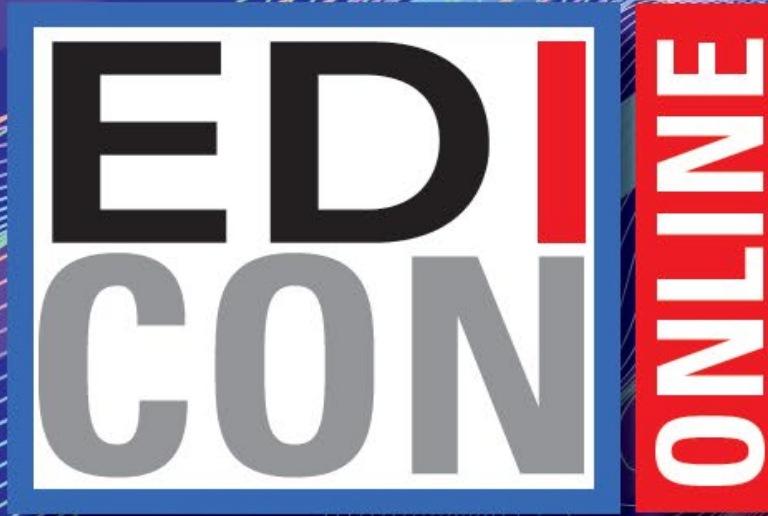




Stability and Performance Improvement with Feedback in VRM Transconductance Error Amplifiers

A Case Study using the Sandler State Space Average VRM Model

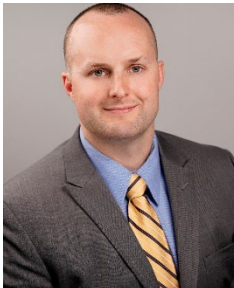
Session Presented By: Benjamin Dannan

Date: 5 October 2022

Track: Technical Session



Presenter Bios



Benjamin Dannan is a Technical Fellow and an experienced signal and power integrity (SI/PI) design engineer, advancing high-performance ASIC and high-speed digital designs. He is a Keysight ADS Certified Expert with expert-level proficiency in high-speed simulation solutions, multiple 3D EM solutions, and multiple test and measurement solutions. Benjamin holds a cybersecurity certification, a BSEE from Purdue University, and a Master of Engineering in Electrical Engineering from The Pennsylvania State University. He has numerous publications and received the prestigious DesignCon best paper award in 2020.

Steve Sandler has been involved with power system engineering for more than 40 years. Steve is the founder and CEO of PICOTEST.com, a company specializing in instruments and accessories for high-performance power systems and distributed system testing. He frequently lectures and leads workshops internationally on the topics of Power Integrity and Distributed Power System Design. He is a Keysight Certified EDA expert.



Heidi Barnes is a Senior Application Engineer for High-Speed Digital applications in the EEsof EDA Group of Keysight Technologies. Her recent activities include the application of electromagnetic, transient, and channel simulators to solve signal and power integrity challenges. Author of over 20 papers on SI and PI and recipient of the DesignCon 2017 Engineer of the Year. Heidi graduated from the California Institute of Technology in 1986 with a bachelor's degree in electrical engineering. She has been with Keysight EEsof since 2012.

Overview

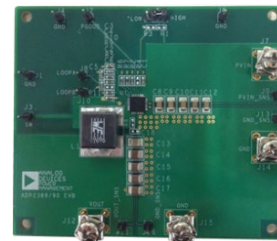
- Why do we care about Gm tolerance of the error amp inside VRMs?
- Background on transconductance amplifiers
- Basics of feedback loops and control theory
- Case study – Gain sensitivity and nonlinear distortion
- Case study – VRM output impedance and stability
- Summary & conclusion

Why do we care about the Gm tolerance of the Error Amp inside of VRMs?

Transient Response Shunt vs. Series Compensation

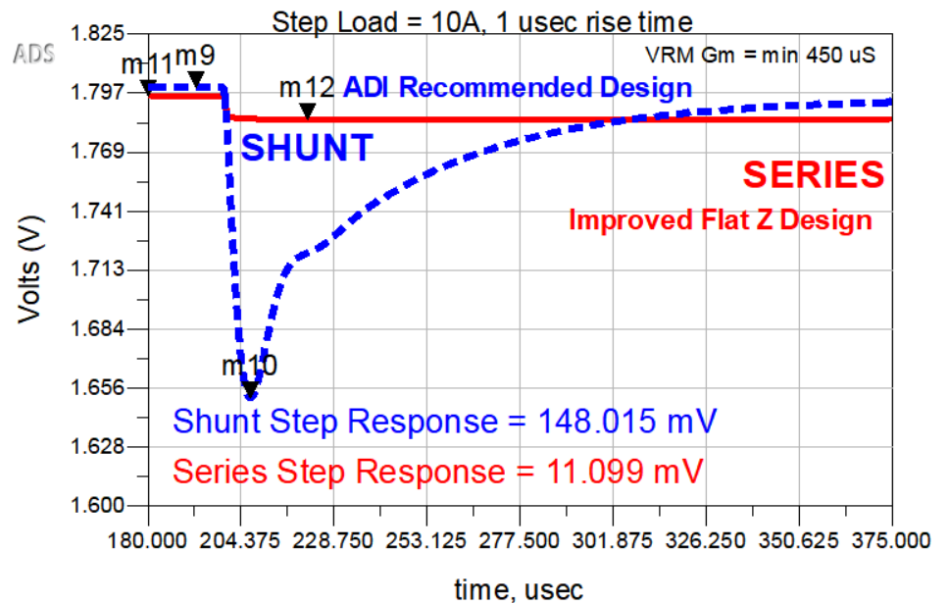
Per ADP2389
Datasheet

ERROR AMPLIFIER (EA)						
Transconductance	g_m	450	500	550	μS	



ADP2389 EVAL

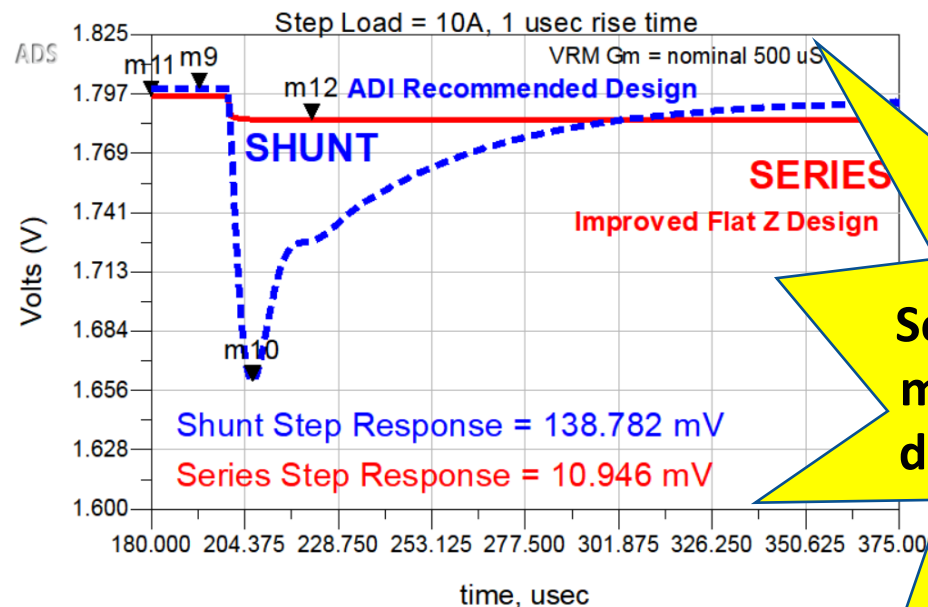
VRM Step Load Response - Shunt vs. Series Compensation



ADP2389 Datasheet **G_m min = 450 μS**

ADP2389 EVAL

VRM Step Load Response - Shunt vs. Series Compensation



ADP2389 Datasheet **G_m nominal = 500 μS**

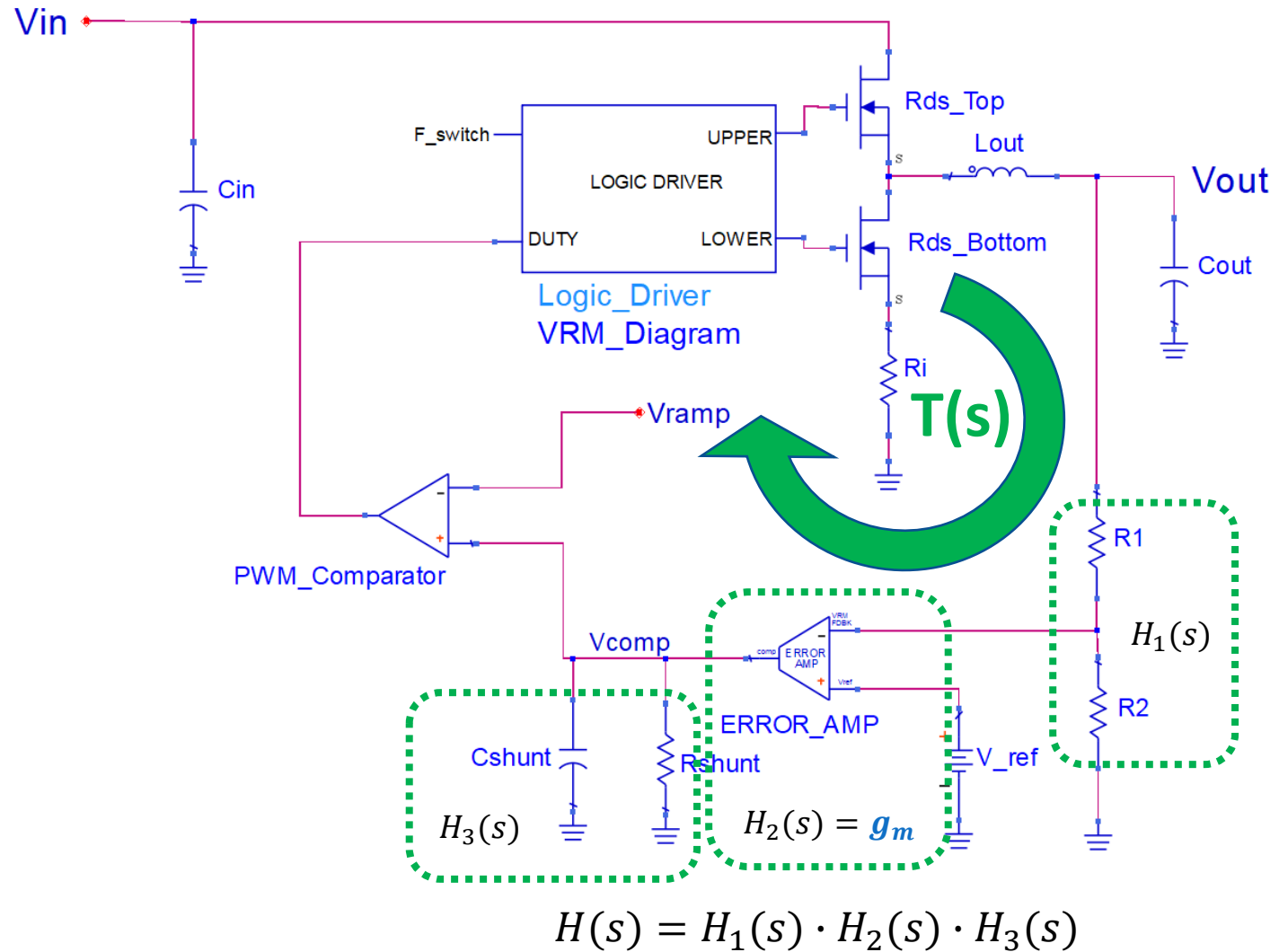
**Series compensation
mitigates the effects
due to G_m tolerance**

Let's talk about how to improve your design WITHOUT ADDING COST

The Voltage Regulator Module (VRM)

- What is the buck regulator VRM composed of?
 - Logic Drivers
 - Switches
 - PWM Comparators with Slope Compensation
 - Error Amplifier
- Loop gain $T(s)$ is part of the VRM's closed-loop transfer function

- The Error Amplifier feedback loop and **transconductance** affect the VRM's output impedance

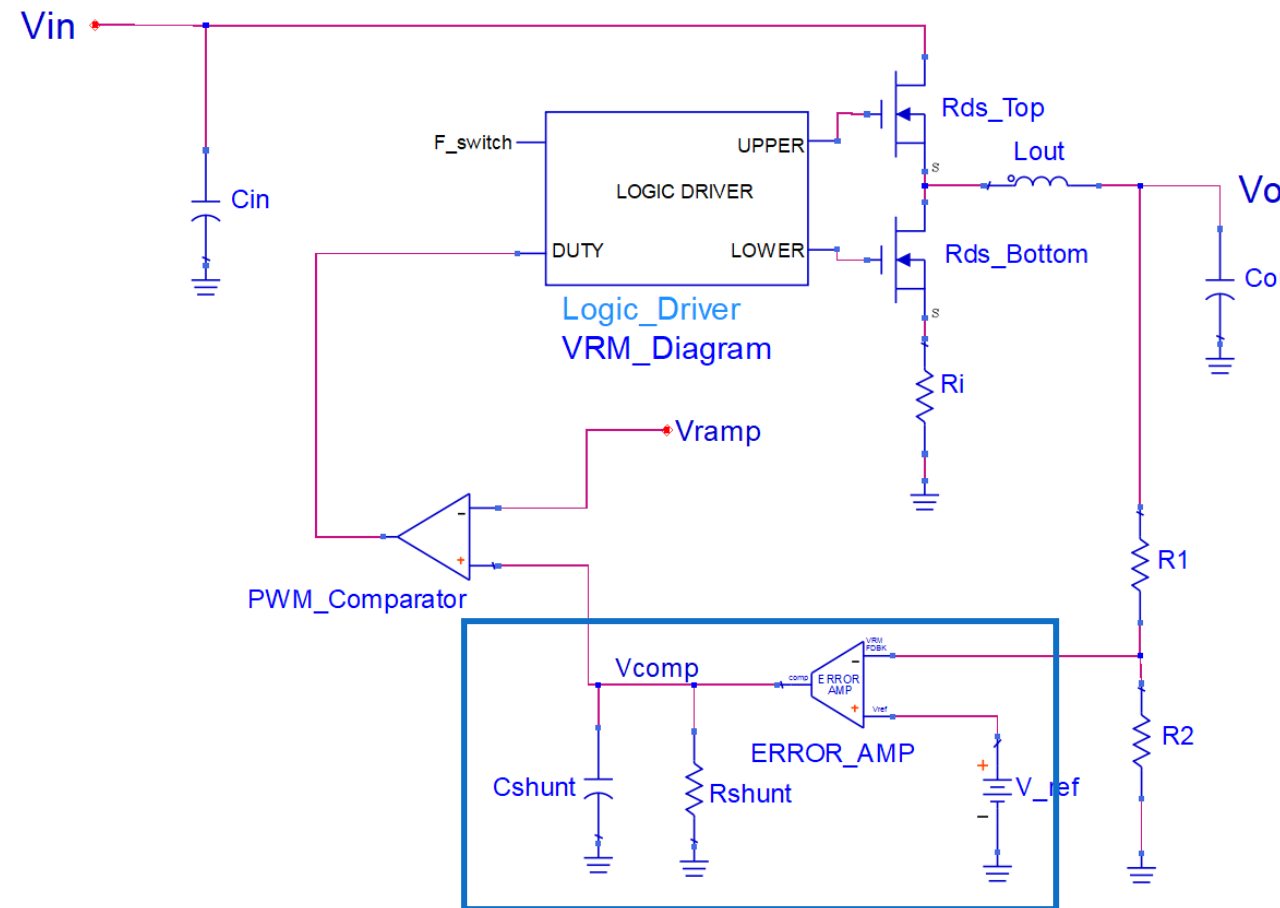


$$\text{Transfer Function: } H(s) = \frac{V_{comp}}{V_{out}} = \frac{R_2}{R_1 + R_2} \cdot g_m \cdot (1 + s \cdot R_{shunt} \cdot C_{shunt})$$

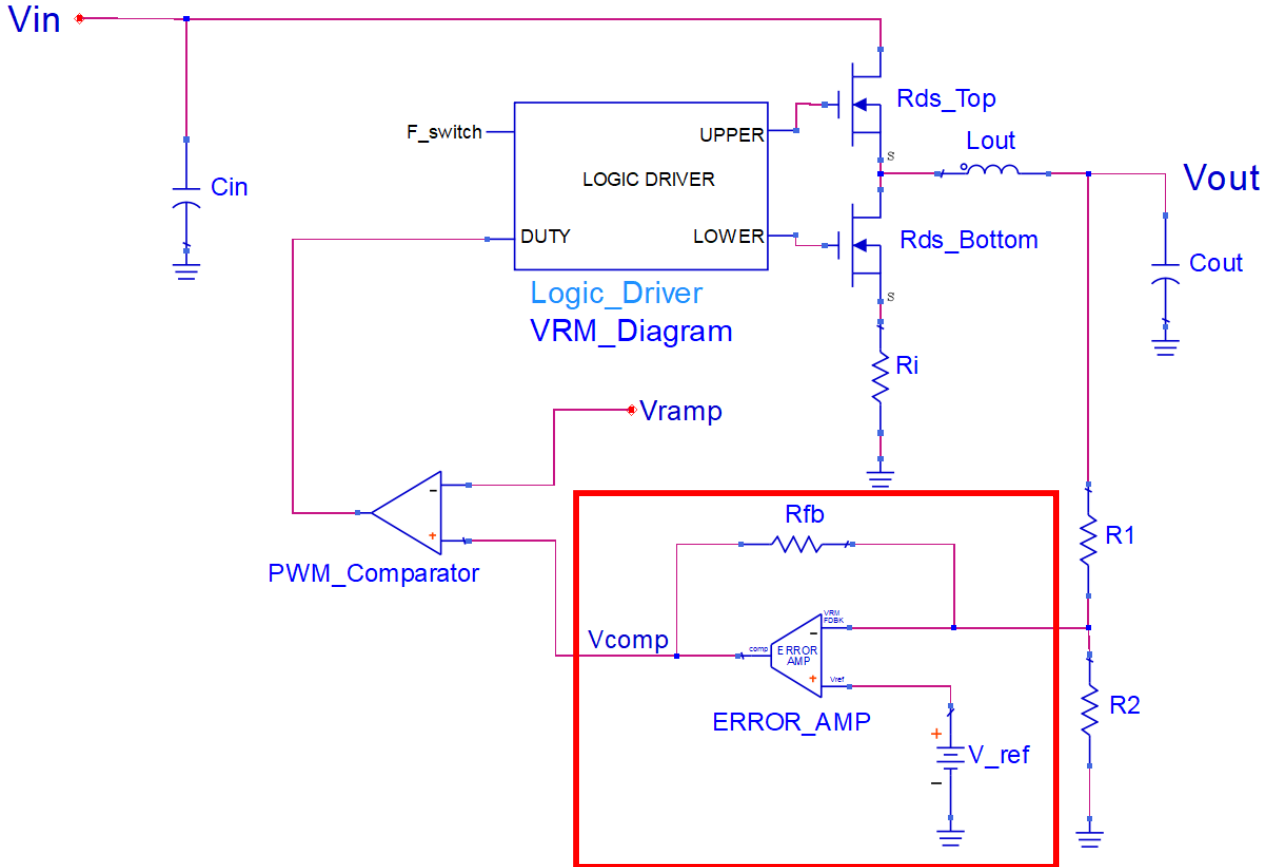
Background on Transconductance Amplifiers

- A voltage-to-current converter, also called a Transconductance amplifier
 - Accepts input voltage V_i and yields an output current of the type $i_o = g_m V_{in}$
 - Current mirror
- Transconductance amplifiers are also known as Error Amplifiers (EA) in the VRM
- These amplifiers have wide bandwidths and are inexpensive feedback amplifiers in a VRM
- This is, perhaps, the most common type of feedback amplifier in use today

VRM Error Amp with Shunt vs. Series Compensation



Error amplifier with **shunt** compensation



Error amplifier with **series** compensation

Negative Feedback Amplifier Basics

An error amplifier accepts the signal V_E and yields the output signal

$$V_o = \alpha V_E$$

A feedback network which samples the V_o and produces a feedback signal is defined by:

$$V_{fb} = \beta V_o$$

Where the difference between the summing network is:

$$V_E = V_{in} - V_{fb} = V_{in} - \beta V_o$$

Eliminating V_{fb} and V_E and solving the equation for $A = V_o/V_{in}$ yields:

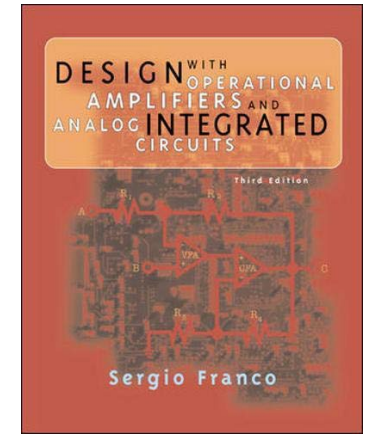
Closed-loop Gain $A = \frac{V_o}{V_{in}} = \frac{\alpha}{1 + \alpha\beta}$

Where our Loop Gain (T) or return ratio is defined by:

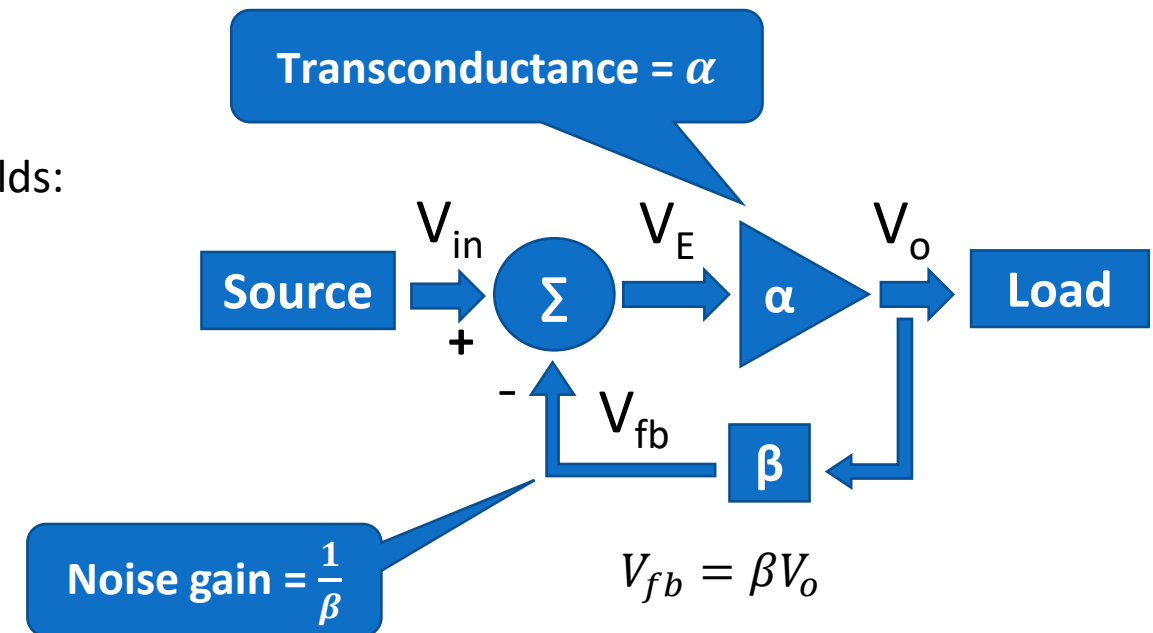
$$T = \alpha\beta$$

Where our desensitivity factor is defined by:

$$= 1 + \alpha\beta$$



Referenced from "Design with Operational Amplifiers and Analog Integrated Circuits by Sergio Franco"



Gain Desensitivity with Feedback

Differentiating the closed-loop gain equation $\frac{\partial A}{\partial \alpha}$ yields:

$$\frac{\partial A}{\partial \alpha} = \frac{1}{(1 + \alpha\beta)^2}$$

Since $1 + \alpha\beta = A/\alpha$, we can rewrite and rearrange the above equation to be:

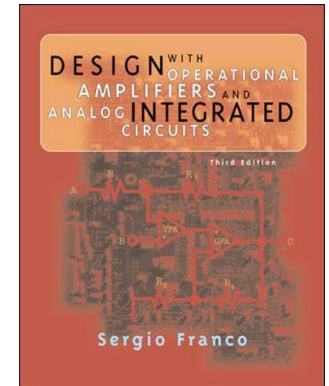
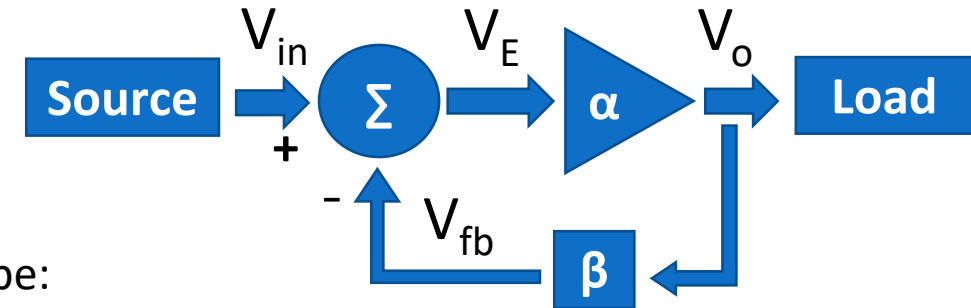
$$\frac{\partial A}{A} = \frac{1}{1 + T} \cdot \frac{\partial \alpha}{\alpha}$$

Replacing differential with finite increments and multiplying both sides by 100, we can approximate:

$$100 \frac{\Delta A}{A} \cong \frac{1}{1 + T} \cdot (100 \frac{\Delta \alpha}{\alpha})$$

For T sufficiently large, even a substantial change in α will cause an insignificant change in A

It becomes apparent that negative feedback desensitizes gain!

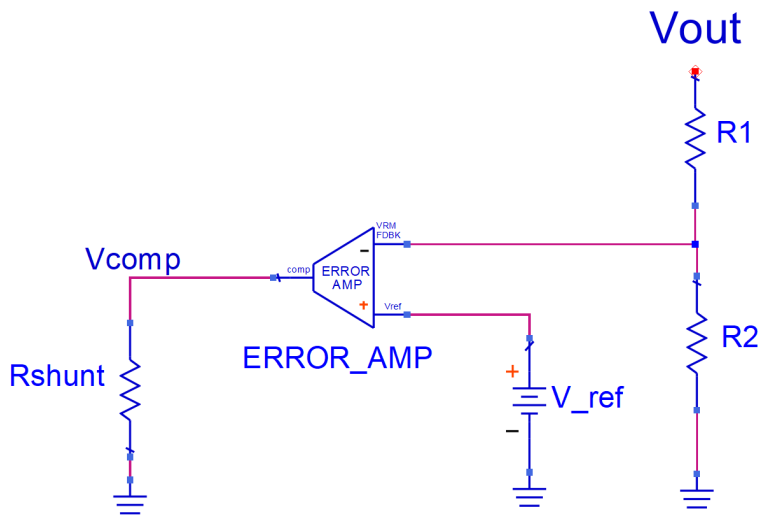


Referenced from "Design with Operational Amplifiers and Analog Integrated Circuits by Sergio Franco"

Gain Insensitivity with Series Feedback

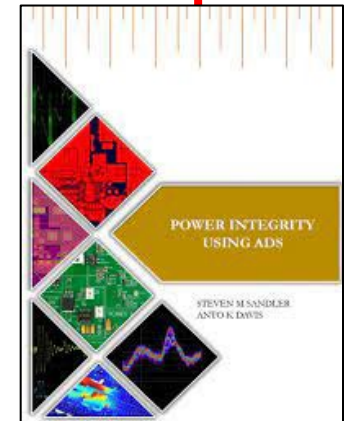
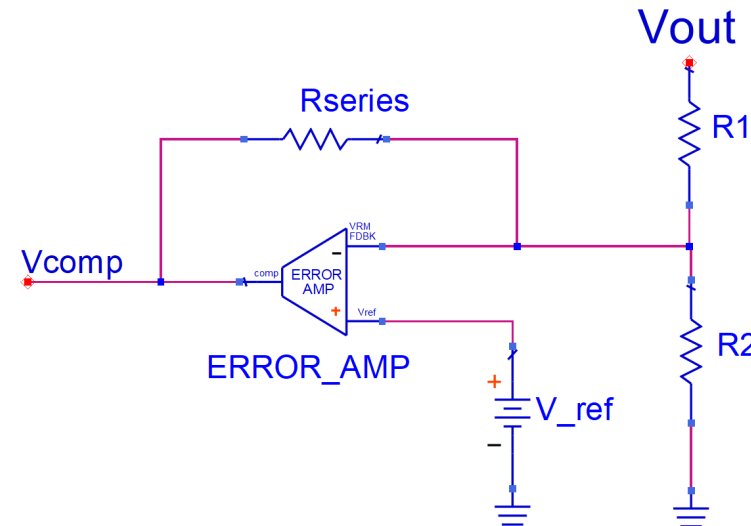
$$Av_{shunt} = \frac{R_2 \cdot G_m \cdot R_{shunt}}{R_1 + R_2}$$

$$\frac{\partial Av_{shunt}}{\partial G_m} = \frac{R_2 \cdot R_{shunt}}{R_1 + R_2}$$



$$Av_{series} = \frac{R_2 \cdot (G_m \cdot R_{series} - 1)}{R_1 + R_2 + G_m \cdot R_1 \cdot R_2}$$

$$\frac{\partial Av_{series}}{\partial G_m} = \frac{R_2 \cdot R_{series}}{R_1 + R_2 + G_m \cdot R_1 \cdot R_2} - \frac{R_1 \cdot R_2^2 \cdot (G_m \cdot R_2 - 1)}{(R_1 + R_2 + G_m \cdot R_1 \cdot R_2)^2}$$



Referenced example from
"Power Integrity Using ADS"

Case Study

Gain Sensitivity & Non-linear Distortion Reduction *Shunt vs. Series Feedback Compensation*

	VRM MPN	MFG	VRM Type	Compensation
CASE 1	ADP2389	Analog Devices	Current Mode	External
CASE 2	ISL8026	Renesas/Intersil	Current Mode	External or Internal**
CASE 3	LM20143	Texas Instruments	Current Mode	External
CASE 4	TPS7H4003*	Texas Instruments	Current Mode	External
CASE 5	MAX20098	Maxim	Current Mode	External

Note:

*Radiation-tolerant, designed for Space applications

**Internal compensation is set based on specific pin configuration. This EVAL used external compensation for this case study

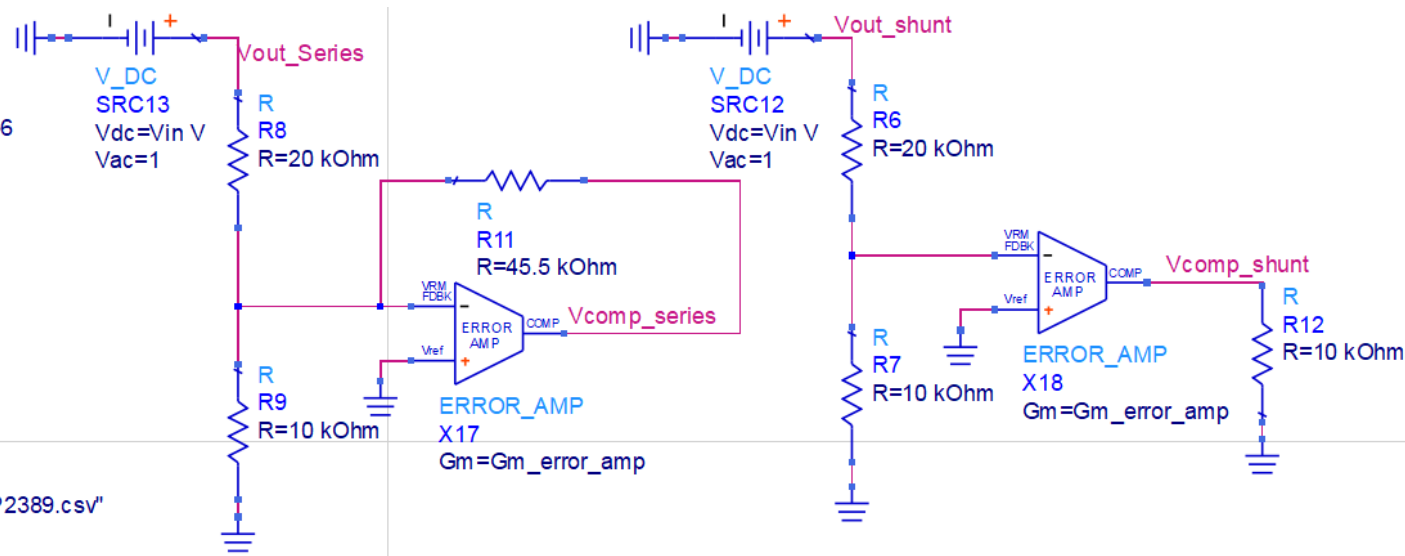
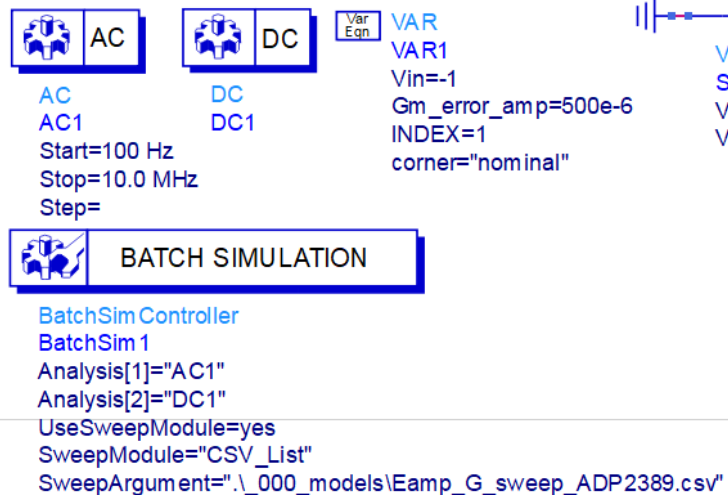
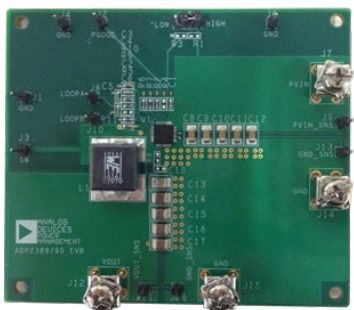
CASE 1 - ADP2389 Error Amplifier

Per ADP2389
Datasheet

ERROR AMPLIFIER (EA)				
Transconductance	g_m		450	μS
EA Source Current	I_{SOURCE}		40	μA
EA Sink Current	I_{SINK}		40	μA

$$A_{v_{shunt}} = 1.67$$

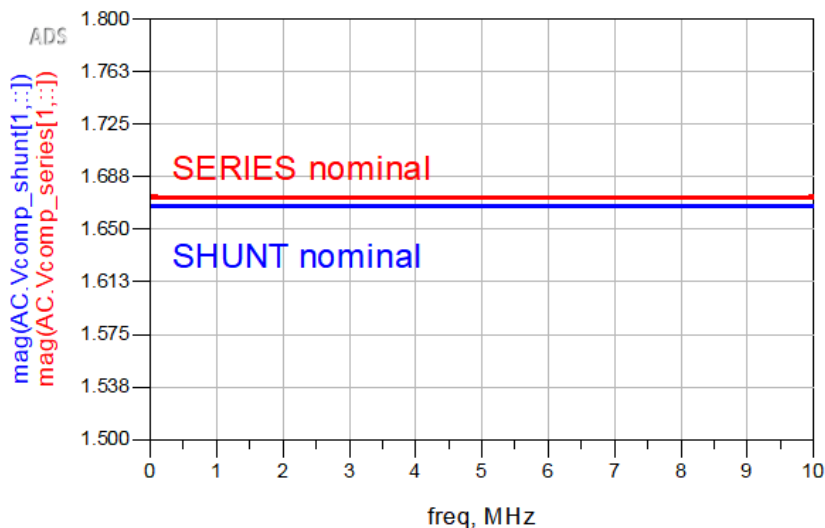
$$A_{v_{series}} = 1.67$$



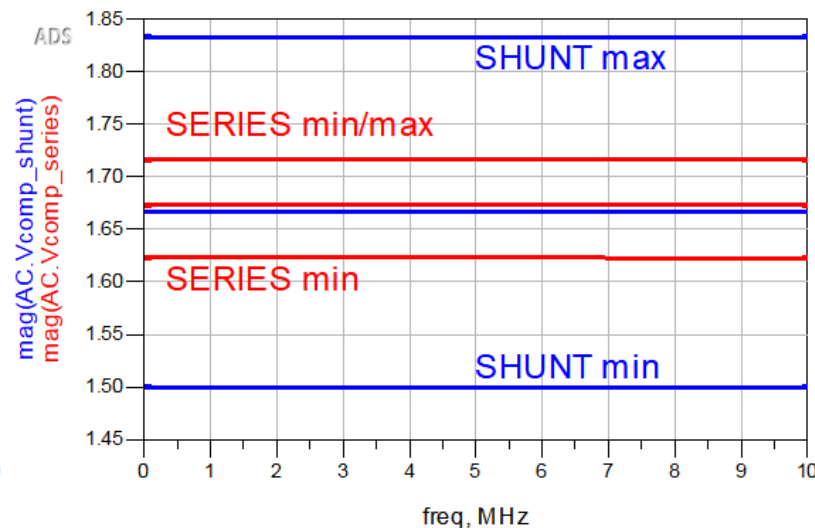
CASE 1 - ADP2389 Error Amplifier Vcomp Output

Gain Sensitivity & Linear Distortion – Shunt vs. Series Feedback

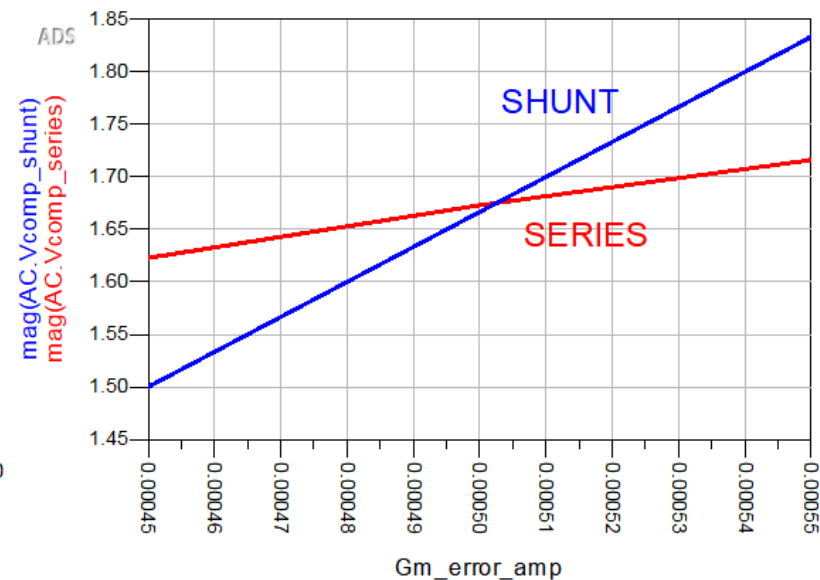
ADP2389 VRM
Nominal Error Amp Output



ADP2389 VRM
Min/Max Error Amp Gain Glope: Series vs. Shunt



ADP2389 VRM
Sensitivity to G_erroramp: Series vs Shunt



This validates there is significantly greater sensitivity with shunt feedback

Series feedback is less sensitive to gain variation and exhibits less linear distortion

CASE 2 - ISL8026 Error Amplifier

Per ISL8026 Datasheet

COMPENSATION					
Error Amplifier Transconductance		Internal compensation		60	$\mu\text{A/V}$
		External compensation		120	$\mu\text{A/V}$

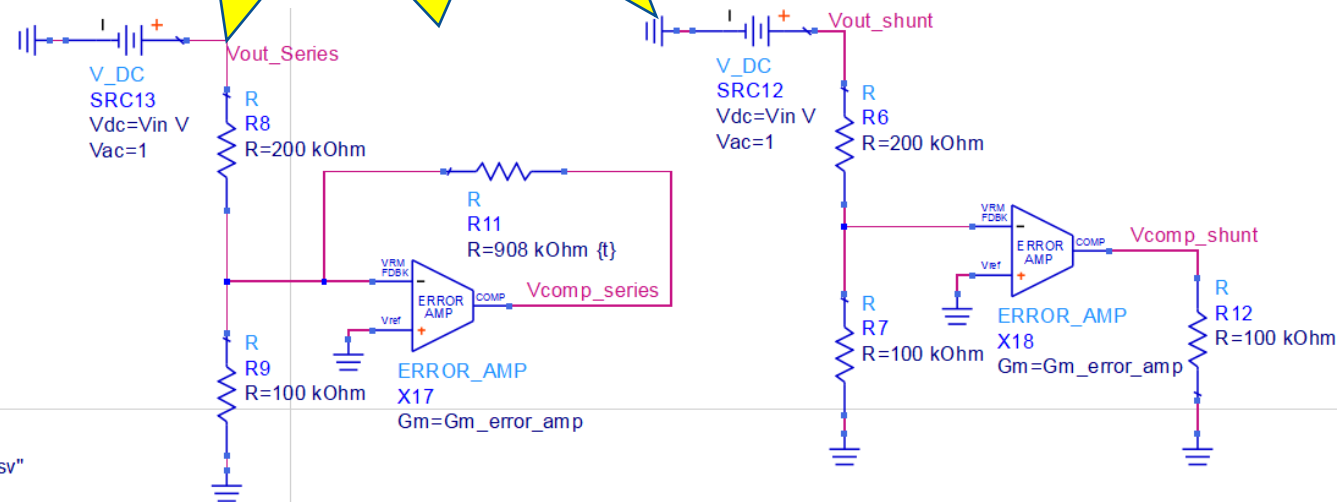
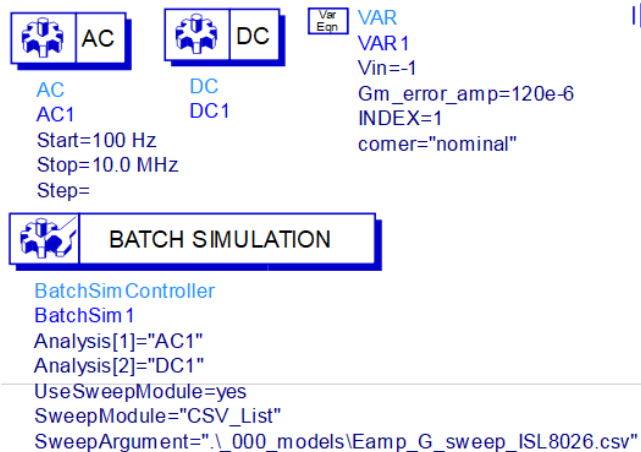
Assume +/-50% variation
Min = 60 $\mu\text{A/V}$, Max = 180 $\mu\text{A/V}$

$$A_{v_{\text{shunt}}} = 4$$

$$A_{v_{\text{series}}} = 4$$

Gm tolerance is a HUGE performance factor

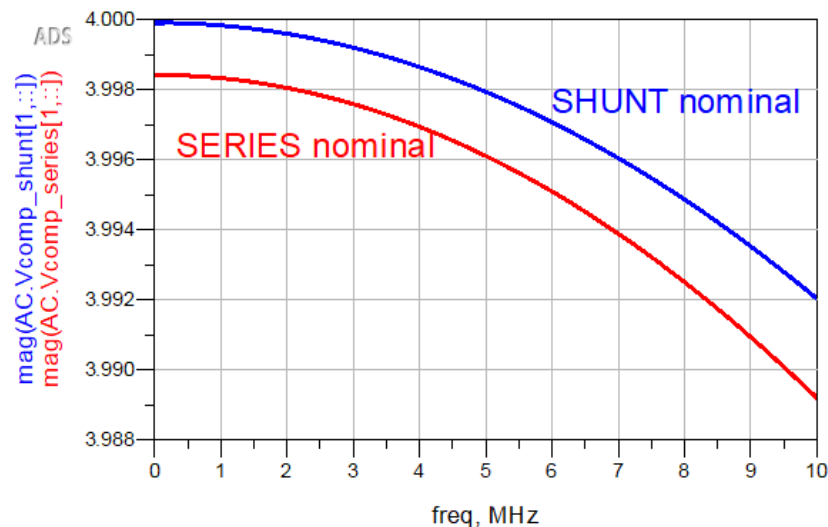
Many VRM datasheets do not include the Gm tolerances



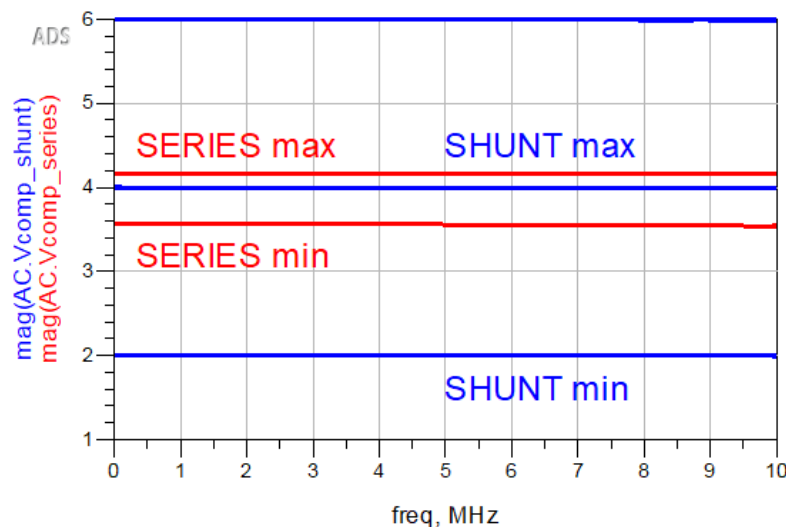
CASE 2 - ISL8026 Error Amplifier Vcomp Output

Gain Sensitivity & Linear Distortion – Shunt vs. Series Feedback

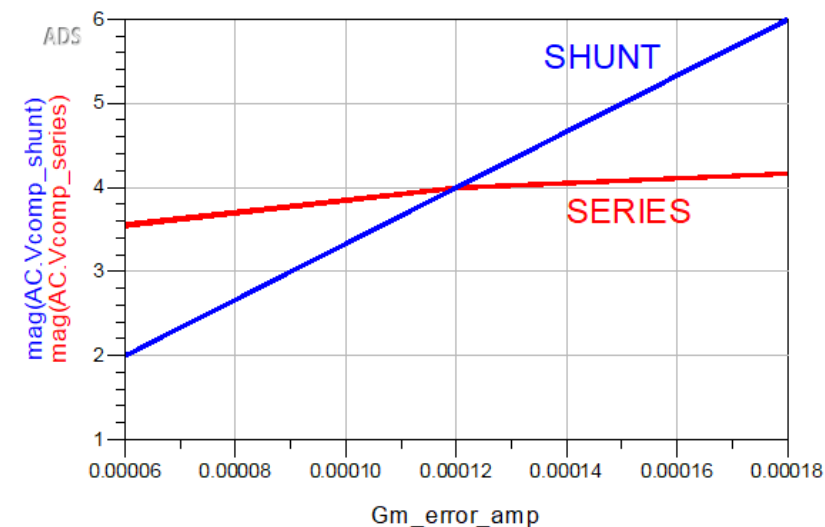
ISL8026 VRM
Nominal Error Amp Output



ISL8026 VRM
Min/Max Error Amp Gain Glope: Series vs. Shunt



ISL8026 VRM
Sensitivity to G_erroramp: Series vs Shunt



This validates there is significantly greater sensitivity with shunt feedback

Series feedback is less sensitive to gain variation and exhibits less linear distortion

CASE 3 - LM20143 Error Amplifier

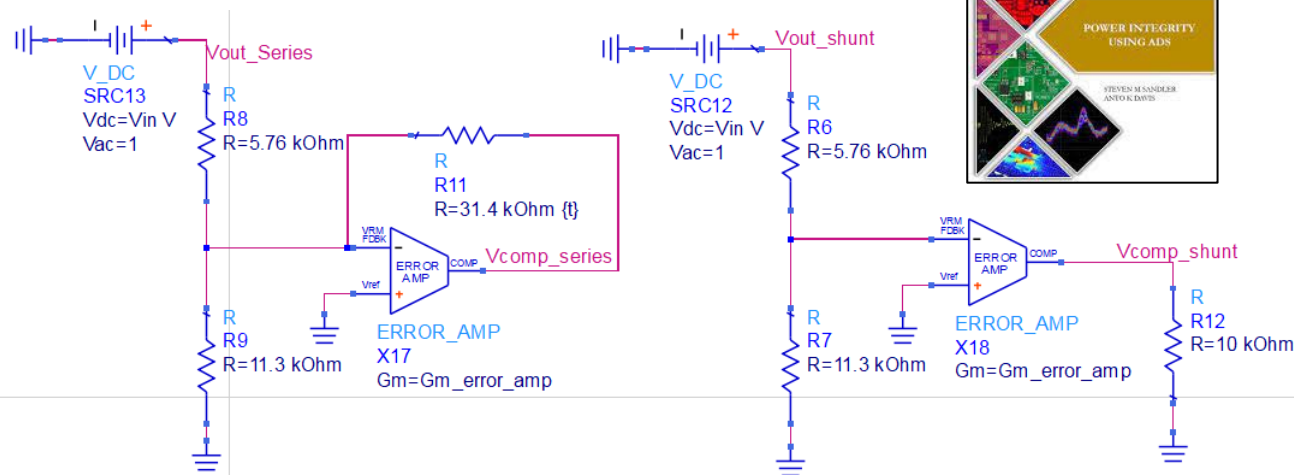
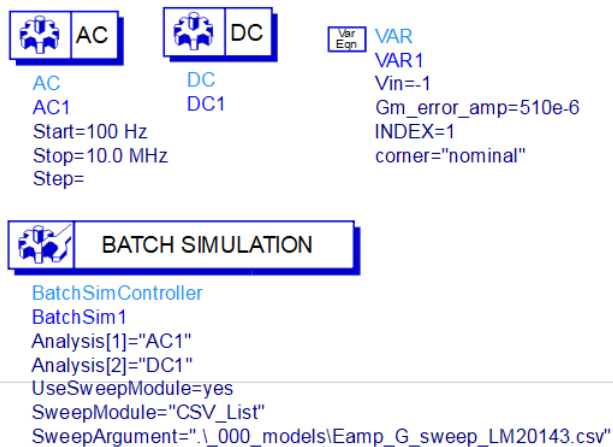
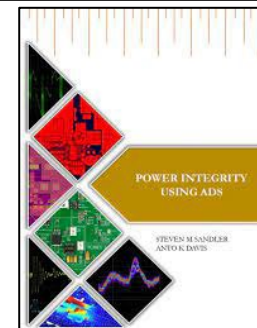
Per LM20143 Datasheet

ERROR AMPLIFIER AND MODULATOR					
I_{FB}	Feedback pin bias current	$V_{FB} = 0.8 \text{ V}$	1	100	nA
I_{COMP_SRC}	COMP Output Source Current	$V_{FB} = V_{COMP} = 0.6 \text{ V}$	80	100	μA
I_{COMP_SNK}	COMP Output Sink Current	$V_{FB} = 1.0 \text{ V}, V_{COMP} = 0.6 \text{ V}$	80	100	μA
G_m	Error Amplifier Transconductance	$I_{COMP} = \pm 50 \mu\text{A}$	450	510	600 μmho
A_{VOL}	Error Amplifier Voltage Gain		2000		V/V

$$A_{v_{shunt}} = 3.38$$

$$A_{v_{series}} = 3.38$$

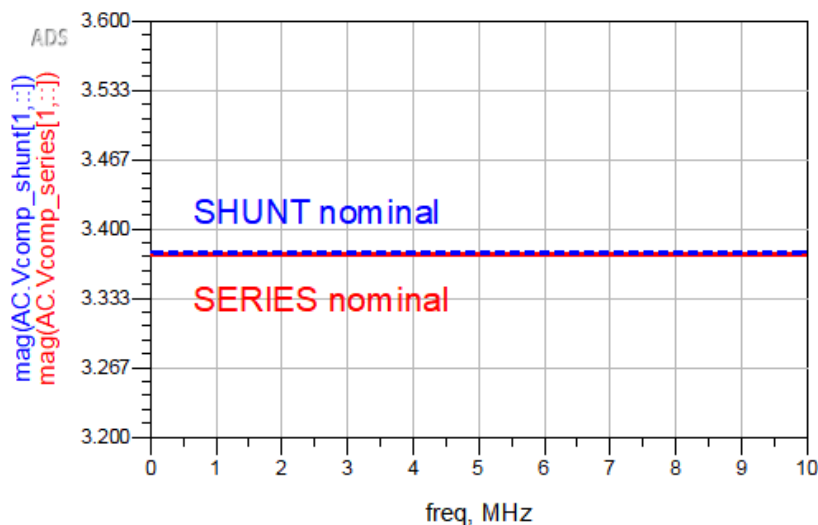
Referenced example from "Power Integrity Using ADS"



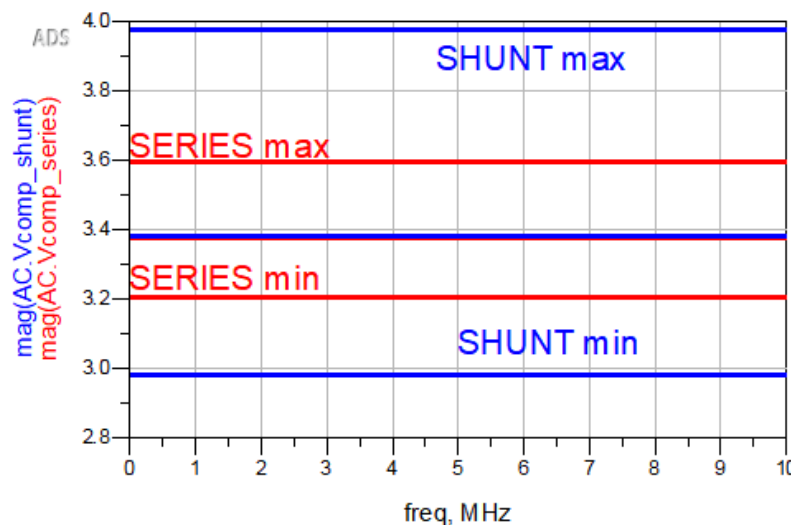
CASE 3 - LM20143 Error Amplifier Vcomp Output

Gain Sensitivity & Linear Distortion – Shunt vs. Series Feedback

LM20143 VRM
Nominal Error Amp Output



LM20143 VRM
Min/Max Error Amp Gain Glope: Series vs. Shunt



LM20143 VRM
Sensitivity to G_erroramp: Series vs Shunt



This validates there is significantly greater sensitivity with shunt feedback

Series feedback is less sensitive to gain variation and exhibits less linear distortion

CASE 4 - TPS7H4003 Error Amplifier

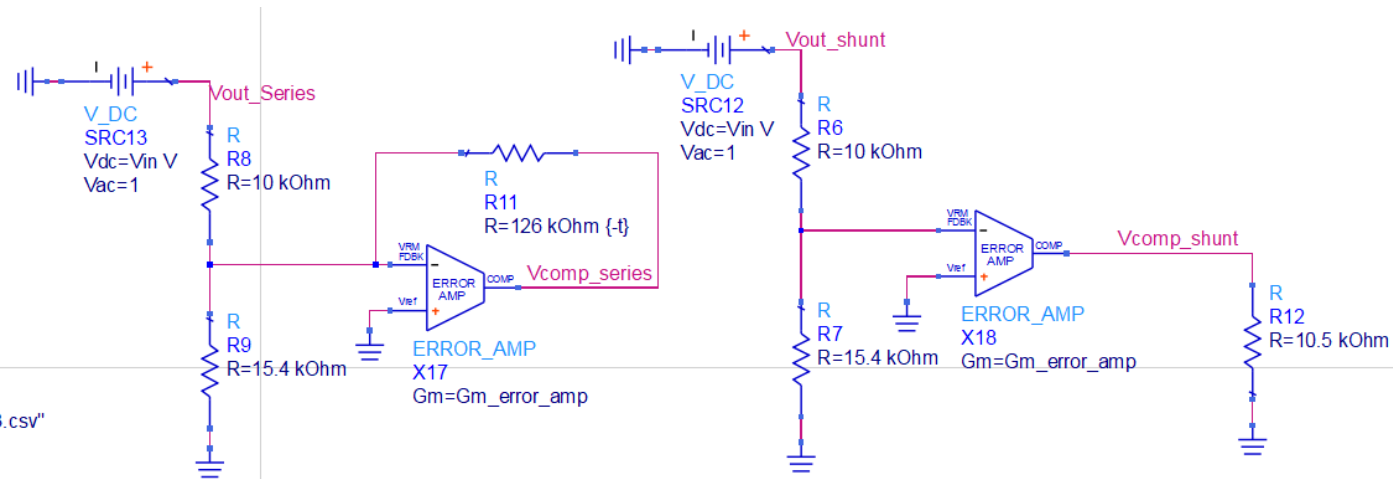
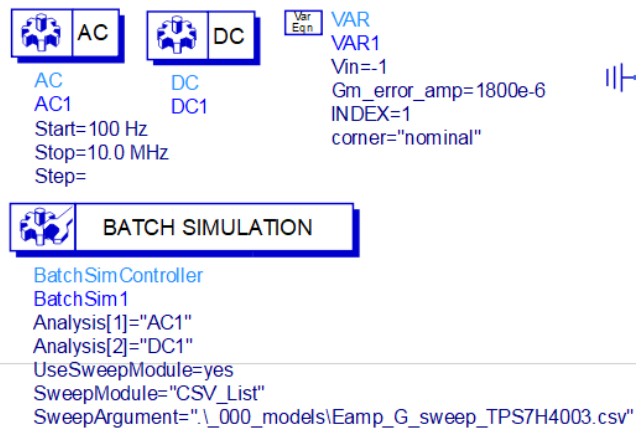
Per TPS7H4003
Datasheet

$$A_{v_{\text{shunt}}} = 11.5$$

$$A_{v_{\text{series}}} = 11.5$$

ERROR AMPLIFIER

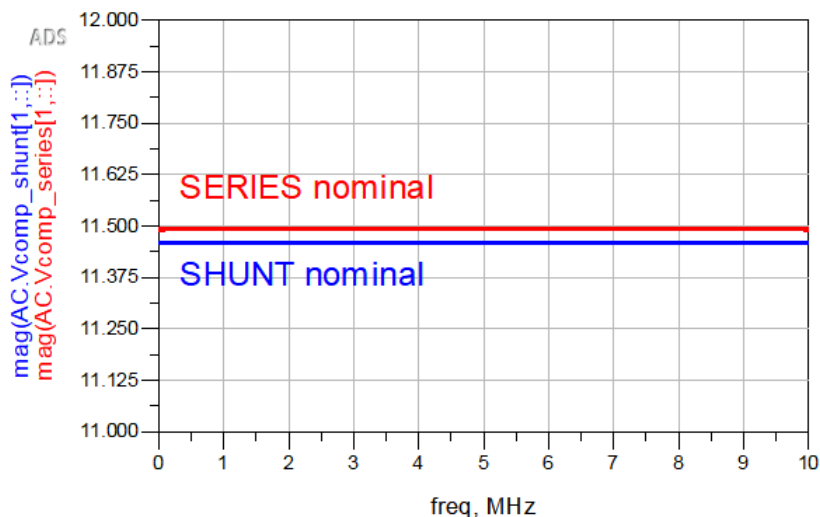
Error amplifier input offset voltage	$V_{\text{SENSE}} = 0.6 \text{ V}$	-2	2.55	mV	
VSENSE pin input current	$V_{\text{SENSE}} = 0.6 \text{ V}$	-15	15	nA	
Error amplifier transconductance (g_m)	$-2 \mu\text{A} < I_{\text{COMP}} < 2 \mu\text{A}, V_{(\text{COMP})} = 1 \text{ V}$	1150	1800	2400	μS
Error amplifier DC gain ⁽²⁾	$V_{\text{SENSE}} = 0.6 \text{ V}$	10000			V/V
Error amplifier source	$V_{(\text{COMP})} = 1 \text{ V}, 100\text{-mV input overdrive}$	100	140	190	μA
Error amplifier sink		100	140	190	μA
Error amplifier output resistance		7			M Ω



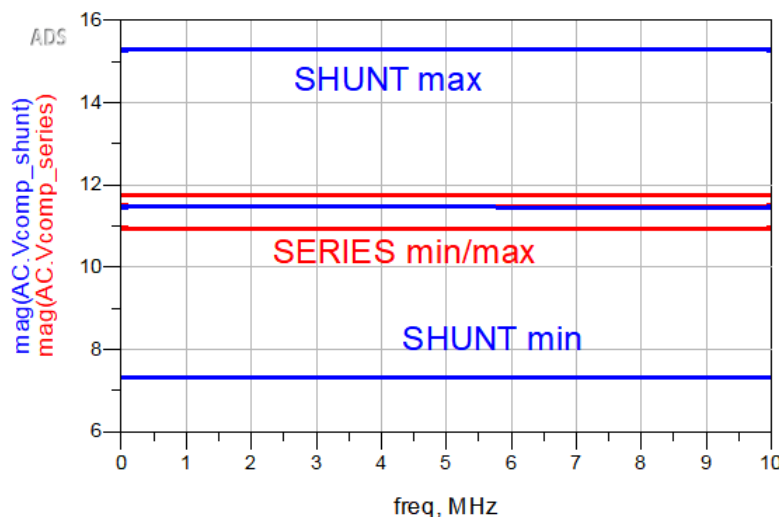
CASE 4 - TPS7H4003 Error Amplifier Vcomp Output

Gain Sensitivity & Linear Distortion – Shunt vs. Series Feedback

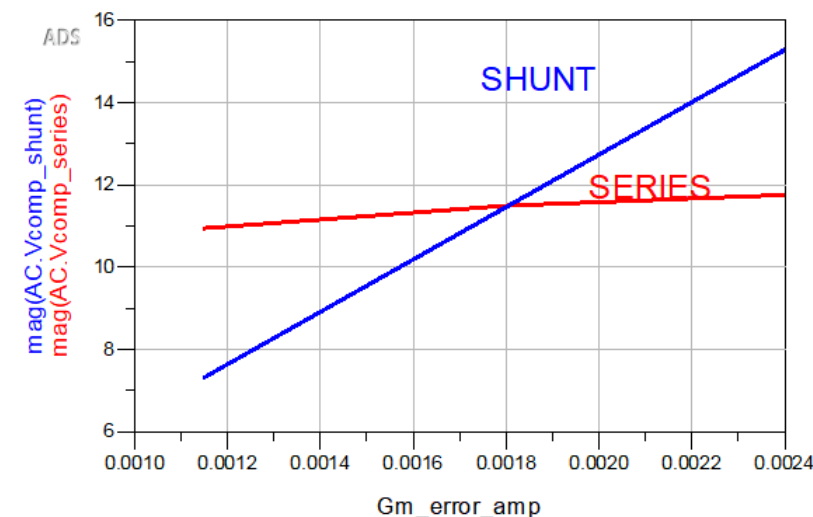
TPS7H4003 VRM
Nominal Error Amp Output



TPS7H4003 VRM
Min/Max Error Amp Gain Glope: Series vs. Shunt



TPS7H4003 VRM
Sensitivity to G_erroramp: Series vs Shunt



This validates there is significantly greater sensitivity with shunt feedback

Series feedback is less sensitive to gain variation and exhibits less linear distortion

CASE 5 - MAX20098 Error Amplifier

Per MAX20098 Datasheet

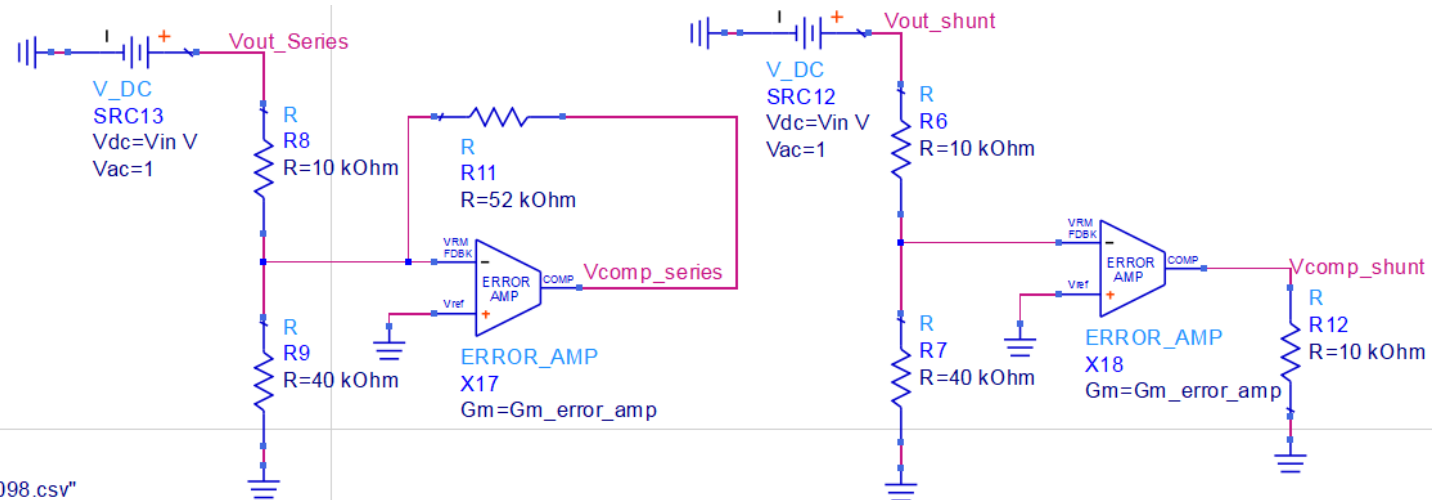
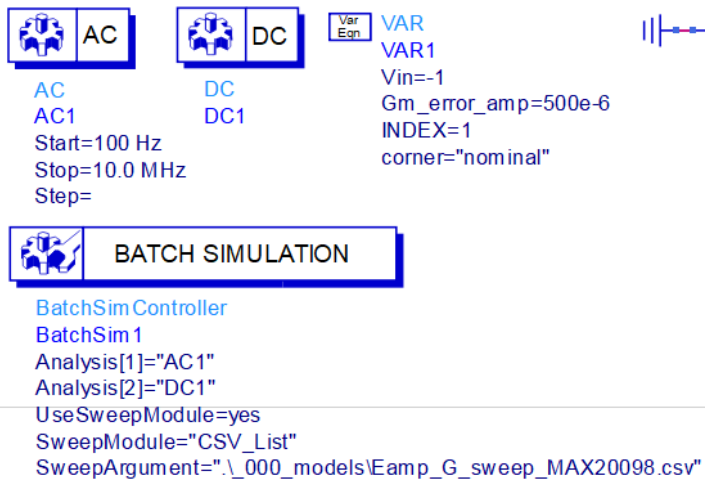
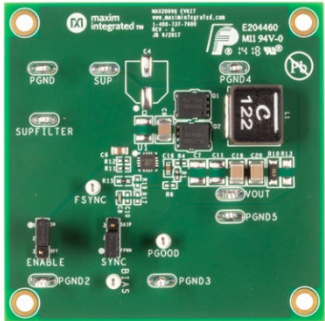
Feedback Leakage Current	I_{FB}	$T_A = +25^\circ\text{C}$	0.01	1	μA
Feedback Line-Regulation Error		$V_{IN} = 3.5\text{V to } 36\text{V}, V_{FB} = 1\text{V}$	0.01		$\%/V$
Transconductance (from FB to COMP)	$g_{m,EA}$	$V_{FB} = 1\text{V}, V_{BIAS} = 5\text{V}$	220	500	650
					μS

$$A_{v_{\text{shunt}}} = 4$$

$$A_{v_{\text{series}}} = 4$$

-44% variation from nominal

+50% variation from nominal

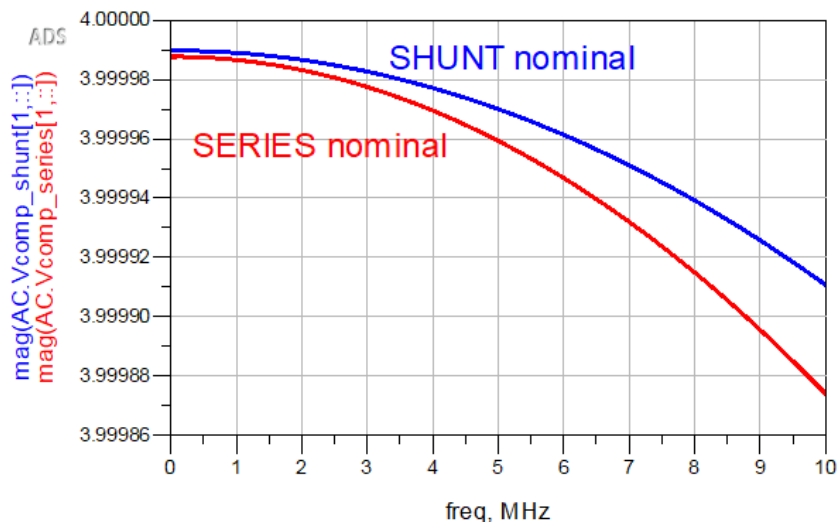


CASE 5 - MAX20098 Error Amplifier Vcomp Output

Gain Sensitivity & Linear Distortion – Shunt vs. Series Feedback

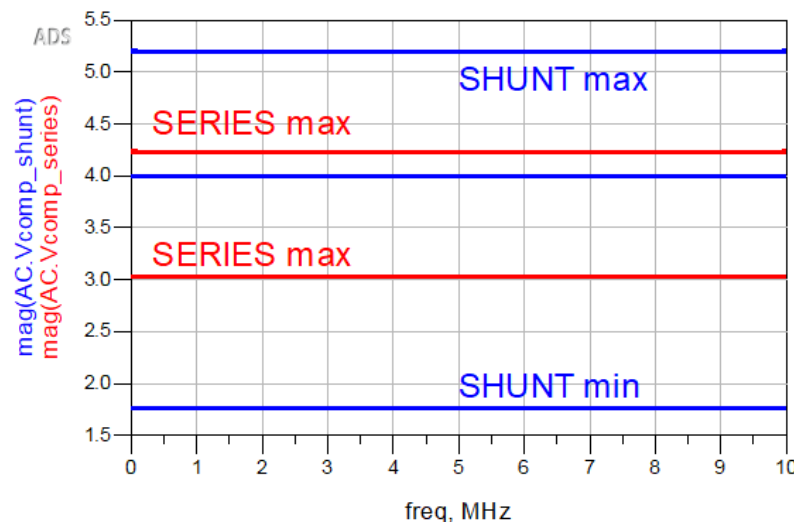
MAX20098 VRM

Nominal Error Amp Output



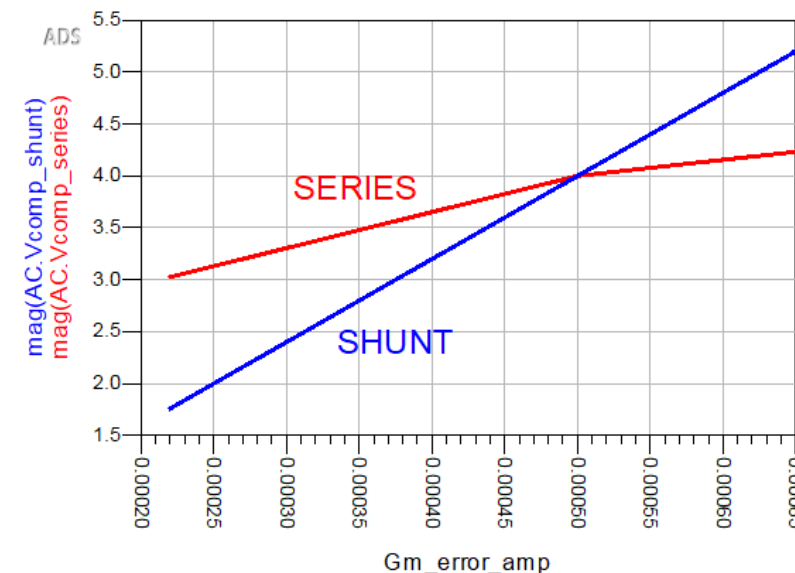
MAX20098 VRM

Min/Max Error Amp Gain Glope: Series vs. Shunt



MAX20098 VRM

Sensitivity to G_erroramp: Series vs Shunt



This validates there is significantly greater sensitivity with shunt feedback

Series feedback is less sensitive to gain variation and exhibits less linear distortion

Case Study using the Sandler State-Space Average Model

VRM Output Impedance and Stability Analysis

Shunt vs. Series Feedback Compensation

	VRM MPN	MFG	VRM Type	Compensation
CASE 1	ADP2389	Analog Devices	Current Mode	External
CASE 2	ISL8026	Renesas/Intersil	Current Mode	External or Internal**
CASE 3	LM20143	Texas Instruments	Current Mode	External
CASE 4	TPS7H4003*	Texas Instruments	Current Mode	External
CASE 5	MAX20098	Maxim	Current Mode	External

Notes:

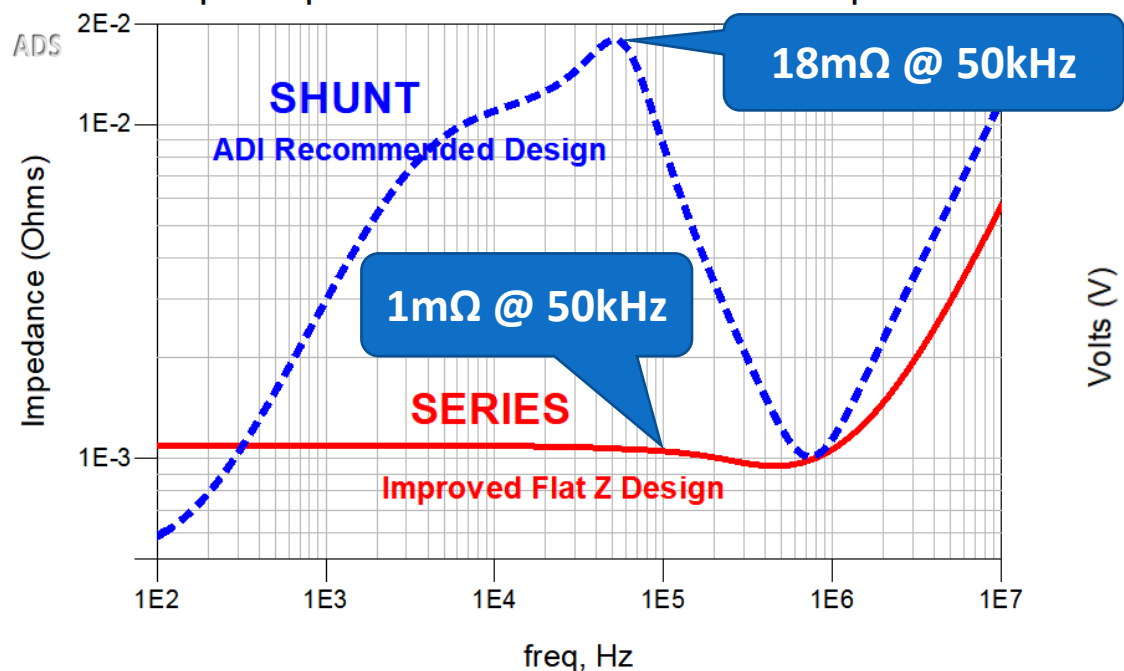
*Radiation-tolerant, designed for Space applications

**Internal compensation is set based on specific pin configuration. This EVAL used external compensation for this case study

CASE 1 - ADP2389 Output Impedance & Step Load Response Shunt vs. Series Compensation

ADP2389 EVAL

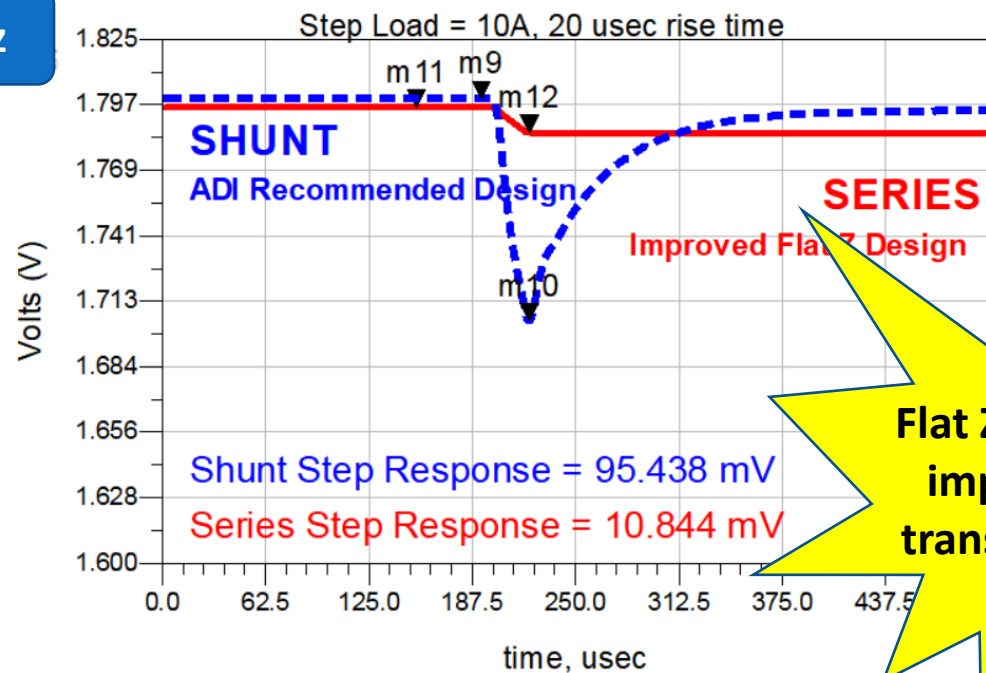
VRM Output Impedance - Shunt vs. Series Compensation



$$R_{\text{series}} = 2.3\text{M}\Omega$$

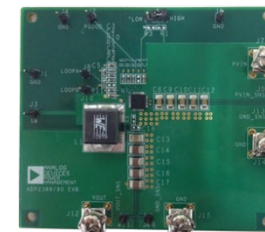
ADP2389 EVAL

VRM Step Load Response - Shunt vs. Series Compensation

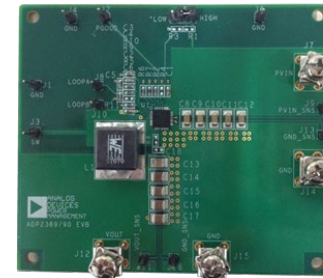


Flat Z means 88.6% improvement in transient response

Series compensation allows VRM output Z to be flat -> Better Transient Response

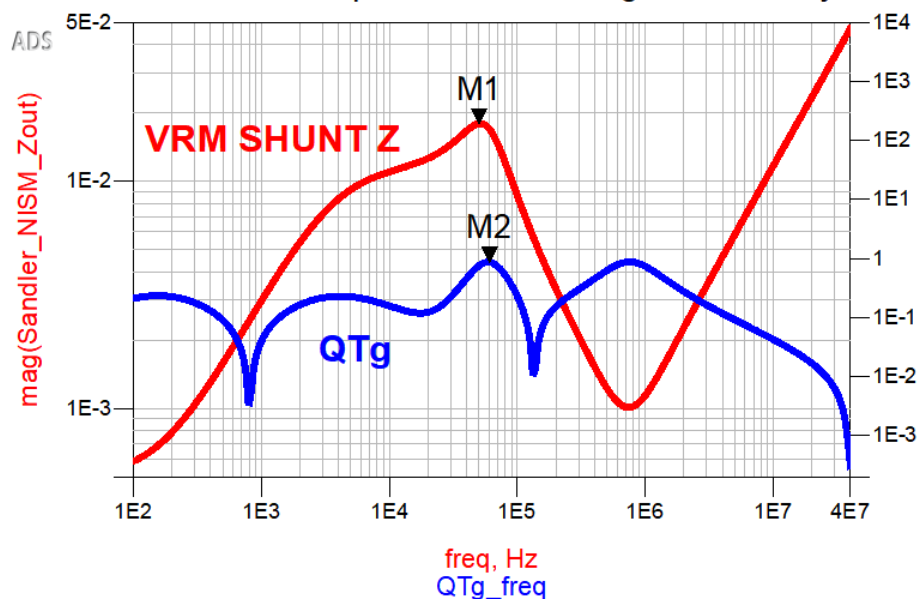


CASE 1 - ADP2389 Stability Analysis with NISM Shunt vs. Series Compensation



ADP2389 EVAL

VRM Shunt Compensation Z vs. QTg - NISM Analysis

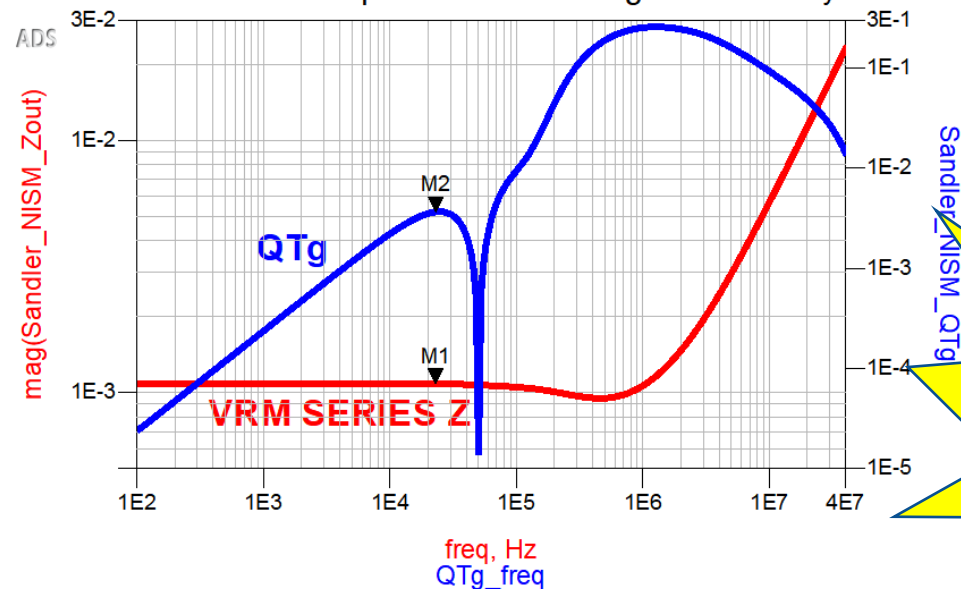


Sandler_NISM_PM: 56.988 degrees
Z Frequency: 50233.474 Hz
Q Frequency: 60398.011 Hz
Effective Q: 0.867

$$R_{\text{series}} = 2.3\text{M}\Omega$$

ADP2389 EVAL

VRM Series Compensation Z vs. QTg - NISM Analysis



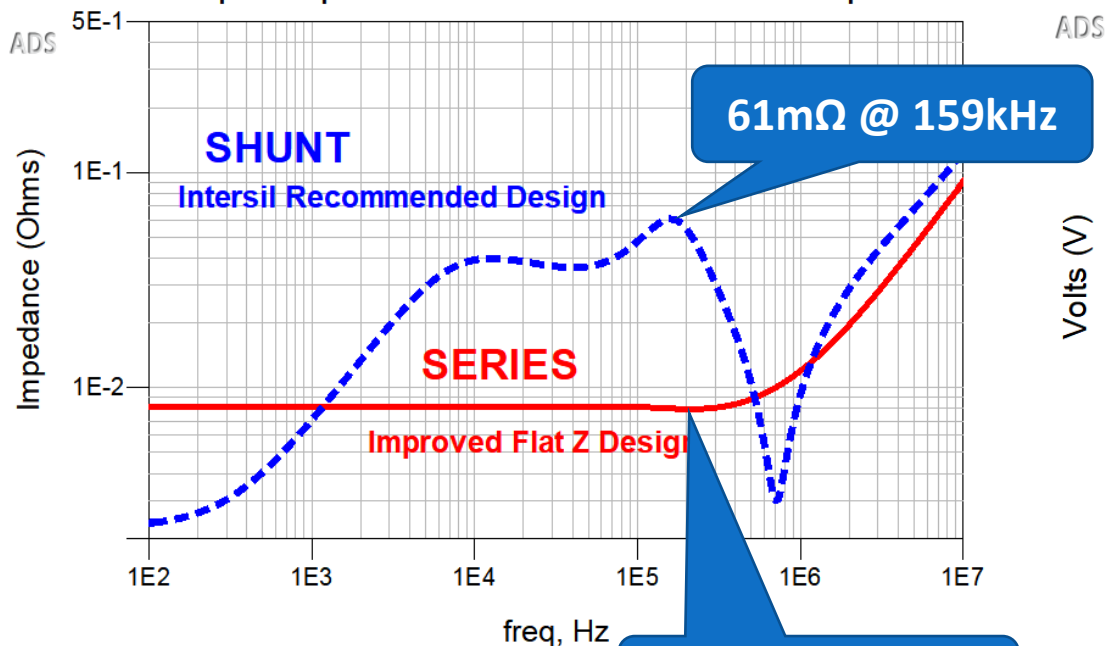
Sandler_NISM_PM: >71 degrees
Z Frequency: 22954.516 Hz
Q Frequency: 22954.516 Hz
Effective Q: 0.004

Flat Z means 99.5%
reduction of Q

CASE 2 - ISL8026 Output Impedance & Step Load Response Shunt vs. Series

ISL8026 EVAL

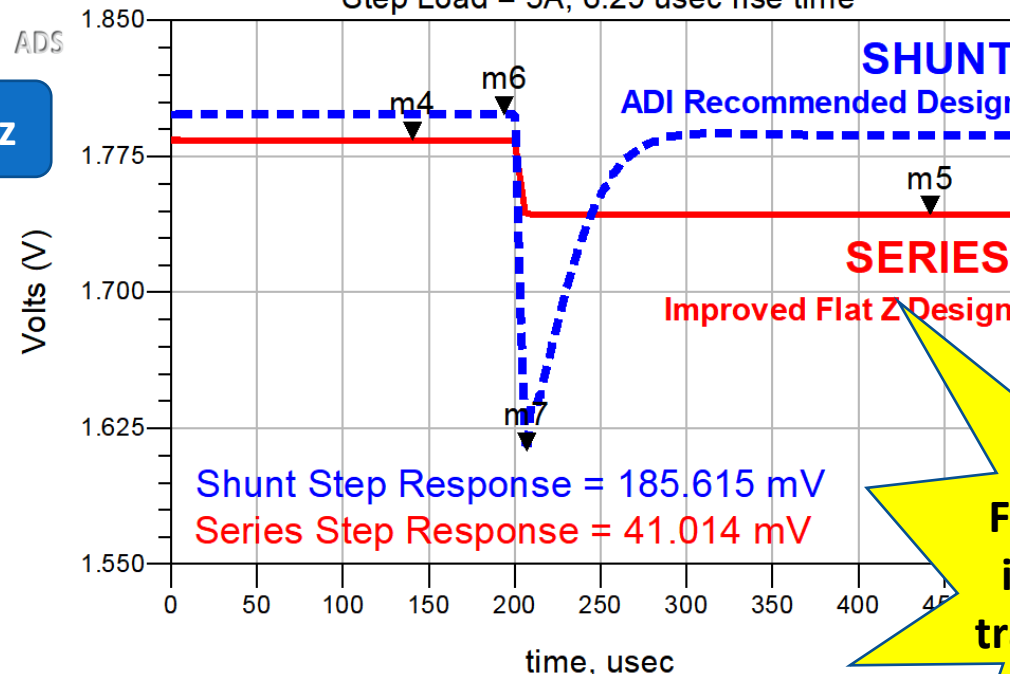
VRM Output Impedance - Shunt vs. Series Compensation



ISL8026 EVAL

VRM Step Load Response - Shunt vs. Series Compensation

Step Load = 5A, 6.29 usec rise time



Flat Z means 77% improvement in transient response

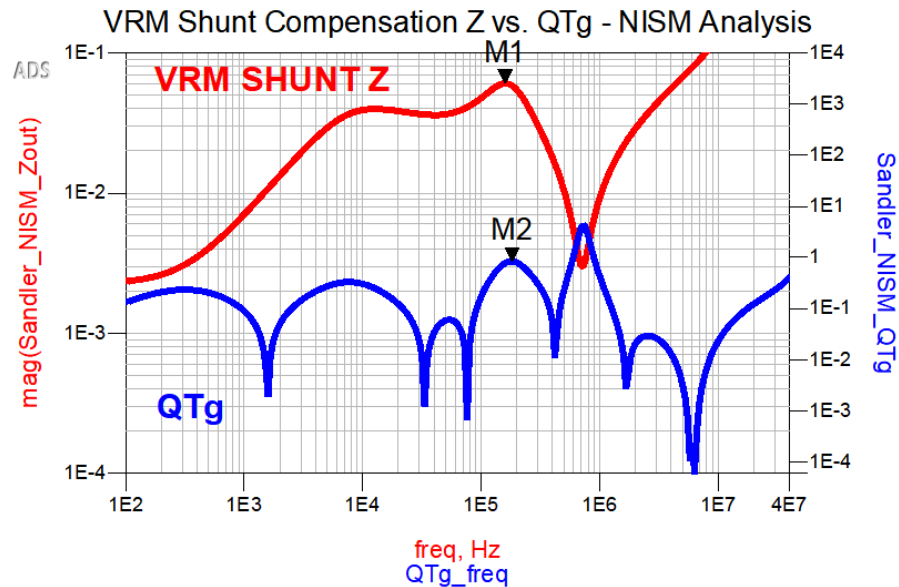


Series compensation allows VRM output Z to be flat -> Better Transient Response

CASE 2 - ISL8026 Stability Analysis with NISM

Shunt vs. Series

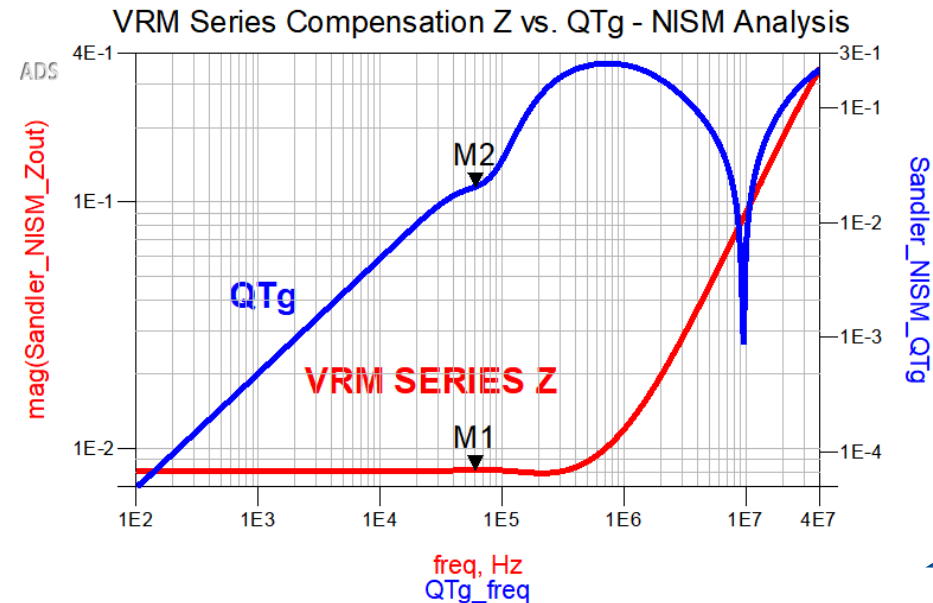
ISL8026 EVAL



Sandler_NISM_PM: 57.150 degrees
Z Frequency: 158919.481 Hz
Q Frequency: 182473.251 Hz
Effective Q: 0.836

$$R_{\text{series}} = 4\text{M}\Omega$$

ISL8026 EVAL



Sandler_NISM_PM: >71 degrees
Z Frequency: 60398.011 Hz
Q Frequency: 60398.011 Hz
Effective Q: 0.021



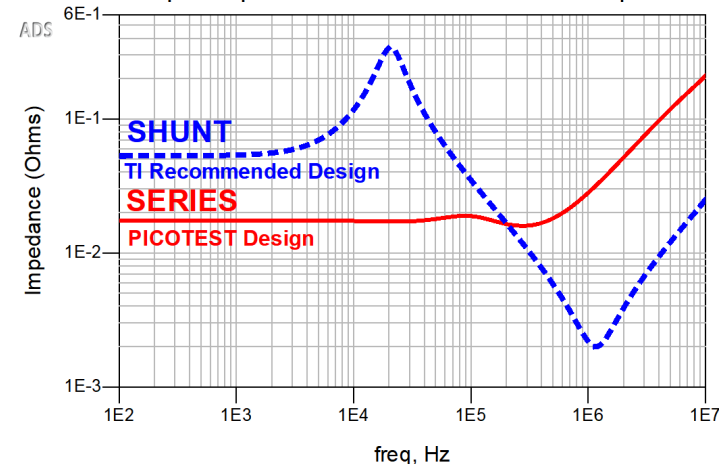
**Flat Z means 97%
reduction of Q**

CASE 3 - LM20143 Output Impedance & Stability with NISM

Shunt vs. Series Compensation

LM20143 EVAL

VRM Output Impedance - Shunt vs. Series Compensation

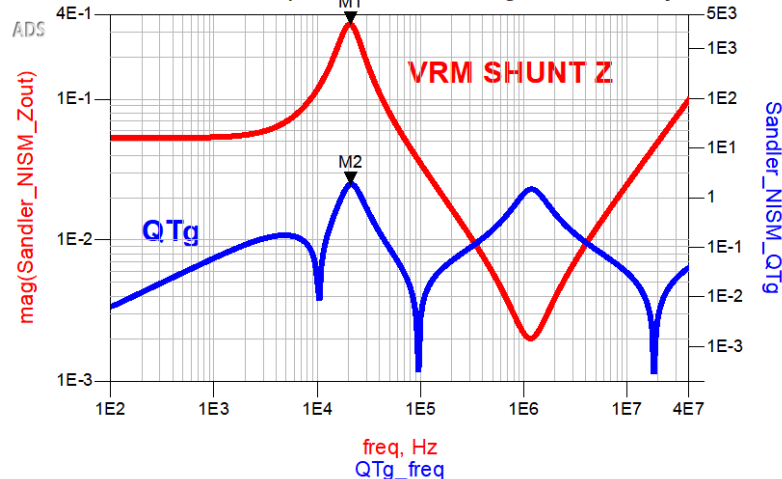


$$R_{\text{series}} = 48.7\text{k}\Omega$$



LM20143 EVAL

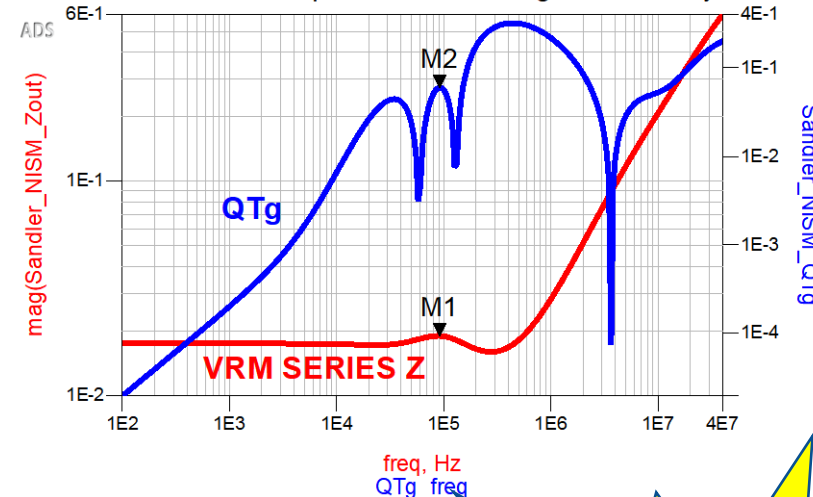
VRM Shunt Compensation Z vs. QTg - NISM Analysis



Sandler_NISM_PM: 27.890 degrees
Z Frequency: 20934.058 Hz
Q Frequency: 20934.058 Hz
Effective Q: 1.869

LM20143 EVAL

VRM Series Compensation Z vs. QTg - NISM Analysis



Sandler_NISM_PM: >71 degrees
Z Frequency: 91430.028 Hz
Q Frequency: 91430.028 Hz
Effective Q: 0.060

Flat Z means 96.7%
reduction of Q

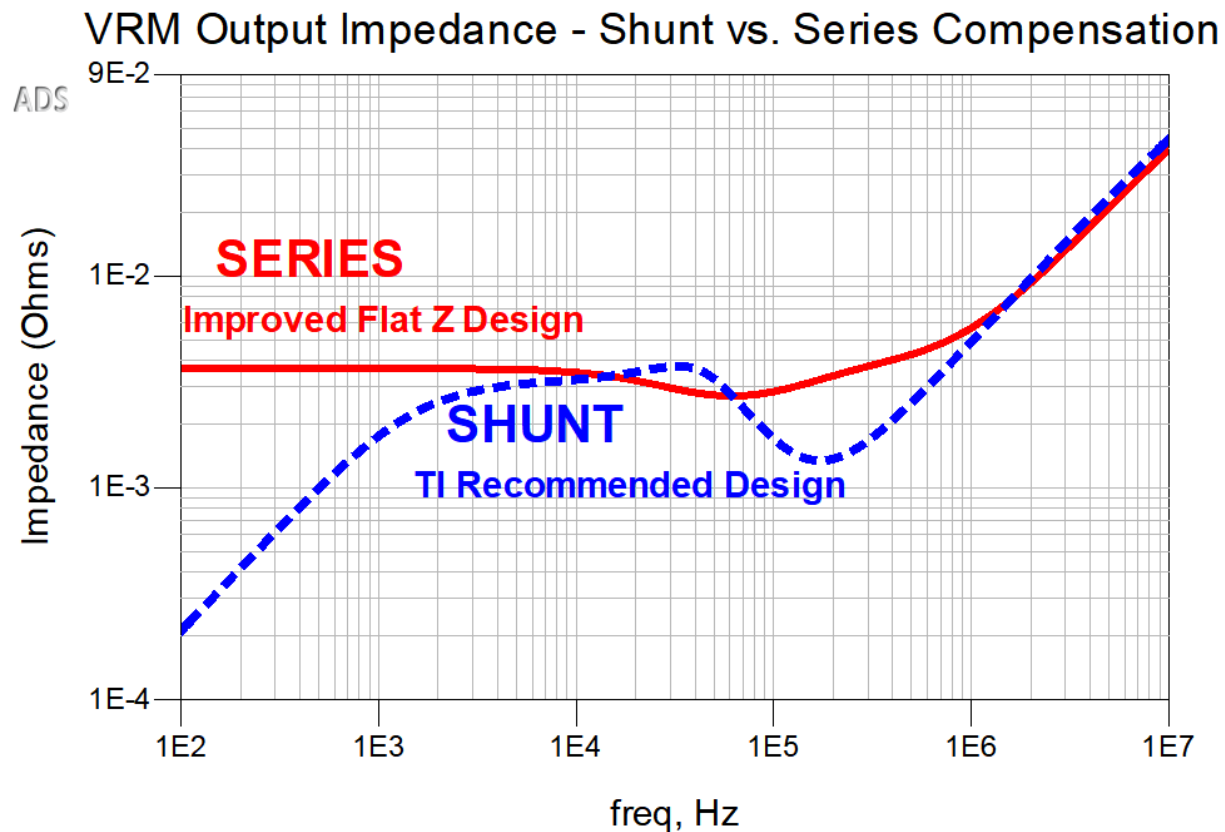
Series compensation allows VRM output Z to be flat -> Better Transient Response

CASE 4 – TPS7H4003 Output Impedance Shunt vs. Series Compensation

TPS7H4003 EVAL



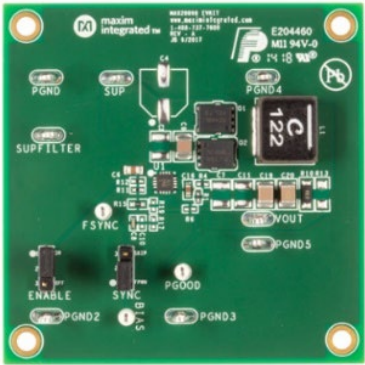
$$R_{\text{series}} = 70\text{k}\Omega$$



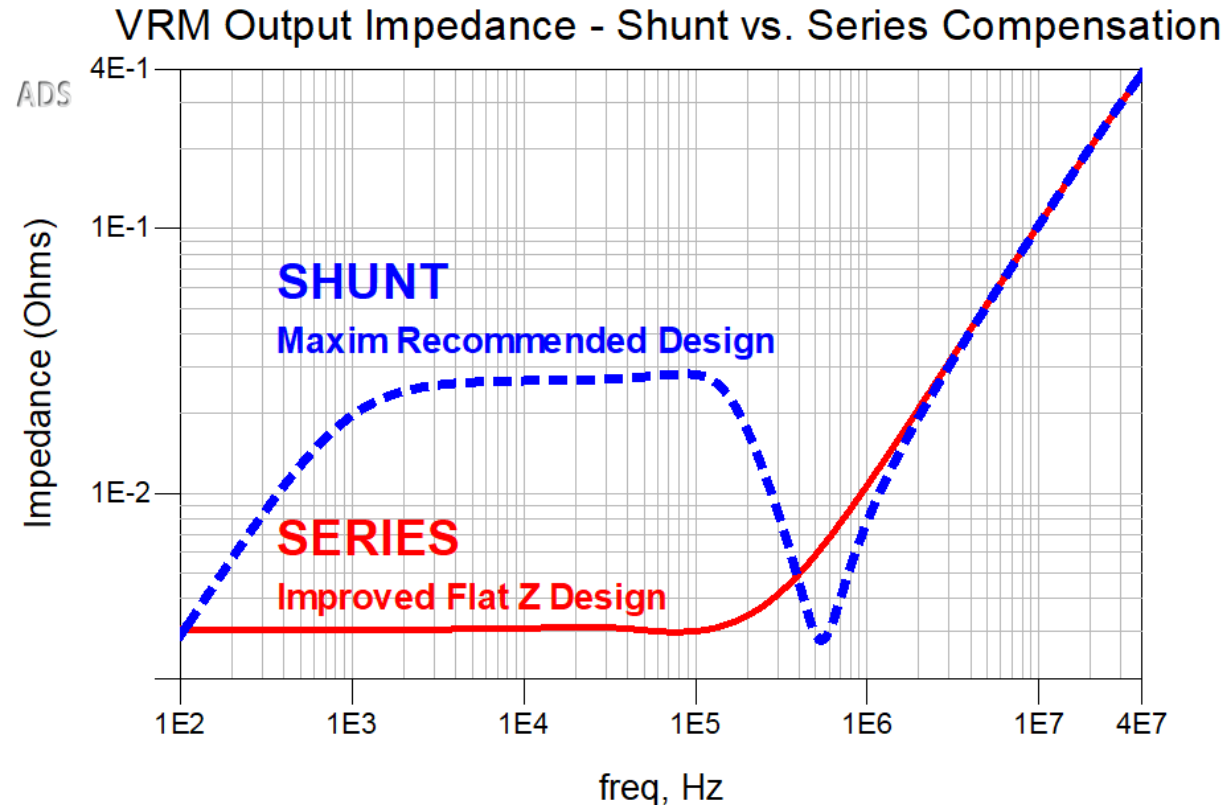
Series compensation allows VRM output Z to be flat -> Better Transient Response

CASE 5 - MAX20098 Output Impedance & Stability with NISM Shunt vs. Series Compensation

MAX20098 EVAL



$$R_{\text{series}} = 650 \text{ k}\Omega$$



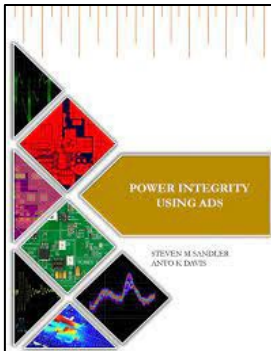
Series compensation allows VRM output Z to be flat -> Better Transient Response

Call to Action

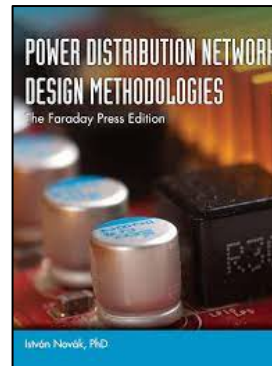
- VRM manufacturers need to provide designers the flexibility to choose between a shunt or series compensation
- Select Current Mode VRMs with the following:
 - Access to Vcomp
 - No internal compensation or at least the ability to disable the internal compensation
- Perfect regulation is a terrible thing.....
 - Because that means zero ohms.
- ***Flat VRM output impedance means better dynamic current response!***

Summary and Conclusions

- Series Compensation with a VRM design allows:
 - Better stability
 - Better transient response
 - Flatter VRM design
 - Reduced gain sensitivity
 - Ability to design the VRM to match the impedance of the load
- *Flatter VRM output impedance means better power delivery to your PDN*



“Power Integrity Using ADS”
by S. Sandler



“Power Distribution Network
Design Methodologies” by I. Novak



“Power Integrity Measuring, Optimizing, and
Troubleshooting Power Related Parameters in Electronics
Systems” by S. Sandler



Thank You for Attending

Feel Free to connect with us on LinkedIn

Join the Power Integrity for Distributed Systems LinkedIn Group

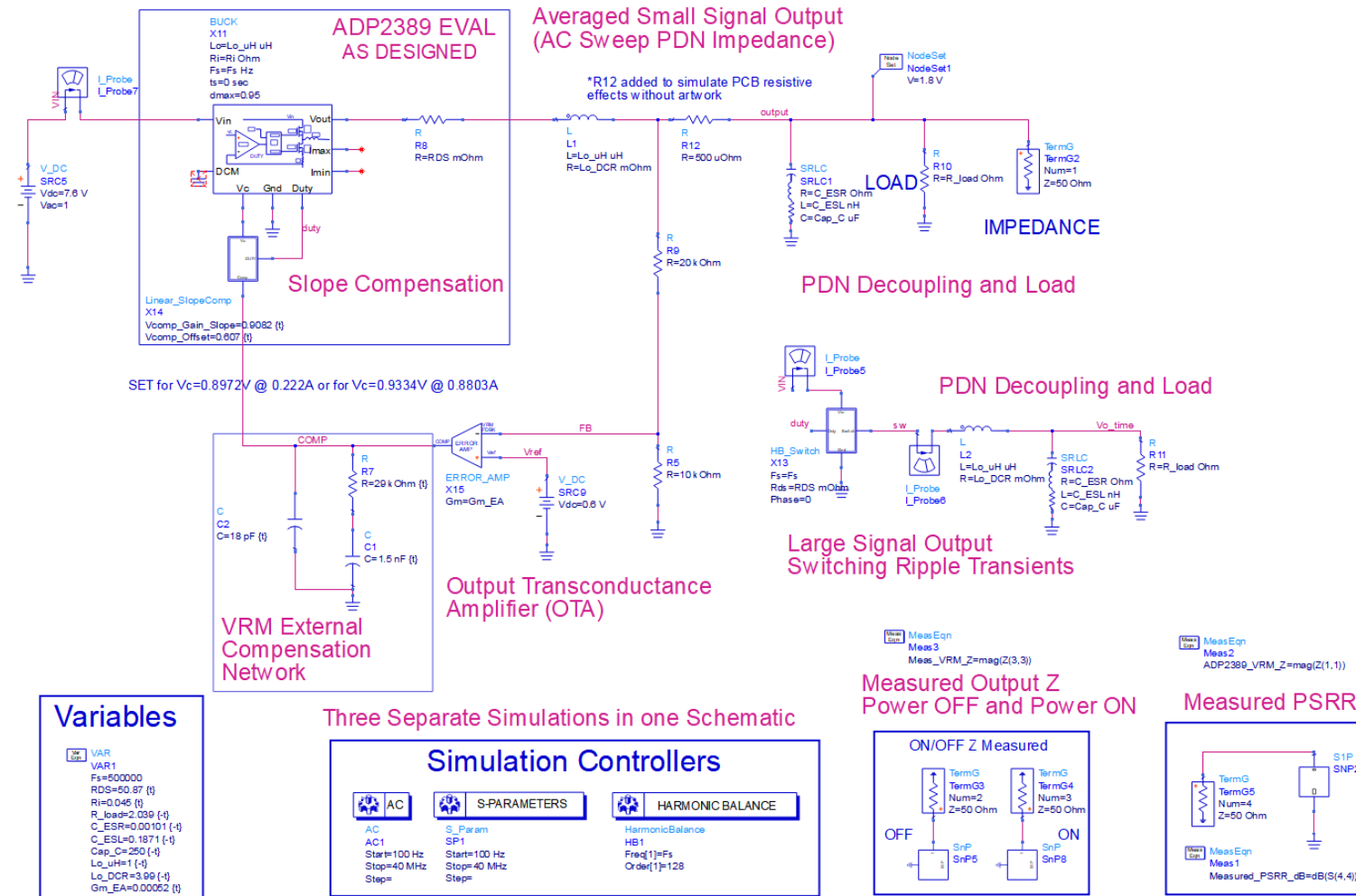


References

1. Sandler, S. (2018). Characterizing and Selecting the VRM. *Signal Integrity Journal*.
2. Sandler, S. M., & Davis, A. K. (2019). *Power Integrity Using Ads*. Faraday Press.
3. Picotest NISM page - <https://www.picotest.com/measurements/NISM.html>
4. Erickson, R. W., & Maksimović Dragan. (2012). *Fundamentals of Power Electronics*. Springer Science + Business Media.
5. Franco, S. (2006). *Design with operational amplifiers and Analog Integrated Circuits*. McGraw-Hill.
6. Maniktala, S. (2012). *Switching power supplies A-Z, 2E*. Elsevier Science & Technology.
7. Novak, I. (2021). *Power Distribution Network Design Methodologies*. Faraday Press.
8. S. Sandler, “How to Design for Power Integrity” Keysight sponsored YouTube Video Series: <http://www.keysight.com/find/how-to-videos-for-pi>
9. Keysight PathWave ADS Site - <https://www.keysight.com/us/en/products/software/pathwave-design-software/pathwave-advanced-design-system.html>
10. Qiao, M., Parto, P., & Amirani, R. (2002, November 14). *Stabilizing Buck Converters with transconductance amplifiers*. EETimes. Retrieved September 4, 2022, from <https://www.eetimes.com/stabilizing-buck-converters-with-transconductance-amplifiers/>
11. Sandler, S. M. (2014). *Power integrity: Measuring, optimizing, and troubleshooting power related parameters in Electronics Systems*. McGraw Hill Education.

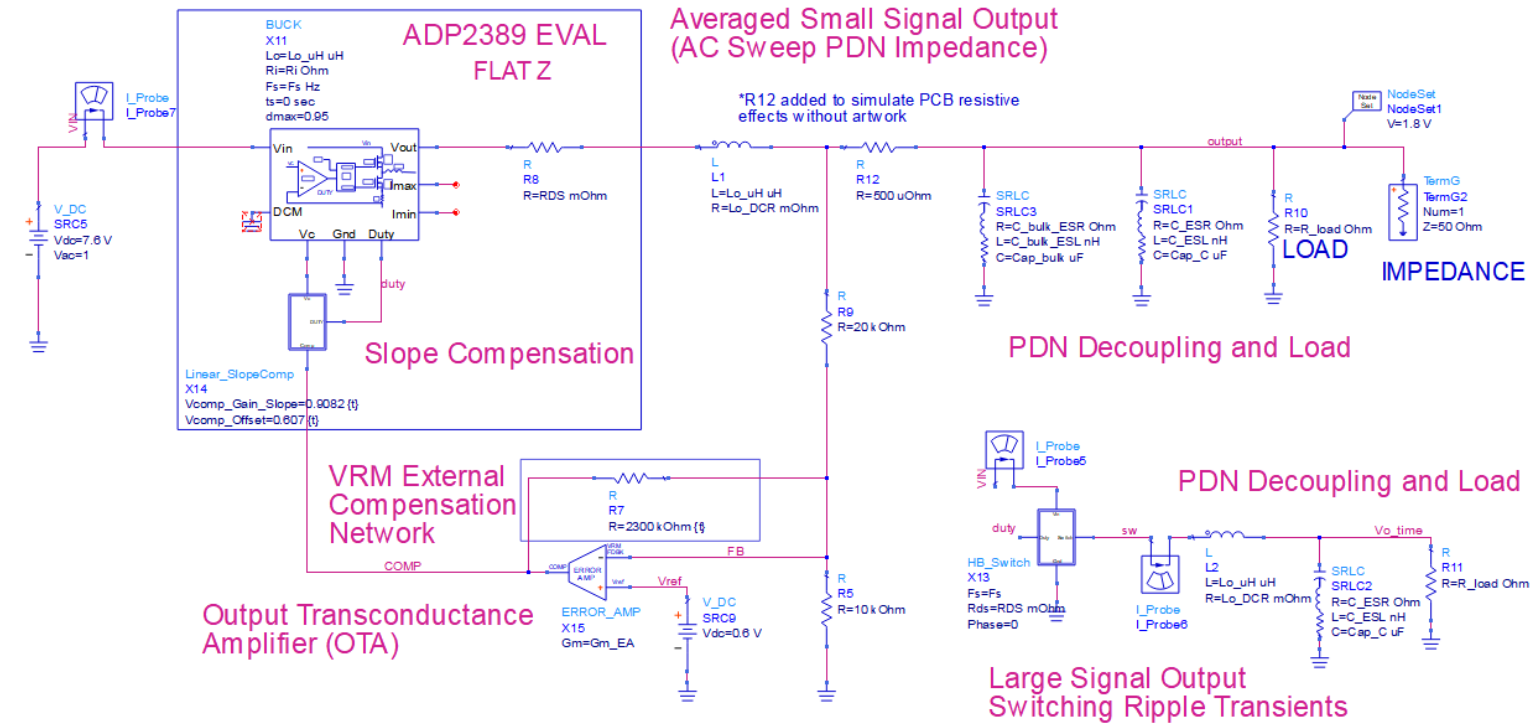
CASE 1 - ADP2389 EVAL - ADI Design

Shunt Compensation



CASE 1 - ADP2389 EVAL - Flat Z Design

Series Compensation



Variables

VAR VAR2	VAR VAR1
$C_{bulk_ESR} = 0.00141$ (t)	$F_s = 500000$
$C_{bulk_ESL} = 0.1871$ (t)	$RDS = 50.87$ (t)
$Cap_bulk = 1205.00057$ (t)	$R_l = 0.045$ (t)
	$R_{load} = 2.039$ (-t)
	$C_{ESR} = 0.00291$ (t)
	$C_{ESL} = 0.1871$ (t)
	$Cap_C = 205.00097$ (t)
	$L_{o_uH} = 1$ (-t)
	$L_{o_DCR} = 3.99$ (-t)
	$G_m_EA = 0.00052$ (t)

Three Separate Simulations in one Schematic

Simulation Controllers



AC
AC1
Start=100 Hz
Stop=40 MHz
Step=



S_Param
SP1
Start=100 Hz
Stop=40 MHz
Step=



HARMONIC BALANCE
HarmonicBalance
HB1
Freq[1]=F_s
Order[1]=128

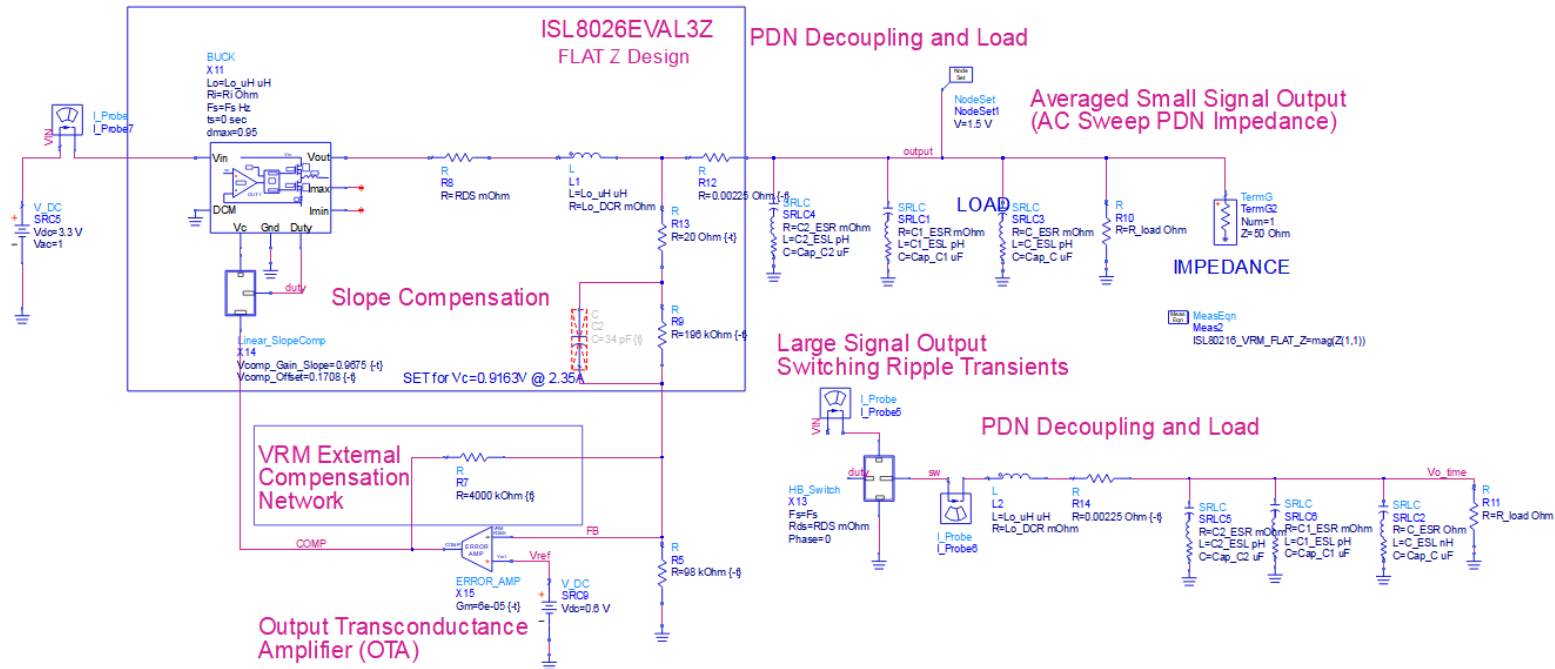
MeasEqn
Meas2
ADP2389_VRM_Flat_Z=mag(Z(1,1))



CASE 2 - ISL8026 EVAL – Flat Z Design

Series Compensation

Small Signal Hybrid State Based Averaged VRM Model
Including Discontinuous and Continuous Mode (DCM) Operation



Tuned Variables for Matching
VRM Model with Measurement

Variables	
VAR1 C1_ESR=30.0000085 (t) C1_ESL=5700 (t) Cap_C1=77.00023 (t)	VAR2 F=1000000 RDS=0.92 (-) Ri=0.09356 (-) R_load=0.736 (-) C_ESR=26.5000047 (t) C_ESL=3300.000034 (t) Cap_C=42.65 (t) Lo_uH=1 (t) Lo_DCR=6.9 (t)
VAR3 C2_ESR=22.0000089 (t) C2_ESL=6000 (t) Cap_C2=118.40026 (t)	

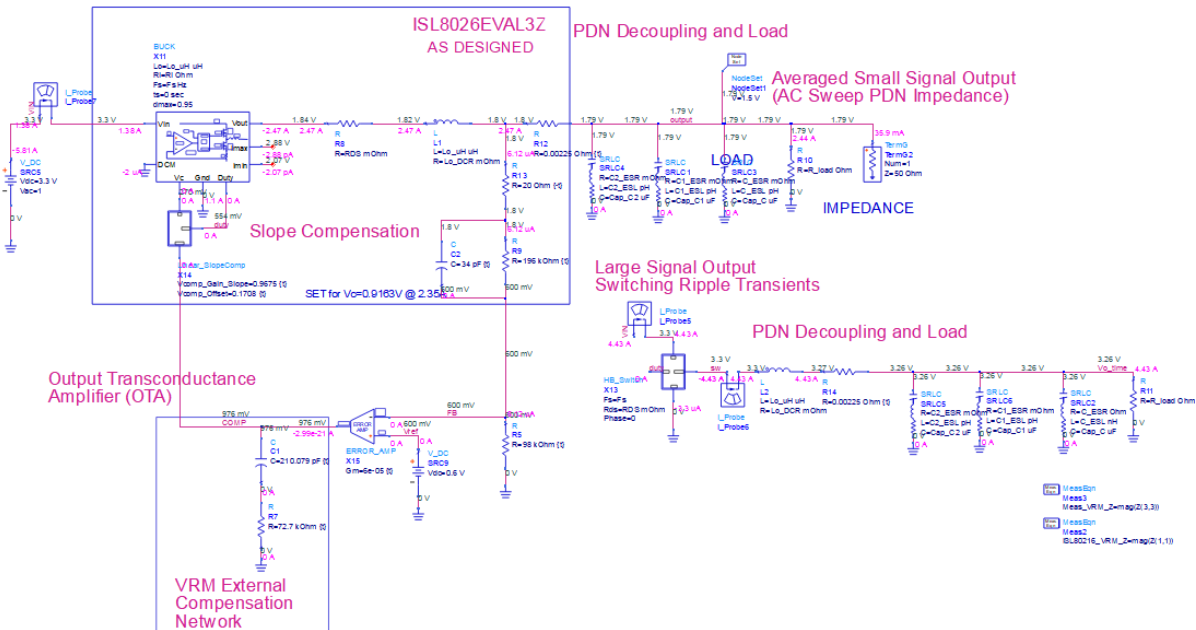
Three Separate Simulations in one Schematic

Simulation Controllers		
AC AC1 Start=100 Hz Stop=40 MHz Steps	S-PARAMETERS SP1 Start=100 Hz Stop=40 MHz Steps	HARMONIC BALANCE HarmoniBalance HB1 Freq(f)=Fs Order(1)=128

CASE 2 - ISL8026 EVAL – Intersil Design

Shunt Compensation

Small Signal Hybrid State Based Averaged VRM Model Including Discontinuous and Continuous Mode (DCM) Operation



Tuned Variables for Matching VRM Model with Measurement

Variables

VAR

VAR2

C1_ESR=95.5000052 (s)

C1_ESR=5700 (s)

Cap_C1=0.0010000000000000048 (s)

VAR

VAR1

F=1000000

RD=8.92 (s)

R=0.03950 (s)

R_Loss=0.738 (s)

C_ESR=3.00000075 (s)

C_ESR=3000.00005 (s)

Cap_C=16.64 (s)

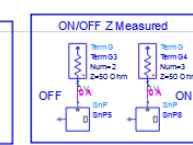
Lo_H=1 (s)

Lo_L=4W6.9 (s)

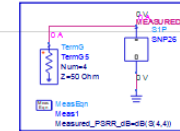
Three Separate Simulations in one Schematic



Measured Output Z
Power OFF and Power ON

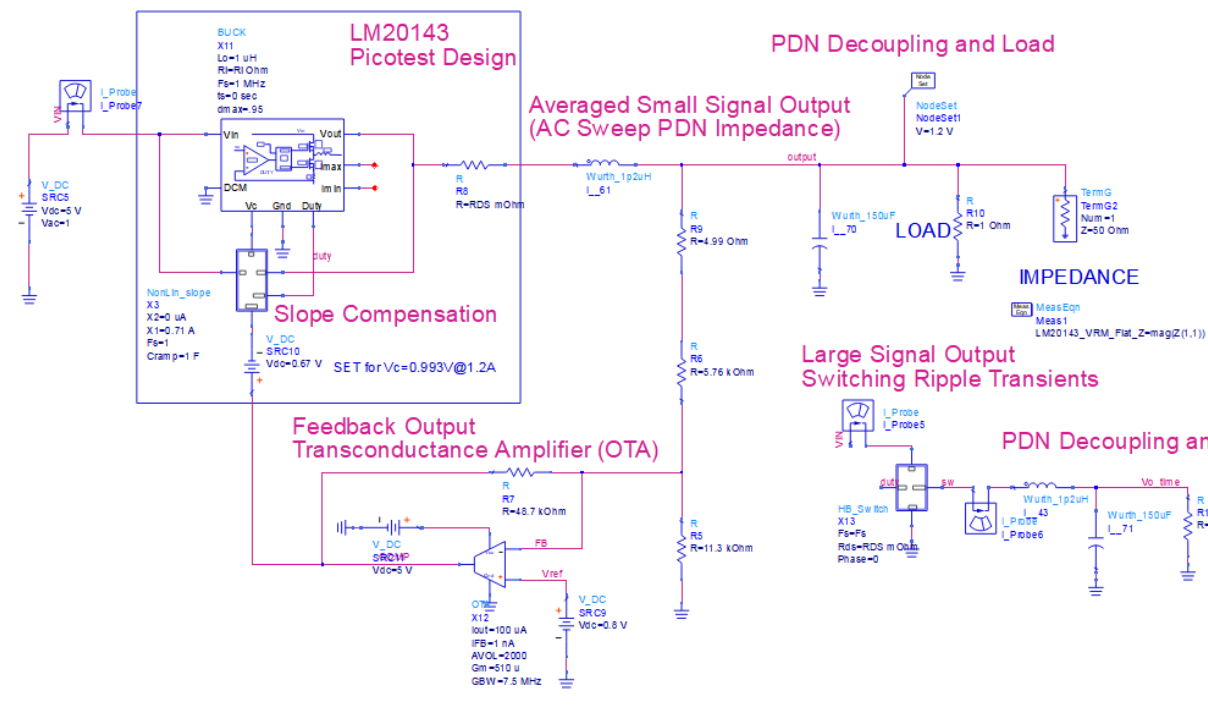


Measured Power Supply Rejection Ratio

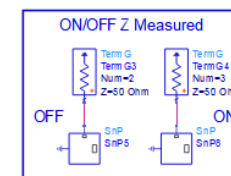


CASE 3 - LM20143 – Picotest Design

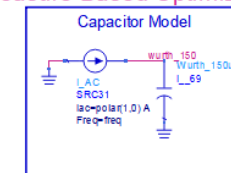
Series Compensation



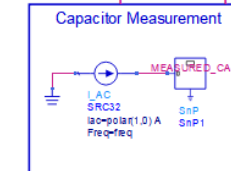
Measured Output Z Power OFF and Power ON



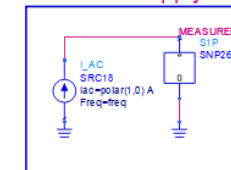
Capacitor RLC Model Measure Based Optimization



Measured Capacitor Impedance



Measured Power Supply Rejection Ratio



Tuned Variables for Matching VRM Model with Measurement

Variables

VAR
VAR1
F=1000000
RDS=33
R1=0.0835 Ohm

Three Separate Simulations in one Schematic

Simulation Controllers

AC
AC1
Start=100 Hz
Stop=40 MHz
Step=

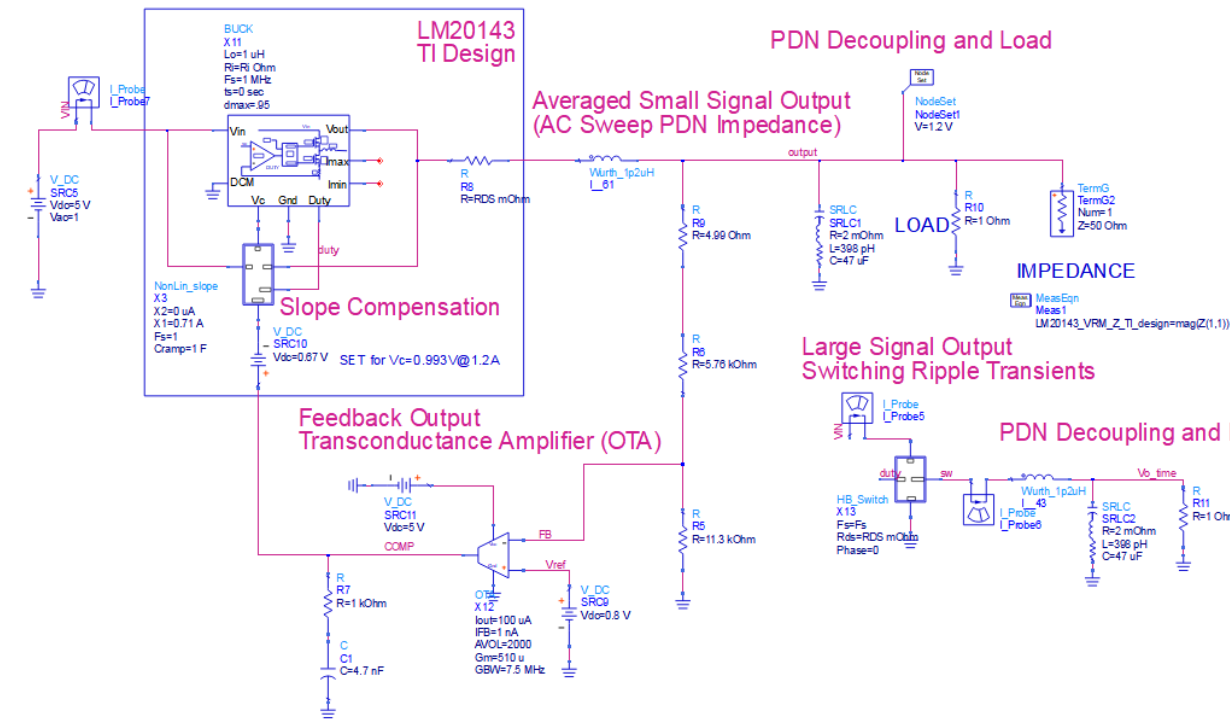
S-PARAMETERS
SP1
Start=100 Hz
Stop=10 MHz
Step=

HARMONIC BALANCE
HB1
Freq[1]=F0
Order[1]=128

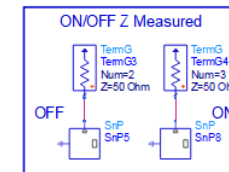


CASE 3 - LM20143 – TI Design

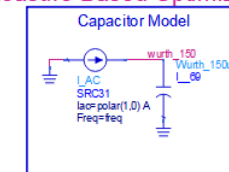
Shunt Compensation



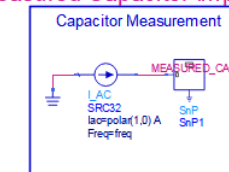
Measured Output Z
Power OFF and Power ON



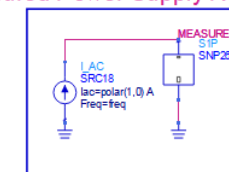
Capacitor RLC Model
Measure Based Optimization



Measured Capacitor Impedance



Measured Power Supply Rejection Ratio



Tuned Variables for Matching
VRM Model with Measurement

Variables

VAR1
F=1000000
RDS=33
R=0.08835 (Ω)

Three Separate Simulations in one Schematic

Simulation Controllers

AC
AC1
Start=100 Hz
Stop=40 MHz
Step=

S-PARAMETERS
S Param
SP1
Start=100 Hz
Stop=40 MHz
Step=

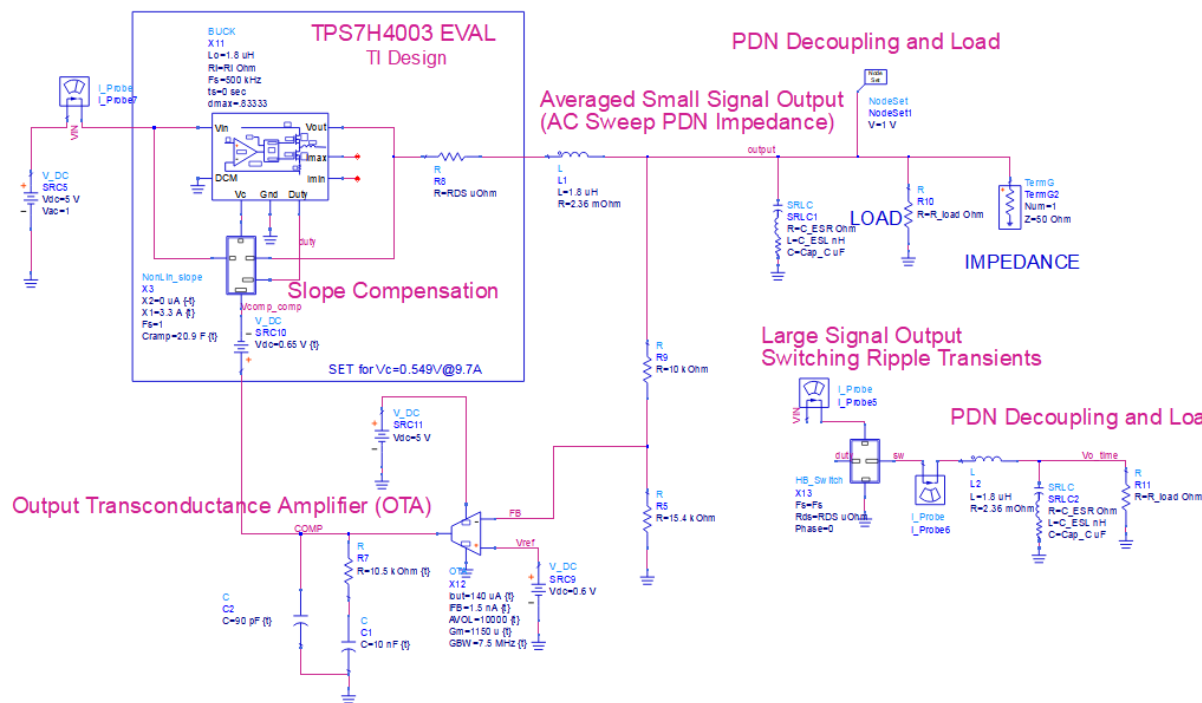
HARMONIC BALANCE
HarmonicBalance
HB1
Freq[1]=Fs
Order[1]=128



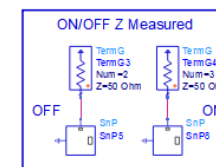
CASE 4 - TPS7H4003 EVAL – TI Design

Shunt Compensation

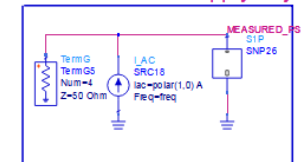
Small Signal Hybrid State Based Averaged VRM Model
Including Discontinuous and Continuous Mode (DCM) Operation



Measured Output Z
Power OFF and Power ON



Measured Power Supply Rejection Ratio



Tuned Variables for Matching
VRM Model with Measurement

Variables
VAR1
Fs=500000
RDS=125 (Ω)
R10=0.023 (Ω)
R11=0.101 (Ω)
C_ESR=0.00131 (F)
C_ESL=0.7811 (F)
Cap_C=1220 (F)

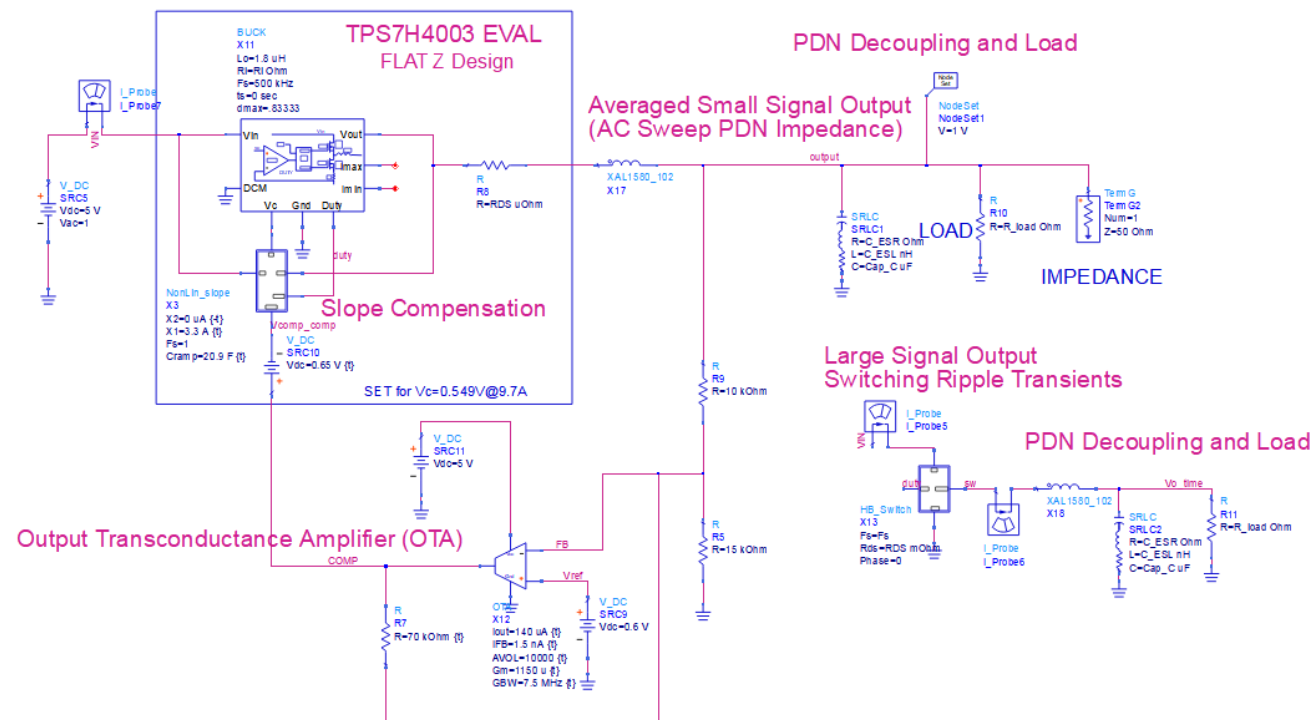
Three Separate Simulations in one Schematic



CASE 4 - TPS7H4003 EVAL – Flat Z Design

Series Compensation

Small Signal Hybrid State Based Averaged VRM Model
Including Discontinuous and Continuous Mode (DCM) Operation



Tuned Variables for Matching
VRM Model with Measurement

Variables

VAR
VAR1
F=500000
RDS=425 (Ω)
R=0.023 (Ω)
R_ESR=0.101 (Ω)
C_ESL=0.00411 (F)
C_ESL=0.7041 (F)
Cap_C=950 (F)

Three Separate Simulations in one Schematic

Simulation Controllers

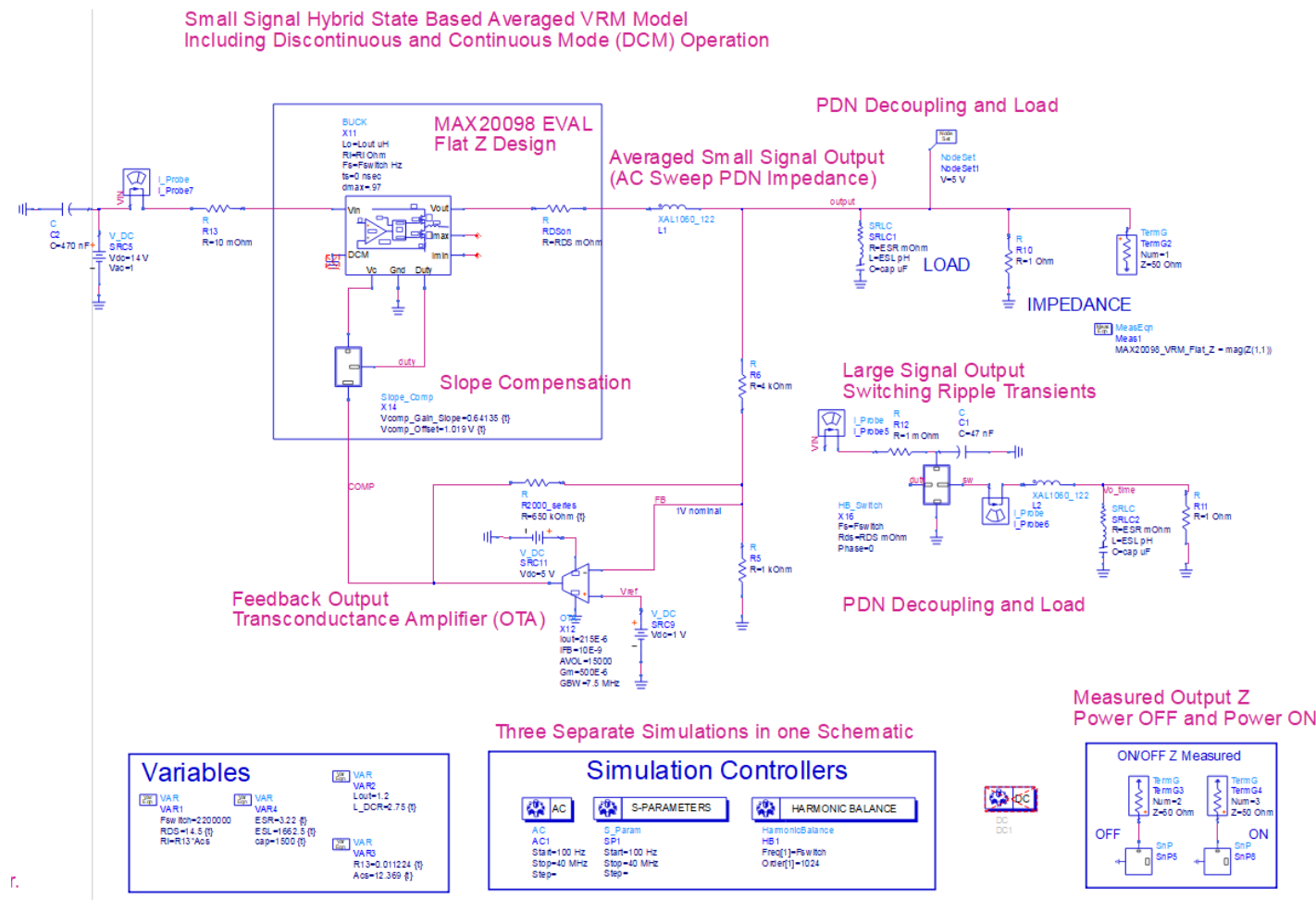
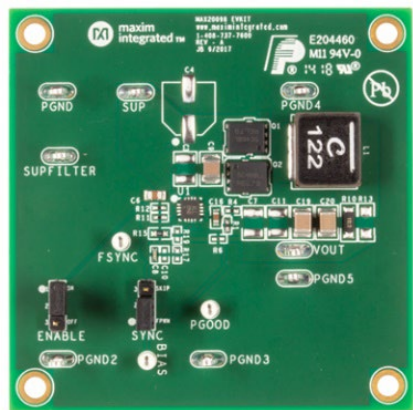
AC
AC1
Start=50 Hz
Stop=40 MHz
Step=

S-PARAMETERS
S_Param
SP1
Start=50 Hz
Stop=40 MHz
Step=

HARMONIC BALANCE
HarmonicBalance
HB1
Freq[1]=Fs
Order[1]=128

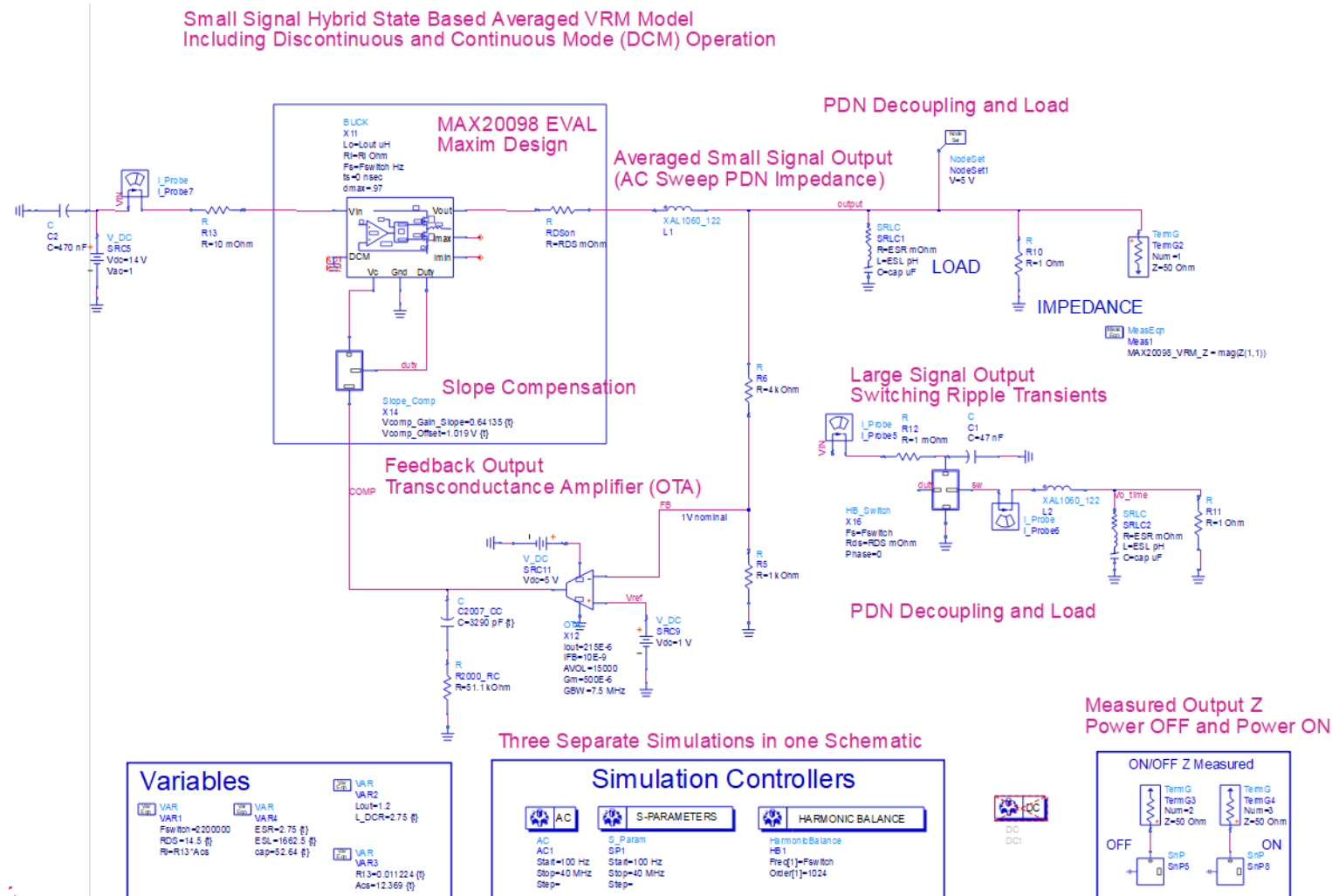
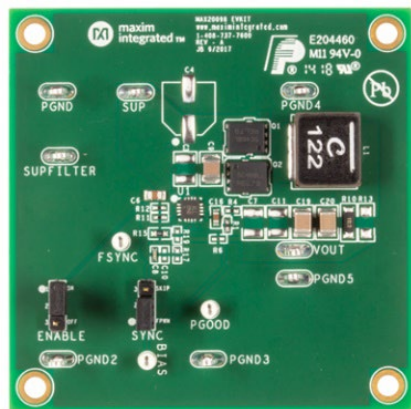
CASE 5 - MAX20098 – Flat Z Design

Series Compensation



CASE 5 - MAX20098 – MAXIM Design

Shunt Compensation





END OF SLIDES

