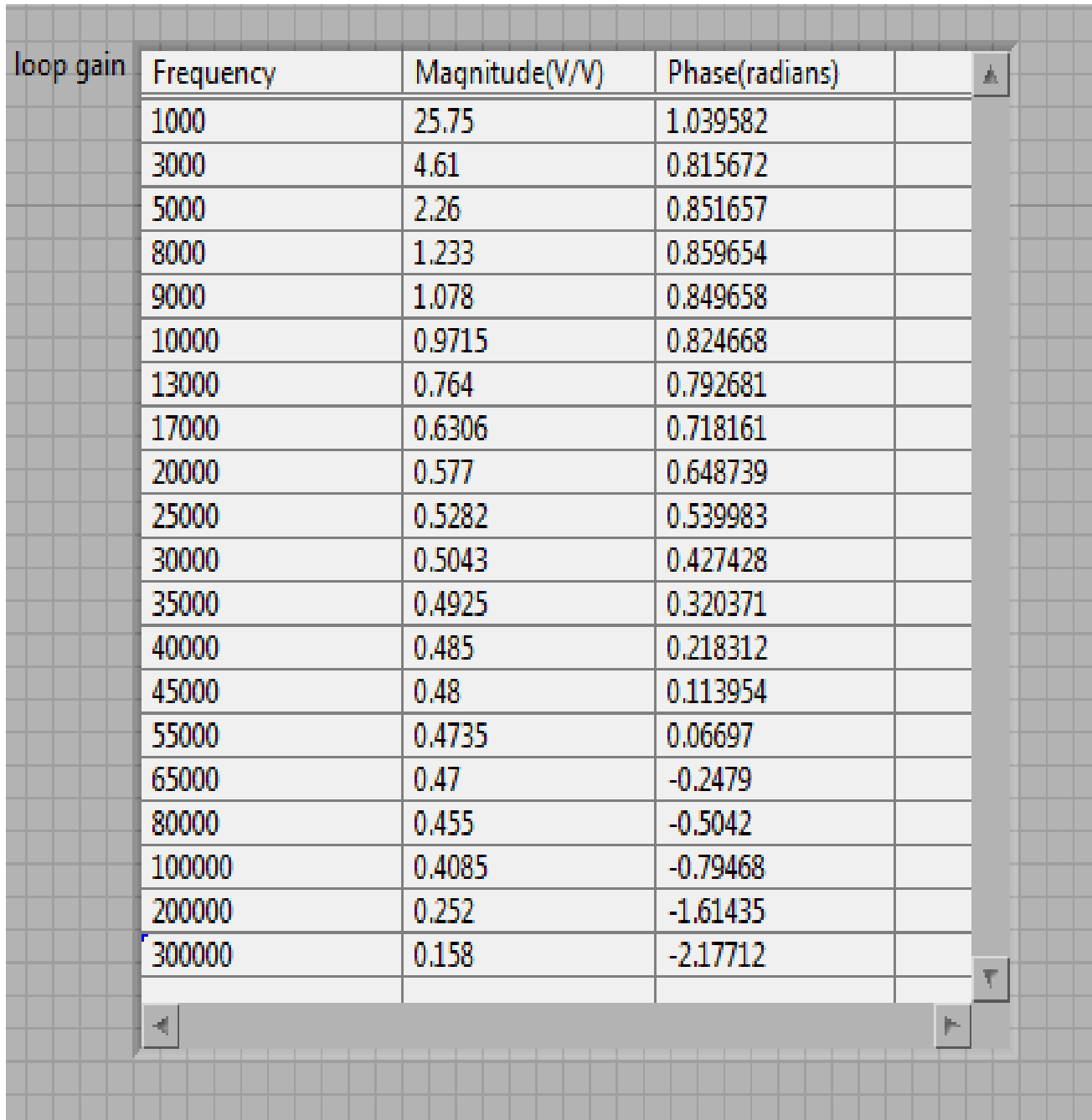
Figure 13. TINA-TI Loop Gain Plot

## 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.



loop gain	Frequency	Magnitude(V/V)	Phase(radians)
	1000	25.75	1.039582
	3000	4.61	0.815672
	5000	2.26	0.851657
	8000	1.233	0.859654
	9000	1.078	0.849658
	10000	0.9715	0.824668
	13000	0.764	0.792681
	17000	0.6306	0.718161
	20000	0.577	0.648739
	25000	0.5282	0.539983
	30000	0.5043	0.427428
	35000	0.4925	0.320371
	40000	0.485	0.218312
	45000	0.48	0.113954
	55000	0.4735	0.06697
	65000	0.47	-0.2479
	80000	0.455	-0.5042
	100000	0.4085	-0.79468
	200000	0.252	-1.61435
	300000	0.158	-2.17712

**Figure 14. Observed Data Using LabVIEW™**

14 Loop Gain Magnitude Plot

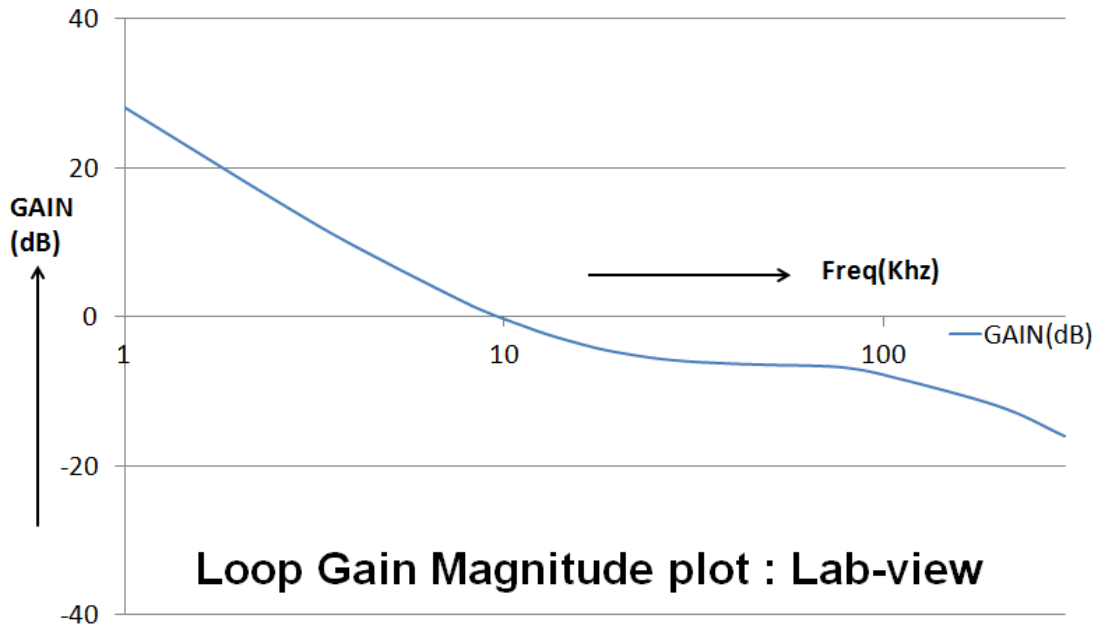


Figure 15. Loop Gain Magnitude Plot: LabVIEW™

15 Loop Gain Phase Plot

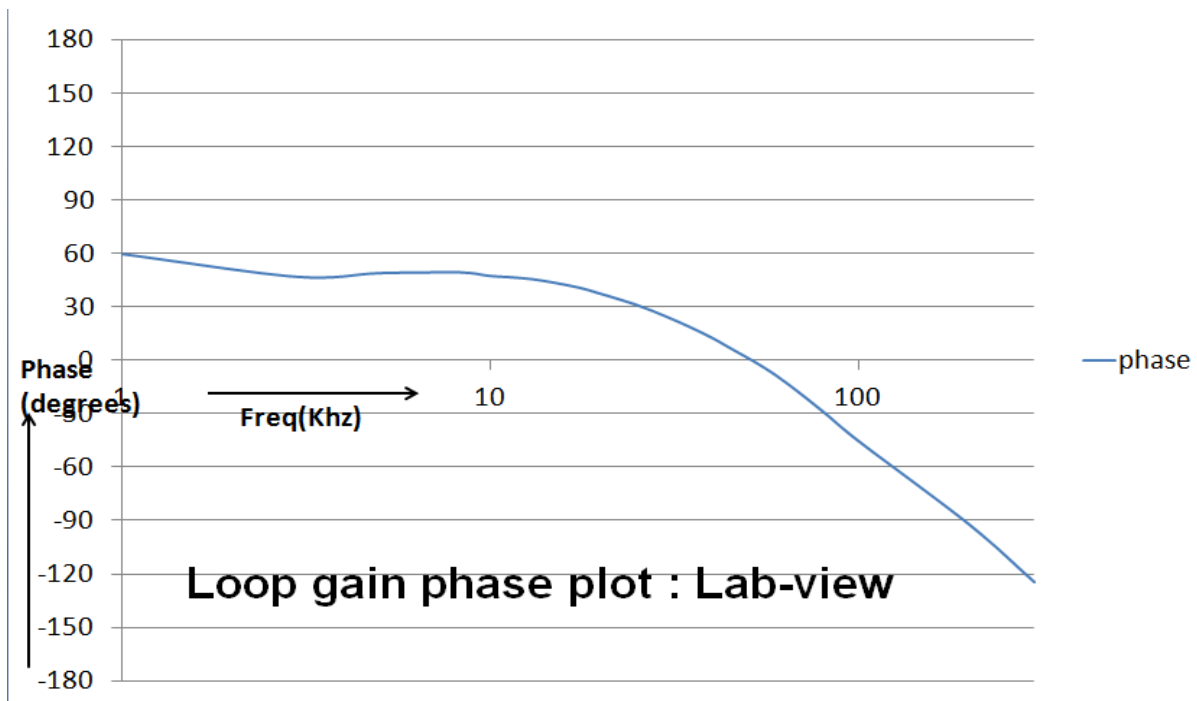


Figure 16. Loop Gain Phase Plot: LabVIEW™

## 16 Loop Gain Plot under Similar Conditions Given in the TPS40210 User Guide

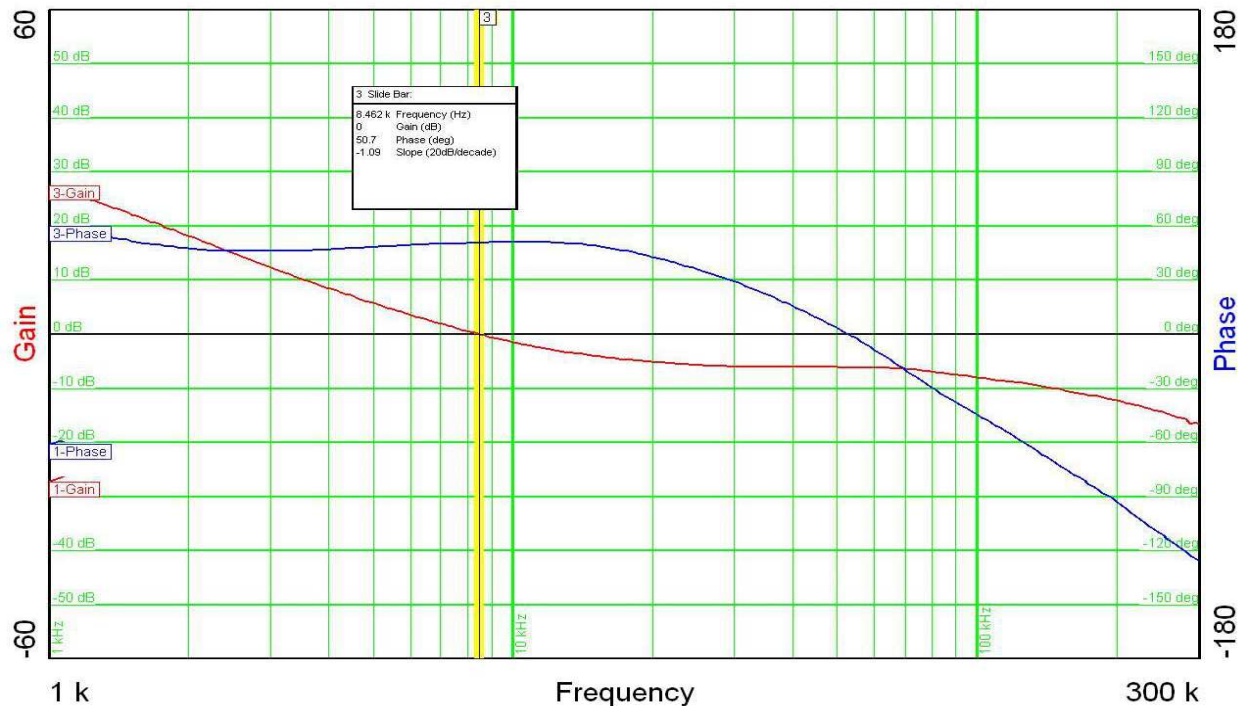


Figure 17. Loop Gain Response Given in User Guide

## 17 Comparison

Table 1.

	Using Automated Lab Test Set-up	User Guide/TINA-TI
TPS40200 Phase Margin(degrees)	68.4	67.5
TPS40200 Crossover Frequency(Hz)	7.12k	7.26k
TPS40210 Phase Margin(degrees)	48.5	50.7
TPS40210 Crossover Frequency(Hz)	9.2k	8.6k

## 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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*User Power/Frequency Use Obligations:* This radio is intended for development/professional use only in legally allocated frequency and power limits. Any use of radio frequencies and/or power availability of this EVM and its development application(s) must comply with local laws governing radio spectrum allocation and power limits for this evaluation module. It is the user's sole responsibility to only operate this radio in legally acceptable frequency space and within legally mandated power limitations. Any exceptions to this are strictly prohibited and unauthorized by Texas Instruments unless user has obtained appropriate experimental/development licenses from local regulatory authorities, which is responsibility of user including its acceptable authorization.

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#### Caution

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Changes or modifications not expressly approved by the party responsible for compliance could void the user's authority to operate the equipment.

### FCC Interference Statement for Class A EVM devices

This equipment has been tested and found to comply with the limits for a Class A digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference when the equipment is operated in a commercial environment. This equipment generates, uses, and can radiate radio frequency energy and, if not installed and used in accordance with the instruction manual, may cause harmful interference to radio communications. Operation of this equipment in a residential area is likely to cause harmful interference in which case the user will be required to correct the interference at his own expense.



### **FCC Interference Statement for Class B EVM devices**

This equipment has been tested and found to comply with the limits for a Class B digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference in a residential installation. This equipment generates, uses and can radiate radio frequency energy and, if not installed and used in accordance with the instructions, may cause harmful interference to radio communications. However, there is no guarantee that interference will not occur in a particular installation. If this equipment does cause harmful interference to radio or television reception, which can be determined by turning the equipment off and on, the user is encouraged to try to correct the interference by one or more of the following measures:

- 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.

### **For EVMs annotated as IC – INDUSTRY CANADA Compliant**

This Class A or B digital apparatus complies with Canadian ICES-003.

Changes or modifications not expressly approved by the party responsible for compliance could void the user's authority to operate the equipment.

### **Concerning EVMs including radio transmitters**

This device complies with Industry Canada licence-exempt RSS standard(s). Operation is subject to the following two conditions: (1) this device may not cause interference, and (2) this device must accept any interference, including interference that may cause undesired operation of the device.

### **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.

### **Concernant les EVMs avec appareils radio**

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 détachables**

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 isotrope rayonnée équivalente (p.i.r.e.) ne dépasse pas l'intensité nécessaire à l'établissement d'une communication satisfaisante.

Le présent émetteur radio a été approuvé par Industrie Canada pour fonctionner avec les types d'antenne énumérés dans le manuel d'usage et ayant un gain admissible maximal et l'impédance requise pour chaque type d'antenne. Les types d'antenne non inclus dans cette liste, ou dont le gain est supérieur au gain maximal indiqué, sont strictement interdits pour l'exploitation de l'émetteur.

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**This development kit is NOT certified as Confirming to Technical Regulations of Radio Law of Japan**

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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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## **EVALUATION BOARD/KIT/MODULE (EVM) WARNINGS, RESTRICTIONS AND DISCLAIMERS**

**For Feasibility Evaluation Only, in Laboratory/Development Environments.** Unless otherwise indicated, this EVM is not a finished electrical equipment and not intended for consumer use. It is intended solely for use for preliminary feasibility evaluation in laboratory/development environments by technically qualified electronics experts who are familiar with the dangers and application risks associated with handling electrical mechanical components, systems and subsystems. It should not be used as all or part of a finished end product.

Your Sole Responsibility and Risk. You acknowledge, represent and agree that:

1. You have unique knowledge concerning Federal, State and local regulatory requirements (including but not limited to Food and Drug Administration regulations, if applicable) which relate to your products and which relate to your use (and/or that of your employees, affiliates, contractors or designees) of the EVM for evaluation, testing and other purposes.
2. You have full and exclusive responsibility to assure the safety and compliance of your products with all such laws and other applicable regulatory requirements, and also to assure the safety of any activities to be conducted by you and/or your employees, affiliates, contractors or designees, using the EVM. Further, you are responsible to assure that any interfaces (electronic and/or mechanical) between the EVM and any human body are designed with suitable isolation and means to safely limit accessible leakage currents to minimize the risk of electrical shock hazard.
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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