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NCP81143

Multiple-Phase Controller with SVID Interface for Desktop and Notebook CPU Applications

The NCP81143 Multi-Phase buck solution is optimized for Intel VR12.5 compatible CPUs with user configurations of 3/2/1 phases this controllers combines true differential voltage sensing, differential inductor DCR current sensing, input voltage feed-forward, and adaptive voltage positioning to provide accurately regulated power for both Desktop and Notebook applications. The control system is based on Dual-Edge pulse-width modulation (PWM) combined with DCR current sensing providing the fastest initial response to dynamic load events at reduced system cost. They have the capability to shed to single phase during light load operation and can auto frequency scale in light load conditions while maintaining excellent transient performance.

The NCP81143 offers two internal MOSFET drivers with a single external PWM signal. High performance operational error amplifiers are provided to simplify compensation of the system. Patented Dynamic Reference Injection further simplifies loop compensation by eliminating the need to compromise between closed-loop transient response and Dynamic VID performance. Patented Total Current Summing provides highly accurate digital current monitoring.

Features

- NCP81143 and Meets Intel® VR12.5 specifications
- Current Mode Dual Edge Modulation for Fastest Initial Response to Transient Loading
- High Performance Operational Error Amplifier
- Digital Soft Start Ramp
- Dynamic Reference Injection
- Accurate Total Summing Current Amplifier
- Dual High Impedance Differential Voltage and Total Current Sense Amplifiers
- Phase-to-Phase Dynamic Current Balancing
- “Lossless” DCR Current Sensing for Current Balancing
- True Differential Current Balancing Sense Amplifiers for Each Phase
- Adaptive Voltage Positioning (AVP)
- Switching Frequency Range of 200 kHz –1 MHz
- Vin range 4.5 V to 25 V
- Startup into Pre-Charged Loads While Avoiding False OVP
- Power Saving Phase Shedding
- Vin Feed Forward Ramp Slope
- Pin Programming for Internal SVID parameters
- Over Voltage Protection (OVP) & Under Voltage Protection (UVP)
- Over Current Protection (OCP)
- VR-RDY Output with Internal Delays
- These are Pb-Free Devices

Applications

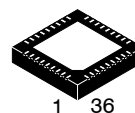
- Desktop & Notebook Processors



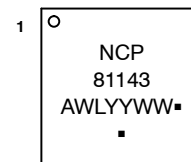
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MARKING DIAGRAM



QFN36
CASE 485CC



A = Assembly Location
WL = Wafer Lot
YY = Year
WW = Work Week
▪ = Pb-Free Package

(Note: Microdot may be in either location)

ORDERING INFORMATION

See detailed ordering and shipping information in the package dimensions section on page 33 of this data sheet.

NCP81143

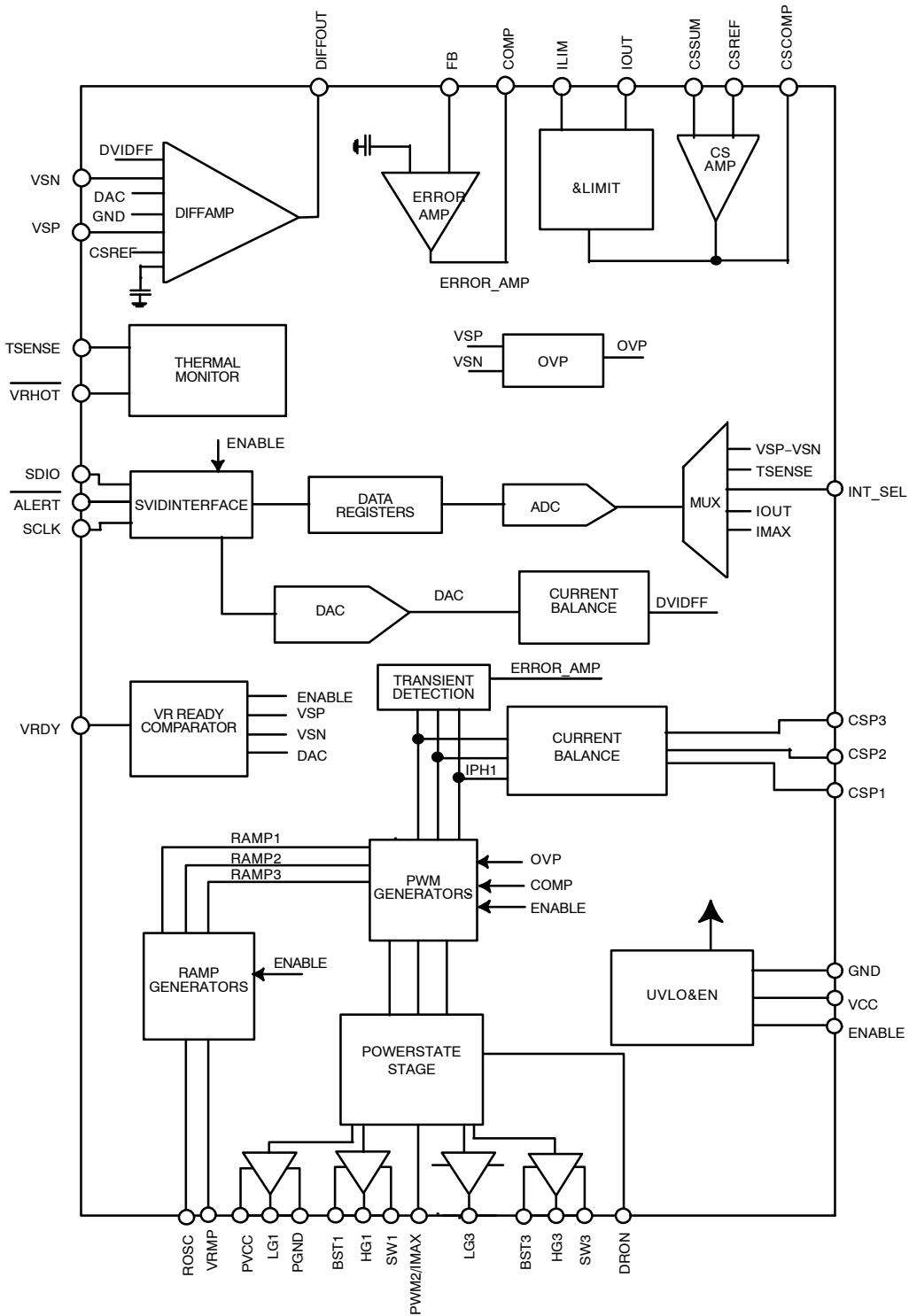


Figure 1. Block Diagram for NCP81143

NCP81143

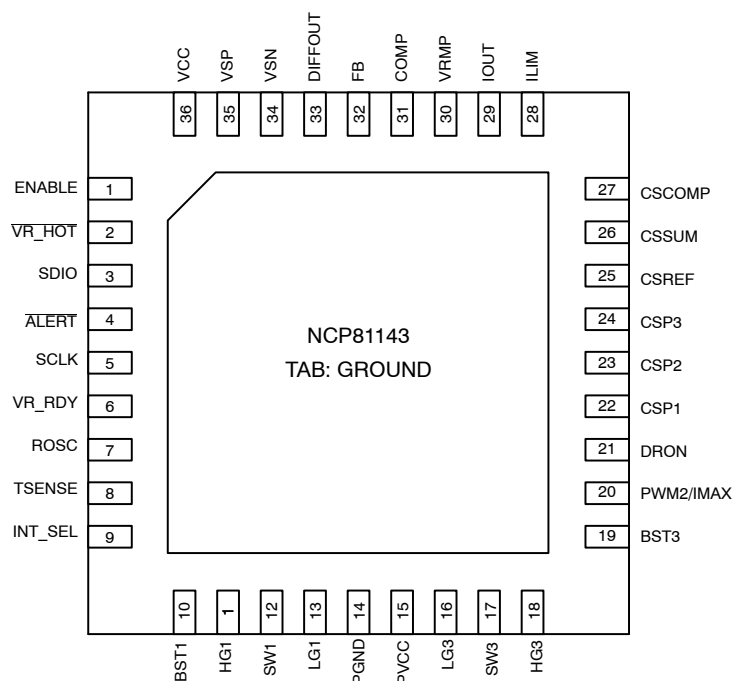


Figure 4. NCP81143 Pin Configuration

NCP81143 SINGLE ROW PIN DESCRIPTIONS

Pin No.	Symbol	Description
1	ENABLE	Logic input. Logic high enables both outputs and logic low disables both outputs
2	VR_HOT#	Thermal logic output for over temperature
3	SDIO	Serial VID data interface
4	ALERT#	Serial VID ALERT#.
5	SCLK	Serial VID clock
6	VR_RDY	Open drain output. High indicates that the output is regulating
7	ROSC	A resistance from this pin to ground programs the oscillator frequency
8	TSENSE	Temp Sense input for the multiphase converter
9	INT_SEL	An input pin to adjust programmable integrator setting. During start up it is used to program INT_SEL with a resistor to ground
10	BST1	High-Side bootstrap supply for phase 1.
11	HG1	High side gate driver output for phase 1
12	SW1	Current return for high side gate driver 1
13	LG1	Low-Side gate driver output for phase 1
14	PGND	Power Ground for gate drivers
15	PVCC	Power Supply for gate drivers
16	LG3	Low-Side gate driver output for phase 3
17	SW3	Current return for high side gate driver 3
18	HG3	High side gate driver output for phase 3
19	BST3	High-Side bootstrap supply for phase 3
20	PWM2/IMAX	Phase 2 PWM output. Also as ICC_MAX Input Pin. During start up it is used to program ICC_MAX with a resistor to ground
21	DRON	Bidirectional gate drive enable output

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NCP81143 SINGLE ROW PIN DESCRIPTIONS

Pin No.	Symbol	Description
22	CSP1	Non-inverting input to current balance sense amplifier for phase 1
23	CSP2	Non-inverting input to current balance sense amplifier for phase 2
24	CSP3	Non-inverting input to current balance sense amplifier for phase 3
25	CSREF	Total output current sense amplifier reference voltage input
26	CSSUM	Inverting input of total current sense amplifier
27	CSCOMP	Output of total current sense amplifier
28	ILIM	Over current shutdown threshold setting. Resistor to CSCOMP to set threshold
29	IOUT	Total output current monitor.
30	VRMP	Feed-forward input of V_{in} for the ramp slope compensation. The current fed into this pin is used to control the ramp of PWM slope
31	COMP	Output of the error amplifier and the inverting inputs of the PWM comparators
32	FB	Error amplifier voltage feedback
33	DIFFOUT	Output of the differential remote sense amplifier
3	VSN	Inverting input to differential remote sense amplifier
35	VSP	Non-inverting input to the differential remote sense amplifier
36	VCC	Power for the internal control circuits. A decoupling capacitor is connected from this pin to ground
37	FLAG /GND	Analog Ground

NCP81143

ABSOLUTE MAXIMUM RATINGS

ELECTRICAL INFORMATION

Pin Symbol	V _{MAX}	V _{MIN}
COMP	V _{CC} + 0.3 V	-0.3 V
CSCOMP	V _{CC} + 0.3 V	-0.3 V
VSN	GND + 300 mV	GND - 300 mV
DIFFOUT	V _{CC} + 0.3 V	-0.3 V
VR_RDY	V _{CC} + 0.3 V	-0.3 V
VCC	6.5 V	-0.3 V
ROSC	V _{CC} + 0.3 V	-0.3 V
IOUT	2.0 V	-0.3 V
VRMP	+25 V	-0.3 V
SW	35 V 40 V ≤ 50 ns	-5 V -10 V ≤ 200 ns
BST	35 V wrt/ GND 40 V ≤ 50 ns wrt/GND 6.5 V wrt/ SW	-0.3 V wrt/SW
LG	V _{CC} + 0.3 V	-0.3 V -5 V ≤ 200 ns
HG	BST + 0.3 V	-0.3 V wrt/ SW -2 V ≤ 200 ns wrt/SW
All Other Pins	V _{CC} + 0.3 V	-0.3 V

*All signals referenced to GND unless noted otherwise.

THERMAL INFORMATION

Description	Symbol	Typ	Unit
Thermal Characteristic QFN Package (Note 1)	R _{θJA}	68	°C/W
Operating Junction Temperature Range (Note 2)	T _J	-10 to +125	°C
Operating Ambient Temperature Range		-40 to +125	°C
Maximum Storage Temperature Range	T _{STG}	- 40 to +150	°C
Moisture Sensitivity Level QFN Package	MSL	1	

*The maximum package power dissipation must be observed.

1. JESD 51-5 (1S2P Direct-Attach Method) with 0 LFM
2. JESD 51-7 (1S2P Direct-Attach Method) with 0 LFM

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NCP81143 ELECTRICAL CHARACTERISTICS

Unless otherwise stated: $-40^{\circ}\text{C} < T_A < 125^{\circ}\text{C}$; $V_{CC} = 5\text{ V}$; $C_{VCC} = 0.1\ \mu\text{F}$

Parameter	Test Conditions	Min	Typ	Max	Unit
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ERROR AMPLIFIER

Input Bias Current	@ 1.3 V	-400		400	nA
Open Loop DC Gain	CL = 20 pF to GND, RL = 10 k Ω to GND		80		dB
Open Loop Unity Gain Bandwidth	CL = 20 pF to GND, RL = 10 k Ω to GND		20		MHz
Slew Rate	$\Delta V_{in} = 100\text{ mV}$, $G = -10\text{ V/V}$, $\Delta V_{out} = 1.5\text{ V} - 2.5\text{ V}$, CL = 20 pF to GND, DC Load = 10k to GND		20		V/ μs
Maximum Output Voltage	I _{SOURCE} = 2.0 mA	3.5			V
Minimum Output Voltage	I _{SINK} = 2.0 mA			1	V

DIFFERENTIAL SUMMING AMPLIFIER

Input Bias Current	VSP, VSN = 1.3 V	-25		25	μA
VSP Input Voltage Range		-0.3		3.0	V
VSN Input Voltage Range		-0.3		0.3	V
-3dB Bandwidth	CL = 20 pF to GND, RL = 10 k Ω to GND		10		MHz
Closed Loop DC gain	VS+ to VS- = 0.5 to 1.3 V		1.0		V/V

CURRENT SUMMING AMPLIFIER

Offset Voltage (V _{os}), (Note 3)		-300		300	μV
Input Bias Current	CSSUM = CSREF = 1 V	-5		5	μA
Open Loop Gain			80		dB
Current Sense Unity Gain Bandwidth	C _L = 20 pF to GND, R _L = 10 k Ω to GND		10		MHz

CURRENT BALANCE AMPLIFIER

Maximum CSCOMP Output Voltage	I _{SOURCE} = 2 mA	3.5			V
Minimum CSCOMP Output Voltage	I _{SINK} = 500 μA			0.1	V
Input Bias Current	CSP ₁₋₃ = CSREF = 1.2	-50		50	nA
Common Mode Input Voltage Range	CSP _x = CSREF	0		2.3	V
Differential Mode Input Voltage Range	CSREF = 1.2 V	-100		100	mV
Input Offset Voltage Matching	CSP _x = CSREF = 1.2 V, Measured from the average	-1.5		1.5	mV
Current Sense Amplifier Gain	0 V < CSP _x - CSREF < 0.1 V,	5.7	6.0	6.3	V/V
Multiphase Current Sense Gain Matching	CSREF = CSP = 10 mV to 30 mV	-3		3	%
-3dB Bandwidth			8		MHz

INPUT SUPPLY

Supply Voltage Range		4.75		5.25	V
VCC Quiescent Current	EN = high, PS0,1,2 Mode		20		mA
	EN = high, PS3 Mode		11		mA
	EN = low		50		μA
UVLO Threshold	VCC rising			4.5	V
	VCC falling	4			V
VCC UVLO Hysteresis			160		mV

3. Guaranteed by design or characterization data, not in production test.

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NCP81143 ELECTRICAL CHARACTERISTICS

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Parameter	Test Conditions	Min	Typ	Max	Unit
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INPUT SUPPLY

UVLO Threshold	VRMP Rising			4.25	V
	VRMP Falling	3			V

DAC SLEW RATE

Soft start slew rate			2.5		mv/ μs
Slew Rate Slow			2.5		mv/ μs
Slew Rate Fast			10		mv/ μs

ENABLE INPUT

Enable High Input Leakage Current	External 1k pull-up to 3.3 V			1.0	μA
Upper Threshold	V_{UPPER}	0.8			V
Lower Threshold	V_{LOWER}			0.3	V
Total Hysteresis	$V_{\text{UPPER}} - V_{\text{LOWER}}$		90		mV
Enable Delay Time	Measure time from Enable transitioning HI to when DRON goes high			2.5	ms

DRON

Output High Voltage	Sourcing 500 μA	3.0			V
Output Low Voltage	Sinking 500 μA			0.1	V
Rise Time	CL (PCB) = 20 pF, $\Delta V_o = 10\%$ to 90%		300		ns
Fall Time			10		
Internal Pull Down Resistance	EN = Low		70		k Ω

IOUT OUTPUT

Input Referred Offset Voltage	Ilimit to CSREF	-3.5		3.5	mV
Output Source Current	Ilimit sink current = 80 μA			850	μA
Current Gain	$(I_{\text{OUT CURRENT}}) / (I_{\text{LIMIT CURRENT}})$, $R_{\text{ILIM}} = 20\text{k}$, $R_{\text{IOUT}} = 5.0\text{k}$, DAC = 0.8 V, 1.25 V, 1.52 V	9.67	10	10.32	

OSCILLATOR

Switching Frequency Range		220		1000	KHz
3 Phase Operation				1000	kHz

OUTPUT OVER VOLTAGE & UNDER VOLTAGE PROTECTION (OVP & UVP)

Absolute Over Voltage Threshold During Soft Start	CSREF		2.9		V
Over Voltage Threshold Above DAC	VSP rising	350	400	425	mV
Over Voltage Delay	VSP rising to PWMx low		50		ns
Under Voltage	Ckt in development		300		mV
Under-voltage Delay	Ckt in development		5		μs

VR12.5 DAC

System Voltage Accuracy	$-40^{\circ}\text{C} - +125^{\circ}\text{C}$ $1.5\text{ V} \leq \text{DAC} < 3.04\text{ V}$ $1.0\text{ V} < \text{DAC} < 1.49\text{ V}$ $0.5\text{ V} < \text{DAC} < 0.99\text{ V}$	-0.9 -14 -14		0.9 14 14	% mV mV
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OVERCURRENT PROTECTION

ILIM Threshold Current (OCP shutdown after 50 μs delay)	(PS0) Rlim = 20k	9.0	10	11.0	μA
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3. Guaranteed by design or characterization data, not in production test.

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NCP81143 ELECTRICAL CHARACTERISTICS

Unless otherwise stated: $-40^{\circ}\text{C} < T_A < 125^{\circ}\text{C}$; $V_{\text{CC}} = 5\text{ V}$; $C_{\text{VCC}} = 0.1\ \mu\text{F}$

Parameter	Test Conditions	Min	Typ	Max	Unit
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OVERCURRENT PROTECTION

ILIM Threshold Current (immediate OCP shutdown)	(PS0) $R_{\text{lim}} = 20\text{k}$	13.5	15	16.5	μA
ILIM Threshold Current (OCP shutdown after 50 μs delay)	(PS1, PS2, PS3) $R_{\text{lim}} = 20\text{k}$, N = number of phases in PS0 mode		10/N		μA
ILIM Threshold Current (immediate OCP shutdown)	(PS1, PS2, PS3) $R_{\text{lim}} = 20\text{k}$, N = number of phases in PS0 mode		15/N		μA

MODULATORS (PWM Comparators)

0% Duty Cycle	COMP voltage when the PWM outputs remain LO		1.3		V
100% Duty Cycle	COMP voltage when the PWM outputs remain HI $V_{\text{RMP}} = 12.0\text{ V}$		2.5		V
PWM Ramp Duty Cycle Matching	COMP = 2 V, PWM Ton matching		1		%
PWM Phase Angle Error	Between adjacent phases		± 5		$^{\circ}$
Ramp Feed-forward Voltage range		5		20	V

VR_HOT#

Output Low Voltage	$I_{\text{VRHOT}} = -4\text{ mA}$			0.3	V
Output Leakage Current	High Impedance State	-1.0		1.0	μA

TSENSE

Alert# Assert Threshold	NTC=100k in parallel with 8.2k @ 97C		491		mV
Alert# De-assert Threshold	NTC=100k in parallel with 8.2k = 94C		513		mV
VRHOT Assert Threshold	NTC=100k in parallel with 8.2k = 100C		472		mV
VRHOT Rising Threshold	NTC=100k in parallel with 8.2k = 97C		494		mV
TSENSE Bias Current	-10°C to 85°C -40°C to 100°C	115	120	125	μA

ADC

Voltage Range		0		2	V
Total Unadjusted Error (TUE)		-1		1	%
Differential Nonlinearity (DNL)	8-bit			1	LSB
Power Supply Sensitivity			± 1		%
Conversion Time			30		μs
Round Robin			90		μs

VR_RDY, (Power Good) OUTPUT

Output Low Saturation Voltage	$I_{\text{VR_RDY}} = 4\text{ mA}$,			0.3	V
Rise Time	External pull-up of 1 k Ω to 3.3 V, $C_{\text{TOT}} = 45\text{ pF}$, $\Delta V_o = 10\%$ to 90%		250		ns
Fall Time	External pull-up of 1 k Ω to 3.3 V, $C_{\text{TOT}} = 45\text{ pF}$, $\Delta V_o = 90\%$ to 10%		30		ns
Output Voltage at Power-up	VR_RDY pulled up to 5 V via 2 k Ω			1.0	V
Output Leakage Current When High	VR_RDY = 5.0 V	-1.0		1.0	μA
VR_RDY Delay (rising)	DAC = TARGET to VR_RDY		50		μs
VR_RDY Delay (falling)	From OCP or OVP		5		μs
VR_REDY Delay (falling)	From OCP		50		μs

3. Guaranteed by design or characterization data, not in production test.

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NCP81143 ELECTRICAL CHARACTERISTICS

Unless otherwise stated: $-40^{\circ}\text{C} < T_A < 125^{\circ}\text{C}$; $V_{CC} = 5\text{ V}$; $C_{VCC} = 0.1\ \mu\text{F}$

Parameter	Test Conditions	Min	Typ	Max	Unit
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PWM OUTPUTS

Output High Voltage	Sourcing 500 μA	$V_{CC} - 0.2\text{V}$			V
Output Mid Voltage	No Load, SetPS = 02	1.9	2.0	2.1	V
Output Low Voltage	Sinking 500 μA			0.7	V
Rise and Fall Time	CL (PCB) = 50 pF, $\Delta V_o = \text{GND to } V_{CC}$		10		ns

PHASE DETECTION

CSP Pin Threshold voltage		4.5			V
Phase Detect Timer			100		μs

SCLK, SDIO

V_{IL}	Input Low Voltage			0.45	V
V_{IH}	Input High Voltage	0.65			V
V_{OH}	Output High Voltage		1.05		V
Leakage Current		-1		1	μA
Pad Capacitance, (Note 3)				4.0	pF
VR clock to data delay (T_{co}), (Note 3)		4		8.3	ns
Setup time (T_{su}), (Note 3)		7			ns
Hold time (T_{hd}), (Note 3)		14			ns

HIGH-SIDE MOSFET DRIVER

Pull-up Resistance, Sourcing Current	BST = PVCC		1.2	3.1	Ω
High Side Driver Sourcing Current	BST = PVCC		4.17		A
Pull-down Resistance, Sinking Current	BST = PVCC		0.8	2.5	Ω
High Side Driver Sinking Current	BST = PVCC		6.25		A
HGx Rise Time	$V_{CC} = 5\text{ V}$, 3 nF load, BST-SW = 5 V	6	16	30	ns
HGx Fall Time	$V_{CC} = 5\text{ V}$, 3 nF load, BST-SW = 5 V	6	11	30	ns
HGx Turn on Propagation Delay $t_{pdH_{DRVH}}$	CLOAD = 3 nF	+	30	47	ns
SWx Pull-Down Resistance	SW to PGND		2		k Ω

LOW-SIDE MOSFET DRIVER

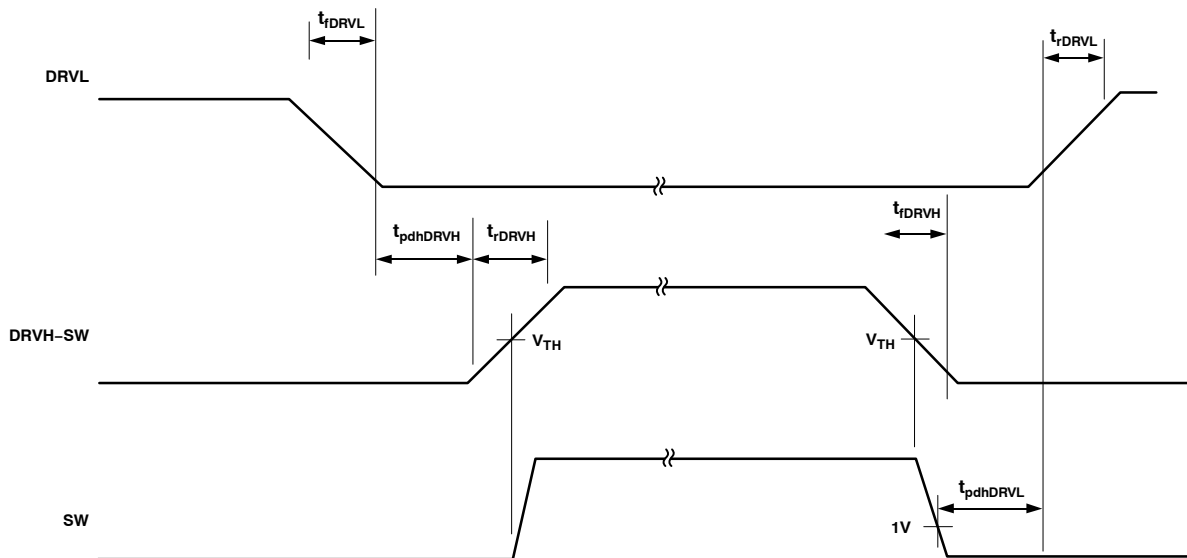
Pull-up Resistance, Sourcing Current			0.9	3.4	Ω
Low Side Driver Sourcing Current			5.56		A
Pull-down Resistance, Sinking Current			0.4	2.0	Ω
Low Side Driver Sinking Current			12.5		A
LGx Rise Time	3 nF load	6	16	30	ns
LGx Fall Time	3 nF load	6	11	30	ns
LGx Turn-On Propagation Delay $t_{pdH_{DRVL}}$	CLOAD = 3 nF		11	30	ns
PVCC Quiescent Current	EN = L (Shutdown) EN = H, no switching		1.0 490	15	μA

BOOTSTRAP ON RESISTANCE

ON Resistance	EN = L or EN = H with DRVL = H	5	9	21	Ω
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3. Guaranteed by design or characterization data, not in production test.

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NOTE: Timing is referenced to the 90% and the 10% points, unless otherwise stated.

Figure 5. Driver Timing Diagram

Table 1. VR12.5 VID CODES

VID7	VID6	VID5	VID4	VID3	VID2	VID1	VID0	Voltage (V)	HEX
0	0	0	0	0	0	0	0	OFF	00
0	0	0	0	0	0	0	1	0.5	01
0	0	0	0	0	0	1	0	0.51	02
0	0	0	0	0	0	1	1	0.52	03
0	0	0	0	0	1	0	0	0.53	04
0	0	0	0	0	1	0	1	0.54	05
0	0	0	0	0	1	1	0	0.55	06
0	0	0	0	0	1	1	1	0.56	07
0	0	0	0	1	0	0	0	0.57	08
0	0	0	0	1	0	0	1	0.58	09
0	0	0	0	1	0	1	0	0.59	0A
0	0	0	0	1	0	1	1	0.60	0B
0	0	0	0	1	1	0	0	0.61	0C
0	0	0	0	1	1	0	1	0.62	0D
0	0	0	0	1	1	1	0	0.63	0E
0	0	0	0	1	1	1	1	0.64	0F
0	0	0	1	0	0	0	0	0.65	10
0	0	0	1	0	0	0	1	0.66	11
0	0	0	1	0	0	1	0	0.67	12
0	0	0	1	0	0	1	1	0.68	13
0	0	0	1	0	1	0	0	0.69	14
0	0	0	1	0	1	0	1	0.70	15
0	0	0	1	0	1	1	0	0.71	16

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Table 1. VR12.5 VID CODES

VID7	VID6	VID5	VID4	VID3	VID2	VID1	VID0	Voltage (V)	HEX
0	0	0	1	0	1	1	1	0.72	17
0	0	0	1	1	0	0	0	0.73	18
0	0	0	1	1	0	0	1	0.74	19
0	0	0	1	1	0	1	0	0.75	1A
0	0	0	1	1	0	1	1	0.76	1B
0	0	0	1	1	1	0	0	0.77	1C
0	0	0	1	1	1	0	1	0.78	1D
0	0	0	1	1	1	1	0	0.79	1E
0	0	0	1	1	1	1	1	0.80	1F
0	0	1	0	0	0	0	0	0.81	20
0	0	1	0	0	0	0	1	0.82	21
0	0	1	0	0	0	1	0	0.83	22
0	0	1	0	0	0	1	1	0.84	23
0	0	1	0	0	1	0	0	0.85	24
0	0	1	0	0	1	0	1	0.86	25
0	0	1	0	0	1	1	0	0.87	26
0	0	1	0	0	1	1	1	0.88	27
0	0	1	0	1	0	0	0	0.89	28
0	0	1	0	1	0	0	1	0.9	29
0	0	1	0	1	0	1	0	0.91	2A
0	0	1	0	1	0	1	1	0.92	2B
0	0	1	0	1	1	0	0	0.93	2C
0	0	1	0	1	1	0	1	0.94	2D
0	0	1	0	1	1	1	0	0.95	2E
0	0	1	0	1	1	1	1	0.96	2F
0	0	1	1	0	0	0	0	0.97	30
0	0	1	1	0	0	0	1	0.98	31
0	0	1	1	0	0	1	0	0.99	32
0	0	1	1	0	0	1	1	1	33
0	0	1	1	0	1	0	0	1.01	34
0	0	1	1	0	1	0	1	1.02	35
0	0	1	1	0	1	1	0	1.03	36
0	0	1	1	0	1	1	1	1.04	37
0	0	1	1	1	0	0	0	1.05	38
0	0	1	1	1	0	0	1	1.06	39
0	0	1	1	1	0	1	0	1.07	3A
0	0	1	1	1	0	1	1	1.08	3B
0	0	1	1	1	1	0	0	1.09	3C
0	0	1	1	1	1	0	1	1.1	3D
0	0	1	1	1	1	1	0	1.11	3E
0	0	1	1	1	1	1	1	1.12	3F

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Table 1. VR12.5 VID CODES

VID7	VID6	VID5	VID4	VID3	VID2	VID1	VID0	Voltage (V)	HEX
0	1	0	0	0	0	0	0	1.13	40
0	1	0	0	0	0	0	1	1.14	41
0	1	0	0	0	0	1	0	1.15	42
0	1	0	0	0	0	1	1	1.16	43
0	1	0	0	0	1	0	0	1.17	44
0	1	0	0	0	1	0	1	1.18	45
0	1	0	0	0	1	1	0	1.19	46
0	1	0	0	0	1	1	1	1.2	47
0	1	0	0	1	0	0	0	1.21	48
0	1	0	0	1	0	0	1	1.22	49
0	1	0	0	1	0	1	0	1.23	4A
0	1	0	0	1	0	1	1	1.24	4B
0	1	0	0	1	1	0	0	1.25	4C
0	1	0	0	1	1	0	1	1.26	4D
0	1	0	0	1	1	1	0	1.27	4E
0	1	0	0	1	1	1	1	1.28	4F
0	1	0	1	0	0	0	0	1.29	50
0	1	0	1	0	0	0	1	1.3	51
0	1	0	1	0	0	1	0	1.31	52
0	1	0	1	0	0	1	1	1.32	53
0	1	0	1	0	1	0	0	1.33	54
0	1	0	1	0	1	0	1	1.34	55
0	1	0	1	0	1	1	0	1.35	56
0	1	0	1	0	1	1	1	1.36	57
0	1	0	1	1	0	0	0	1.37	58
0	1	0	1	1	0	0	1	1.38	59
0	1	0	1	1	0	1	0	1.39	5A
0	1	0	1	1	0	1	1	1.4	5B
0	1	0	1	1	1	0	0	1.41	5C
0	1	0	1	1	1	0	1	1.42	5D
0	1	0	1	1	1	1	0	1.43	5E
0	1	0	1	1	1	1	1	1.44	5F
0	1	1	0	0	0	0	0	1.45	60
0	1	1	0	0	0	0	1	1.46	61
0	1	1	0	0	0	1	0	1.47	62
0	1	1	0	0	0	1	1	1.48	63
0	1	1	0	0	1	0	0	1.49	64
0	1	1	0	0	1	0	1	1.5	65
0	1	1	0	0	1	1	0	1.51	66
0	1	1	0	0	1	1	1	1.52	67
0	1	1	0	1	0	0	0	1.53	68

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Table 1. VR12.5 VID CODES

VID7	VID6	VID5	VID4	VID3	VID2	VID1	VID0	Voltage (V)	HEX
0	1	1	0	1	0	0	1	1.54	69
0	1	1	0	1	0	1	0	1.55	6A
0	1	1	0	1	0	1	1	1.56	6B
0	1	1	0	1	1	0	0	1.57	6C
0	1	1	0	1	1	0	1	1.58	6D
0	1	1	0	1	1	1	0	1.59	6E
0	1	1	0	1	1	1	1	1.6	6F
0	1	1	1	0	0	0	0	1.61	70
0	1	1	1	0	0	0	1	1.62	71
0	1	1	1	0	0	1	0	1.63	72
0	1	1	1	0	0	1	1	1.64	73
0	1	1	1	0	1	0	0	1.65	74
0	1	1	1	0	1	0	1	1.66	75
0	1	1	1	0	1	1	0	1.67	76
0	1	1	1	0	1	1	1	1.68	77
0	1	1	1	1	0	0	0	1.69	78
0	1	1	1	1	0	0	1	1.7	79
0	1	1	1	1	0	1	0	1.71	7A
0	1	1	1	1	0	1	1	1.72	7B
0	1	1	1	1	1	0	0	1.73	7C
0	1	1	1	1	1	0	1	1.74	7D
0	1	1	1	1	1	1	0	1.75	7E
0	1	1	1	1	1	1	1	1.76	7F
1	0	0	0	0	0	0	0	1.77	80
1	0	0	0	0	0	0	1	1.78	81
1	0	0	0	0	0	1	0	1.79	82
1	0	0	0	0	0	1	1	1.8	83
1	0	0	0	0	1	0	0	1.81	84
1	0	0	0	0	1	0	1	1.82	85
1	0	0	0	0	1	1	0	1.83	86
1	0	0	0	0	1	1	1	1.84	87
1	0	0	0	1	0	0	0	1.85	88
1	0	0	0	1	0	0	1	1.86	89
1	0	0	0	1	0	1	0	1.87	8A
1	0	0	0	1	0	1	1	1.88	8B
1	0	0	0	1	1	0	0	1.89	8C
1	0	0	0	1	1	0	1	1.9	8D
1	0	0	0	1	1	1	0	1.91	8E
1	0	0	0	1	1	1	1	1.92	8F
1	0	0	1	0	0	0	0	1.93	90
1	0	0	1	0	0	0	1	1.94	91

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Table 1. VR12.5 VID CODES

VID7	VID6	VID5	VID4	VID3	VID2	VID1	VID0	Voltage (V)	HEX
1	0	0	1	0	0	1	0	1.95	92
1	0	0	1	0	0	1	1	1.96	93
1	0	0	1	0	1	0	0	1.97	94
1	0	0	1	0	1	0	1	1.98	95
1	0	0	1	0	1	1	0	1.99	96
1	0	0	1	0	1	1	1	2	97
1	0	0	1	1	0	0	0	2.01	98
1	0	0	1	1	0	0	1	2.02	99
1	0	0	1	1	0	1	0	2.03	9A
1	0	0	1	1	0	1	1	2.04	9B
1	0	0	1	1	1	0	0	2.05	9C
1	0	0	1	1	1	0	1	2.06	9D
1	0	0	1	1	1	1	0	2.07	9E
1	0	0	1	1	1	1	1	2.08	9F
1	0	1	0	0	0	0	0	2.09	A0
1	0	1	0	0	0	0	1	2.1	A1
1	0	1	0	0	0	1	0	2.11	A2
1	0	1	0	0	0	1	1	2.12	A3
1	0	1	0	0	1	0	0	2.13	A4
1	0	1	0	0	1	0	1	2.14	A5
1	0	1	0	0	1	1	0	2.15	A6
1	0	1	0	0	1	1	1	2.16	A7
1	0	1	0	1	0	0	0	2.17	A8
1	0	1	0	1	0	0	1	2.18	A9
1	0	1	0	1	0	1	0	2.19	AA
1	0	1	0	1	0	1	1	2.2	AB
1	0	1	0	1	1	0	0	2.21	AC
1	0	1	0	1	1	0	1	2.22	AD
1	0	1	0	1	1	1	0	2.23	AE
1	0	1	0	1	1	1	1	2.24	AF
1	0	1	1	0	0	0	0	2.25	B0
1	0	1	1	0	0	0	1	2.26	B1
1	0	1	1	0	0	1	0	2.27	B2
1	0	1	1	0	0	1	1	2.28	B3
1	0	1	1	0	1	0	0	2.29	B4
1	0	1	1	0	1	0	1	2.3	B5

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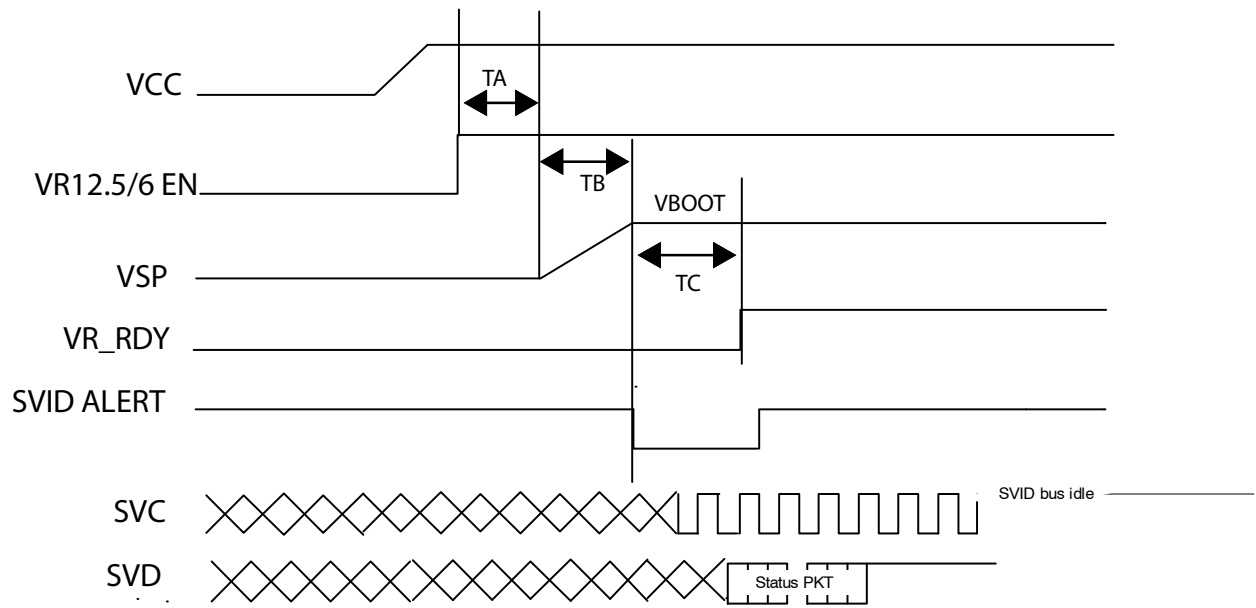


Figure 6. Startup Timing

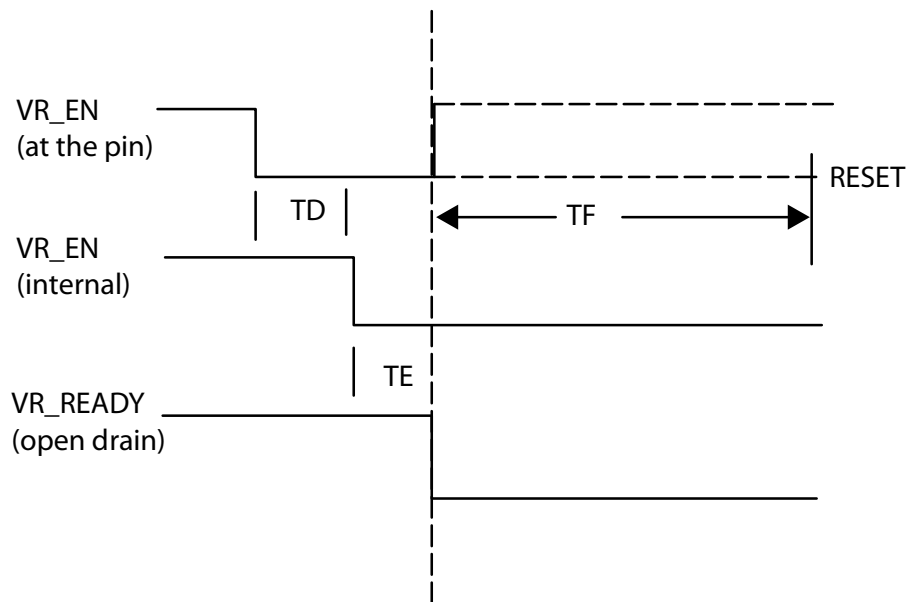


Figure 7. Disable Timing

	Min	Typ	Max
TA			5 ms
TB			Slew rate
TC	0 μ s		6 μ s
TD	0 μ s		1 μ s
TE			500 ns
TF		10 ms	

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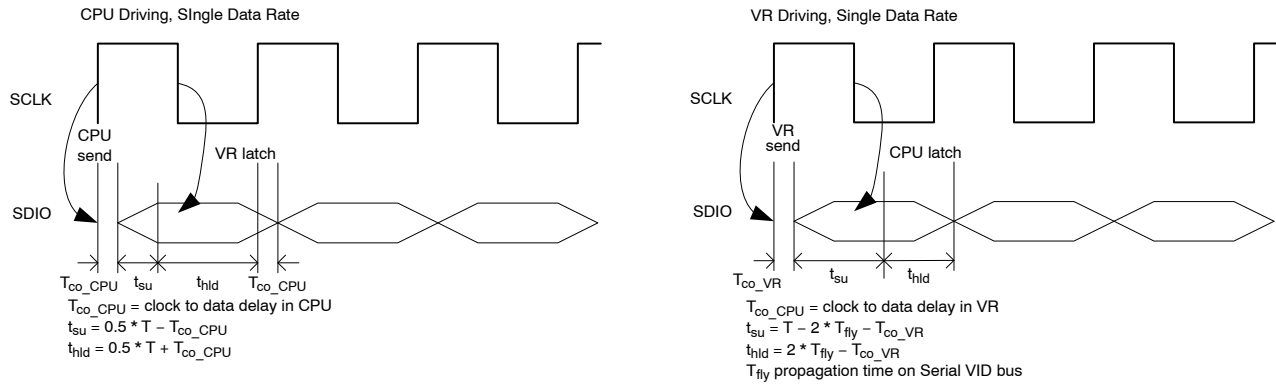


Figure 8.

STATE TRUTH TABLE

State	VR_RDY Pin	Error AMP Comp Pin	OVP & UVP	DRON Pin	Method of Reset
POR $0 < VCC < UVLO$	N/A	N/A	N/A	Resistive pull down	
Disabled $EN < \text{threshold}$ $UVLO > \text{threshold}$	Low	Low	Disabled	Low	
Start up Delay & Calibration $EN > \text{threshold}$ $UVLO > \text{threshold}$	Low	Low	Disabled	Low	
DRON Fault $EN > \text{threshold}$ $UVLO > \text{threshold}$ $DRON < \text{threshold}$	Low	Low	Disabled	Resistive pull up	Driver must release DRON to high
Soft Start $EN > \text{threshold}$ $UVLO > \text{threshold}$ $DRON > \text{High}$	Low	Operational	Active / No latch	High	
Normal Operation $EN > \text{threshold}$ $UVLO > \text{threshold}$ $DRON > \text{High}$	High	Operational	Active / Latching	High	N/A
Over Voltage	Low	N/A	DAC + 400 mV	High	
Over Current	Low	Operational	Last DAC Code	Low	
VID Code = 00h	Low: if Reg34h:bit0 = 0; High: if Reg34h:bit0 = 1;	Clamped at 0.9 V	Disabled	High, PWM outputs in low state	

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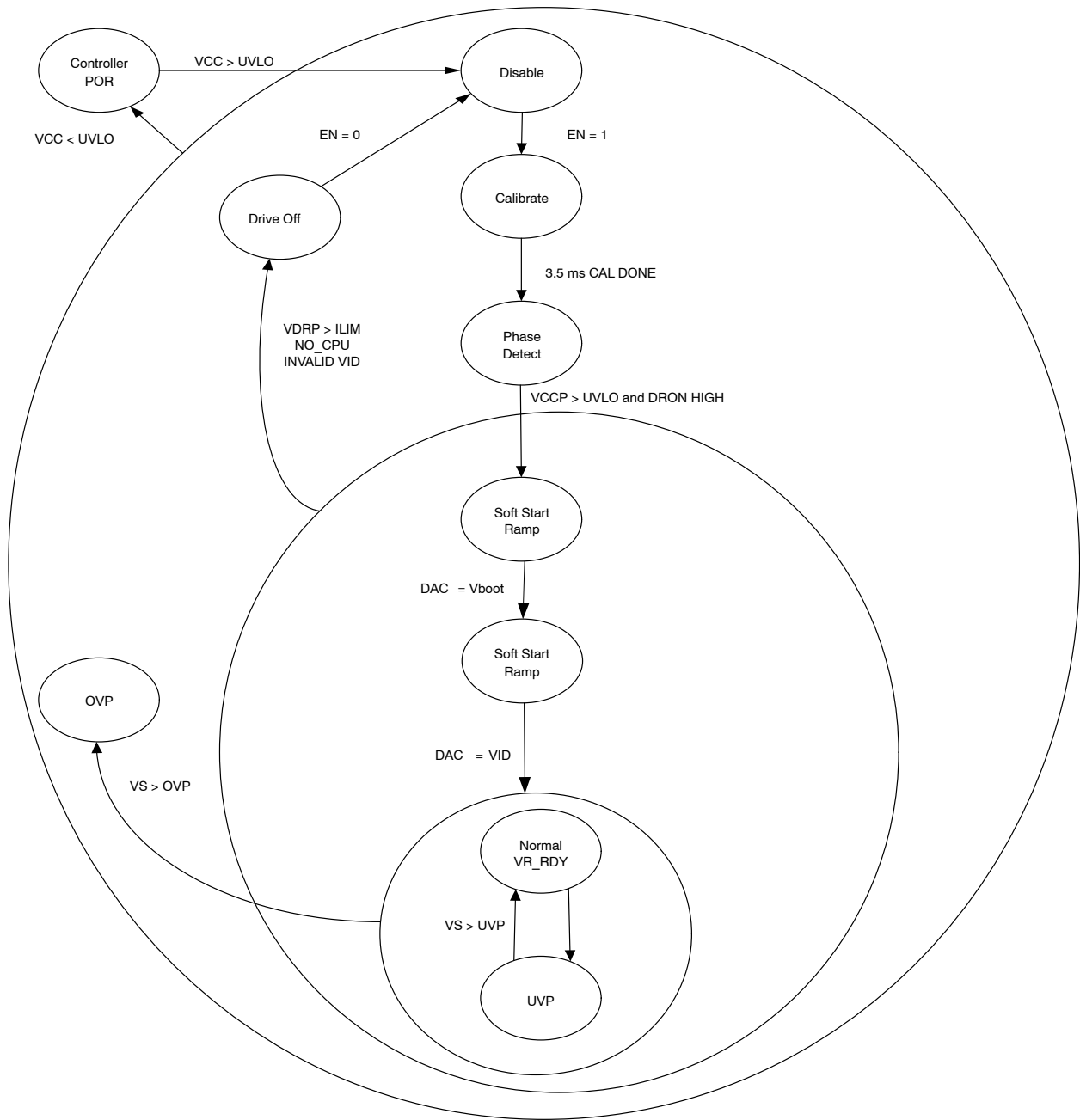


Figure 9. State Diagram

NCP81143

General

The NCP81143 is a three phase dual edge modulated multiphase PWM controller, with a serial SVID control interface. The NCP81143 is optimized to meet Intel's VR12.5 Specifications and implements PS0, PS1, PS2 and PS3 power saving states. It is designed to work in notebook, desktop, and server applications.

Power Status	PWM Output Operating Mode
PS0	Multi-phase PWM interleaving output
PS1	Single-phase RPM CCM mode (PWM1 only, PWM2~3 stay in Mid)
PS2	Single-phase RPM DCM mode (PWM1 only, PWM2~3 stay in Mid)
PS3	Single-phase RPM DCM mode (PWM1 only, PWM2~3 stay in Mid)

The NCP81143 has two integrated drivers and one external PWM signal. Internally, there are 2 PWM signals: PWM1/3, DRV1 is driven by PWM1, DRV3 is driven by PWM3, and the third phase has a PWM output, PWM2, to drive an external driver such as the NCP81151.

Phase	PWM Output
3	Internal PWM
2	External PWM
1	Internal PWM

Serial VID interface (SVID)

The Serial VID Interface (SVID Interface) is a three wire digital interface used to transfer power management information between the CPU (Master) and the NCP81143. The 3 wires are clock (SCLK), data (SDIO) and ALERT#. The SCLK is unidirectional and generated by the master. The SDIO is bi-directional, used for transferring data from the CPU to the NCP81143 and from the NCP81143 to the CPU. The ALERT# is an open drain output from the NCP8110 to signal to the master that the Status Register should be read.

SCLK, SDIO and ALERT# should be pulled high to CPU I/O voltage V_{tt} (which is typically 1.0 to 1.1 V) using 55 Ω Resistors.

The SVID bus will operate at a max frequency of 43 MHz.

VID code change is supported by SVID interface with three options as below:

Option	SVID Command Code	Feature Description for NCP81143	Register Address (Indicating the slew rate of VID code change)
SetVID_Fast	01h	>10 mV/μs VID code change slew rate	24h
SetVID_Slow	02h	=1/4 of SetVID_Fast VID code change slew rate	25h
SetVID_Decay	03h	No control, VID code down	N/A

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Serial VID

The NCP81143 supports the Intel serial VID interface. It communicates with the microprocessor through three wires (SCLK, SDIO, ALERT#). The table of supported registers is shown below.

Index	Name	Description	Access	Default
00h	Vendor ID	Uniquely identifies the VR vendor. The vendor ID assigned by Intel to ON Semiconductor is 0x1Ah	R	0x1Ah
01h	Product ID	Uniquely identifies the VR product. The VR vendor assigns this number.	R	0x13
02h	Product Revision	Uniquely identifies the revision or stepping of the VR control IC. The VR vendor assigns this data.	R	0x01
03h	Product date code ID		R	00
05h	Protocol ID	Identifies the SVID Protocol the controller supports	R	0x02
06h	Capability	<p>Informs the Master of the controller's Capabilities, 1 = supported, 0 = not supported</p> <p>Bit 7 = iout_format. Bit 7 = 0 when 1A = 1LSB of Reg 15h. Bit 7 = 1 when Reg 15 FFh = lcc_Max. Default = 1</p> <p>Bit 6 = ADC Measurement of Temp Supported = 1</p> <p>Bit 5 = ADC Measurement of Pin Supported = 0</p> <p>Bit 4 = ADC Measurement of Vin Supported = 0</p> <p>Bit 3 = ADC Measurement of Iin Supported = 0</p> <p>Bit 2 = ADC Measurement of Pout Supported = 1</p> <p>Bit 1 = ADC Measurement of Vout Supported = 1</p> <p>Bit 0 = ADC Measurement of Iout Supported = 1</p>	R	0xC7
10h	Status_1	Data register read after the ALERT# signal is asserted. Conveying the status of the VR.	R	00h
11h	Status_2	Data register showing optional status_2 data.	R	00h
12h	Temp zone	Data register showing temperature zones the system is operating in	R	00h
15h	I_out	8 bit binary word ADC of current. This register reads 0xFF when the output current is at lcc_Max	R	01h
16h	V_out	8 bit binary word ADC of output voltage, measured between VSP and VSN. LSB size is 8 mV	R	01h
17h	VR_Temp	8 bit binary word ADC of voltage. Binary format in °C, IE 100C = 64h. A value of 00h indicates this function is not supported	R	01h
18h	P_out	8 bit binary word representative of output power. The output voltage is multiplied by the output current value and the result is stored in this register. A value of 00h indicates this function is not supported	R	01h
1Ch	Status 2 Last read	When the status 2 register is read its contents are copied into this register. The format is the same as the Status 2 Register.	R	00h
21h	lcc_Max	Data register containing the lcc_Max the platform supports. The value is measured on the ICCMAX pin on power up and placed in this register. From that point on the register is read only.	R	00h
22h	Temp_Max	Data register containing the max temperature the platform supports and the level VR_hot asserts. This value defaults to 100°C and programmable over the SVID Interface	R/W	64h
24h	SR_fast	Slew Rate for SetVID_fast commands. Binary format in mV/us.	R	0Ah
25h	SR_slow	Slew Rate for SetVID_slow commands. It is 16, 8, 4 or 2 times slower than the SR_fast rate. Binary format in mV/us	R	02h
26h	Vboot	The Vboot is set at 1.7 V The controller will ramp to Vboot and hold at Vboot until it receives a new SVID SetVID command to move to a different voltage.	R	00h
30h	Vout_Max	Programmed by master and sets the maximum VID the VR will support. If a higher VID code is received, the VR should respond with "not supported" acknowledge. VR 12.5/6 VID format.	RW	B5h
31h	VID setting	Data register containing currently programmed VID voltage. VID data format.	RW	00h
32h	Pwr State	Register containing the current programmed power state.	RW	00h

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Index	Name	Description	Access	Default
33h	Offset	Sets offset in VID steps added to the VID setting for voltage margining. Bit 7 is sign bit, 0 = positive margin, 1= negative margin. Remaining 7 BITS are # VID steps for margin 2s complement. 00h = no margin 01h = +1 VID step 02h = +2 VID steps FFh = -1 VID step FEh = -2 VID steps.	RW	00h
34h	MultiVR Config			

BOOT VOLTAGE PROGRAMMING

The Boot voltage for the NCP81143 is configured to 1.7 V. The Vboot value can be read back over the SVID interface in registers (0x26).

INT_SEL

The remote Sense Amplifier output is applied to a Type III compensation network formed by the error amplifier and external tuning components. The non-inverting input of the error amplifier is connected to the same reference voltage used to bias the Remote sense amplifier output. The integrating function of the Type III feedback compensation is performed internally and does not require external capacitor CF1.

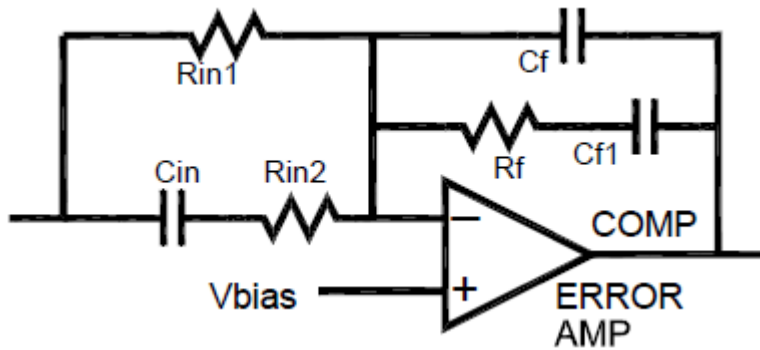


Figure 10. Type III Compensation

Initial tuning should be based on the traditional TYPE III compensation. When ideal Type III component values have been determined, the closest setting for the internal integrator is given by the following equation :

$$\text{INT_SETTING} = 4.83 \times 10^{-12} \times R_F \times R_{in1} \times C_{F1}$$

R_F & R_{in1} in ohms
C_{F1} in nF

Optimization of the traditional Type 3 compensation should be rechecked until the closest Type 3 C_{F1} equivalent in order to determine if readjustment of other component values are required. The Type III C_{F1} value that is equivalent to the integrator setting is given by the following equation:

$$C_{f1}(\text{nF}) = 2.07 \times 10^5 \times \text{INT_Setting} / (R_F \times R_{in1})$$

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Table 2. RF = 5k and Rin = 1 kΩ

Resistor Range	Int_select Setting	Phase Count in PS1	Equivalent Cf1 in Type III Compensation	Equivalent Rf in Type III Compensation
0 – 5.08 kΩ	0000	1	43 pF	5 kΩ
5.08 kΩ – 14.1 kΩ	0001	1	82 pF	5 kΩ
14.1 kΩ – 21.9 kΩ	0010	1	160 pF	5 kΩ
21.9 kΩ – 30.1 kΩ	0011	1	330 pF	5 kΩ
30.1 kΩ – 39.1 kΩ	0100	1	430 pF	5 kΩ
39.1 kΩ – 48.4 kΩ	0101	1	510 pF	5 kΩ
48.4 kΩ – 57.8 kΩ	0110	1	680 pF	5 kΩ
57.8 kΩ – 67.6 kΩ	0111	1	1300 pF	5 kΩ
67.6 kΩ – 78.1 kΩ	1000	1	2700 pF	5 kΩ
78.1 kΩ – 89.5 kΩ	0000	2	43 pF	5 kΩ
89.5 kΩ – 101 kΩ	0001	2	82 pF	5 kΩ
101 kΩ – 113 kΩ	0010	2	160 pF	5 kΩ
113 kΩ – 125 kΩ	0011	2	330 pF	5 kΩ
125 kΩ – 138 kΩ	0100	2	430 pF	5 kΩ
138 kΩ – 151 kΩ	0101	2	510 pF	5 kΩ
151 kΩ – 163 kΩ	0110	2	680 pF	5 kΩ
163 kΩ – 177 kΩ	0111	2	1300 pF	5 kΩ
177 kΩ – 193 kΩ	1000	2	2700 pF	5 kΩ

Table 3. RF = 7.5k and Rin = 1 kΩ

Resistor Range	Int_select Setting	Phase Count in PS1	Equivalent Cf1 in Type III Compensation	Equivalent Rf in Type III Compensation
0 – 5.08 kΩ	0000	1	27 pF	7.5 kΩ
5.08 kΩ – 14.1 kΩ	0001	1	56 pF	7.5 kΩ
14.1 kΩ – 21.9 kΩ	0010	1	110 pF	7.5 kΩ
21.9 kΩ – 30.1 kΩ	0011	1	220 pF	7.5 kΩ
30.1 kΩ – 39.1 kΩ	0100	1	270 pF	7.5 kΩ
39.1 kΩ – 48.4 kΩ	0101	1	330 pF	7.5 kΩ
48.4 kΩ – 57.8 kΩ	0110	1	430 pF	7.5 kΩ
57.8 kΩ – 67.6 kΩ	0111	1	910 pF	7.5 kΩ
67.6 kΩ – 78.1 kΩ	1000	1	1800 pF	7.5 kΩ
78.1 kΩ – 89.5 kΩ	0000	2	27 pF	7.5 kΩ
89.5 kΩ – 101 kΩ	0001	2	56 pF	7.5 kΩ
101 kΩ – 113 kΩ	0010	2	110 pF	7.5 kΩ
113 kΩ – 125 kΩ	0011	2	220 pF	7.5 kΩ
125 kΩ – 138 kΩ	0100	2	270 pF	7.5 kΩ
138 kΩ – 151 kΩ	0101	2	330 pF	7.5 kΩ
151 kΩ – 163 kΩ	0110	2	430 pF	7.5 kΩ
163 kΩ – 177 kΩ	0111	2	910 pF	7.5 kΩ
177 kΩ – 193 kΩ	1000	2	1800 pF	7.5 kΩ

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Table 4. $R_F = 10k$ and $R_{in} = 1 k\Omega$

Resistor Range	Int_select Setting	Phase Count in PS1	Equivalent Cf1 in Type III Compensation	Equivalent Rf in Type III Compensation
0 – 5.08 k Ω	0000	1	20 pF	10 k Ω
5.08 k Ω – 14.1 k Ω	0001	1	43 pF	10 k Ω
14.1 k Ω – 21.9 k Ω	0010	1	82 pF	10 k Ω
21.9 k Ω – 30.1 k Ω	0011	1	160 pF	10 k Ω
30.1 k Ω – 39.1 k Ω	0100	1	200 pF	10 k Ω
39.1 k Ω – 48.4 k Ω	0101	1	240 pF	10 k Ω
48.4 k Ω – 57.8 k Ω	0110	1	330 pF	10 k Ω
57.8 k Ω – 67.6 k Ω	0111	1	680 pF	10 k Ω
67.6 k Ω – 78.1 k Ω	1000	1	1300 pF	10 k Ω
78.1 k Ω – 89.5 k Ω	0000	2	20 pF	10 k Ω
89.5 k Ω – 101 k Ω	0001	2	43 pF	10 k Ω
101 k Ω – 113 k Ω	0010	2	82 pF	10 k Ω
113 k Ω – 125 k Ω	0011	2	160 pF	10 k Ω
125 k Ω – 138 k Ω	0100	2	200 pF	10 k Ω
138 k Ω – 151 k Ω	0101	2	240 pF	10 k Ω
151 k Ω – 163 k Ω	0110	2	330 pF	10 k Ω
163 k Ω – 177 k Ω	0111	2	680 pF	10 k Ω
177 k Ω – 193 k Ω	1000	2	1300 pF	10 k Ω

For further explanation on the integrator setting and operation please refer to application note.

Boost Capacitor Refresh Mode

The NCP81143 include a boost capacitor refresh mode which aids the correct operation of inactive phase when exiting low power states. The mode is used where phases are shed in PS1,2 and 3 modes; in these cases it is possible that the drivers boost capacitor voltage, V_{bst} , may drop below 1.7 V. If this occurs the Boost capacitor charge will not be able to meet the gate source requirements for the first firing of the high side MOSFET when returning to PS0 power state. For further information on the operation of the boost capacitor refresh mode please see application note.

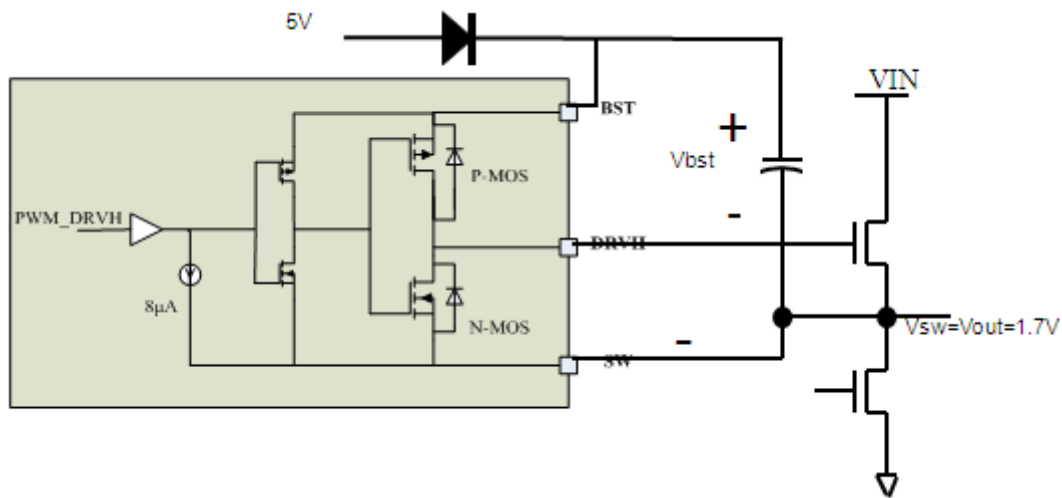


Figure 11. Boost Cap Refresh

Remote Sense Amplifier

A high performance high input impedance true differential amplifier is provided to accurately sense the output voltage of the regulator. The VSP and VSN inputs should be connected to the regulator’s output voltage sense points. The remote sense amplifier takes the difference of the output voltage with the DAC voltage and adds the droop voltage to

$$V_{DIFFOUT} = (V_{VSP} - V_{VSN}) + (1.3\text{ V} - V_{DAC}) + (V_{DROOP} - V_{CSREF})$$

This signal then goes through a standard error compensation network and into the inverting input of the error amplifier. The non-inverting input of the error amplifier is connected to the same 1.3 V reference used for the differential sense amplifier output bias.

High Performance Voltage Error Amplifier

A high performance error amplifier is provided for high bandwidth transient performance. A standard type II compensation circuit is normally used to compensate the system.

Differential Current Feedback Amplifiers

Each phase has a low offset differential amplifier to sense that phase current for current balance. The inputs to the CSNx and CSPx pins are high impedance inputs. It is recommended that any external filter resistor RCSN does not exceed 10 kΩ to avoid offset issues with leakage current. It is also recommended that the voltage sense element be no less than 0.5 mΩ for accurate current balance. Fine tuning of this time constant is generally not required. The individual phase current is summed into the PWM comparator feedback this way current is balanced via a current mode control approach.

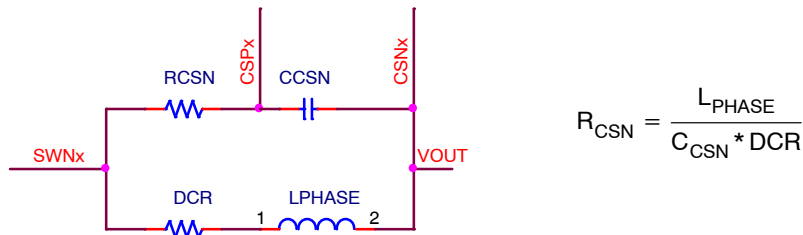


Figure 12. Differential Current Feedback

Total Current Sense Amplifier

The NCP81143 uses a patented approach to sum the phase currents into a single temperature compensated total current signal. This signal is then used to generate the output voltage droop, total current limit, and the output current monitoring functions. The total current signal is floating with respect to CSREF. The current signal is the difference between CSCOMP and CSREF. The Ref(n) resistors sum the signals from the output side of the inductors to create a low impedance virtual ground. The amplifier actively filters and gains up the voltage applied across the inductors to recover the voltage drop across the inductor series resistance (DCR). Rth is placed near an inductor to sense the temperature of the inductor. This allows the filter time constant and gain to be a function of the Rth NTC resistor and compensate for the change in the DCR with temperature.

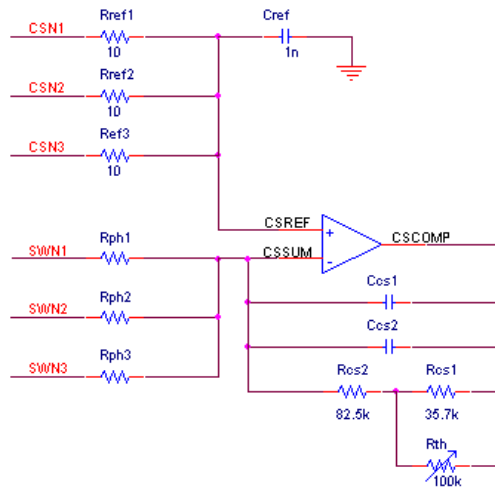


Figure 13. Total Current Sense