

## Triple Channel PWM Controller for IMVP8 Mobile CPU Core Power Supply

### General Description

The RT3602AE is an IMVP8 compliant CPU power controller which includes three voltage rails : a 2/1 phase synchronous Buck controller, the MAIN VR, a single phase synchronous Buck controller, the auxiliary VR, and a single phase synchronous Buck controller, the VCCSA VR. The RT3602AE adopts G-NAVP™ (Green Native AVP) which is Richtek's proprietary topology derived from finite DC gain of EA amplifier with current mode control, making it easy to set the droop to meet all Intel CPU requirements of AVP (Adaptive Voltage Positioning). Based on the G-NAVP™ topology, the RT3602AE also features a quick response mechanism for optimized AVP performance during load transient. The RT3602AE supports mode transition function with various operating states. A serial VID (SVID) interface is built in the RT3602AE to communicate with Intel IMVP8 compliant CPU. The RT3602AE supports VID on-the-fly function with three different slew rates : Fast, Slow and Decay. By utilizing the G-NAVP™ topology, the operating frequency of the RT3602AE varies with VID, load and input voltage to further enhance the efficiency even in CCM. Moreover, the G-NAVP™ with CCRCOT (Constant Current Ripple COT) technology provides superior output voltage ripple over the entire input/output range. The built-in high accuracy DAC converts the SVID code ranging from 0.25V to 1.52V with 5mV per step. The RT3602AE integrates a high accuracy ADC for platform setting functions, such as quick response trigger level. Besides, the setting function also supposes this two rails address exchange. The RT3602AE provides VR ready output signals. It also features complete fault protection functions including over-voltage (OV), negative voltage (NV), over-current (OC) and under-voltage lockout (UVLO). The RT3602AE is available in the WQFN-48L 6x6 small foot print package.

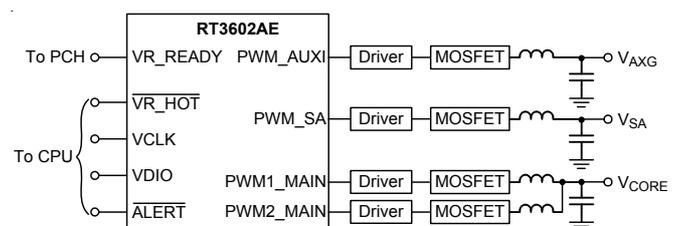
### Features

- Intel IMVP8 Serial VID Interface Compatible Power Management States
- 2/1 Phase (MAIN VR) + Single Phase (Auxiliary VR) + Single Phase (VCCSA VR) PWM Controller
- G-NAVP™ (Green Native Adaptive Voltage Positioning) Topology
- 0.5% DAC Accuracy
- Differential Remote Voltage Sensing
- Built-in ADC for Platform Programming
- Accurate Current Balance
- System Thermal Compensated AVP
- Diode Emulation Mode at Light Load Condition for Multiple or Single Phase Operation
- Fast Transient Response
- VR Ready Indicator
- Thermal Throttling
- Current Monitor Output
- OVP, OCP, NVP, UVLO
- Slew Rate Setting/Address Flip Function
- Rail Address Flexibility
- DVID Enhancement
- RoHS Compliant and Halogen Free

### Applications

- IMVP8 Intel Core Supply
- Notebook/ Desktop Computer/ Servers Multi-phase CPU Core Supply
- AVP Step-Down Converter

### Simplified Application Circuit



## Ordering Information

RT3602AE □ □

- Package Type  
QW : WQFN-48L 6x6 (W-Type)  
(Exposed Pad-Option 1)
- Lead Plating System  
G : Green (Halogen Free and Pb Free)

Note :

Richtek products are :

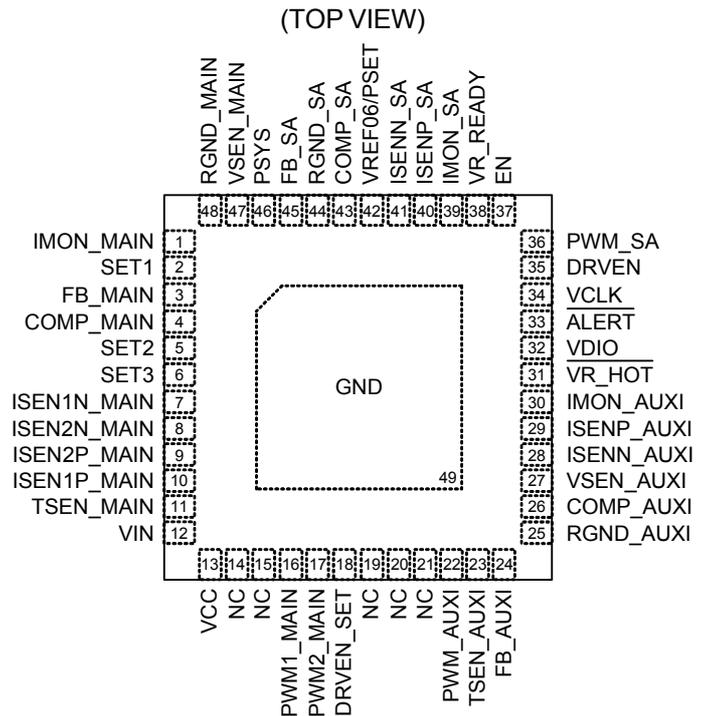
- ▶ RoHS compliant and compatible with the current requirements of IPC/JEDEC J-STD-020.
- ▶ Suitable for use in SnPb or Pb-free soldering processes.

## Marking Information



RT3602AEGQW : Product Number  
YMDNN : Date Code

## Pin Configuration



WQFN-48L 6x6

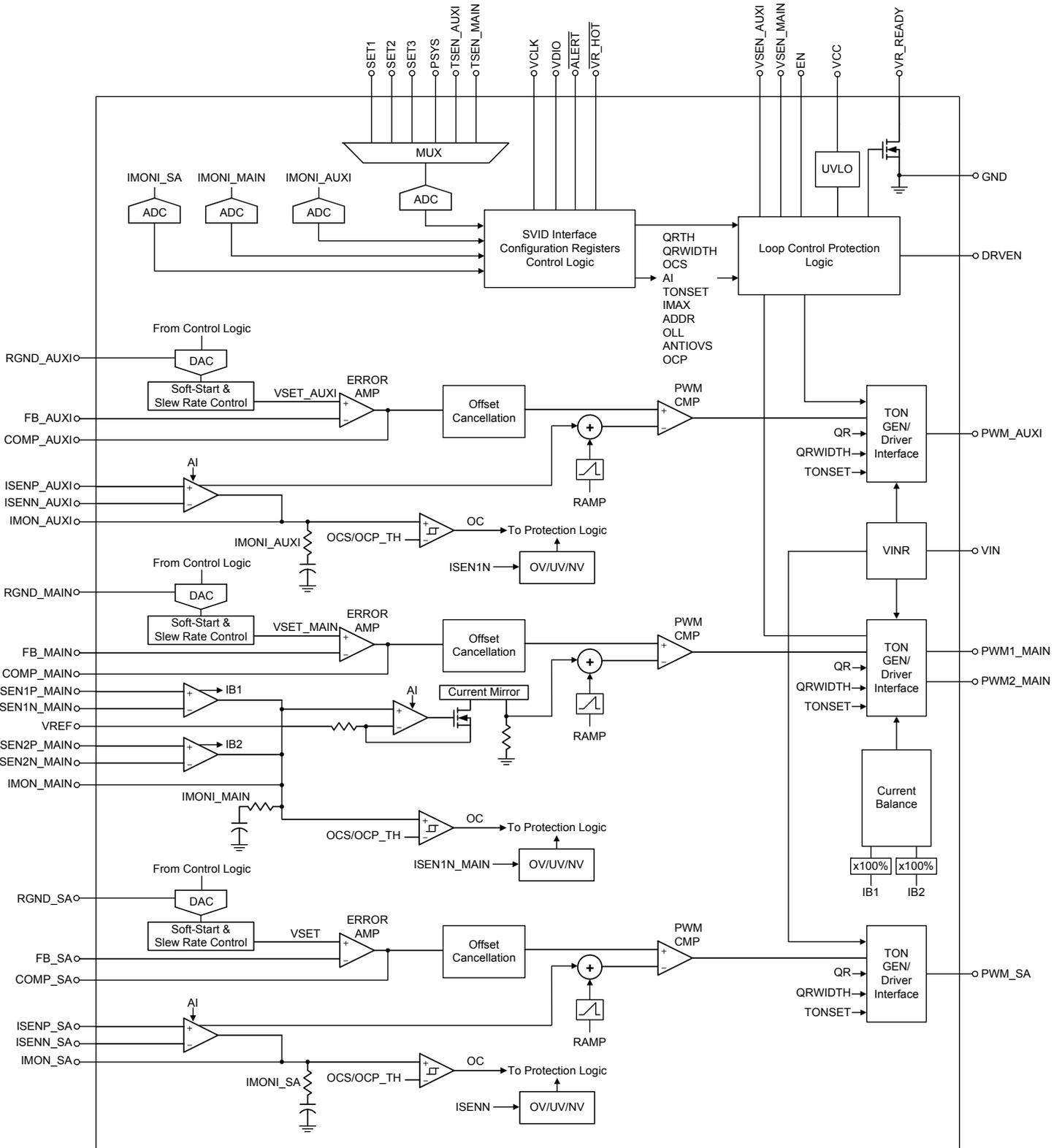
## Functional Pin Description

Pin No	Pin Name	Pin Function
1	IMON_MAIN	Main rail VR current monitor output. This pin outputs a voltage proportional to the output current.
2	SET1	Platform setting. Platform can use this pin to set switching frequency, ki gain, QRTH, QR width and anti-overshoot for Auxiliary VR. Connect the SET1 pin to 5V and turn-on the EN pin, if the soldering is good, $V_{SEN\_MAIN} = V_{SEN\_AUX1} = 1.1V$ and $V_{SEN\_SA} = 1.05V$ .
3	FB_MAIN	Negative input of the error amplifier. This pin is for main rail VR output voltage feedback to controller.
4	COMP_MAIN	Main rail VR compensation. This pin is error amplifier output pin.
5	SET2	Platform setting. Platform can use this pin to set switching frequency, ki gain, QRTH, QR width and anti-overshoot for MAIN VR.
6	SET3	Platform Setting. Platform can use this pin to set switching frequency, ki gain zero load-line, QRTH and QR width for VCCSA rail. And it can be set DVID_TH and force-non-zero VBOOT function for Main and AUX1 rail.
7, 8	ISEN[1:2]N_MAIN	Negative current sense inputs of multi-phase main rail VR Channel 1 and 2.
10, 9	ISEN[1:2]P_MAIN	Positive current sense inputs of multi-phase main rail VR Channel 1 and 2.
11	TSEN_MAIN	Thermal sense input for main rail VR.
12	VIN	VIN input pin. Connect a low pass filter to this pin to set on-time.
13	VCC	Controller power supply. Connect this pin to 5V and place a decoupling capacitor 2.2 $\mu$ F at least. The decoupling capacitor is as close PWM controller as possible.

Pin No	Pin Name	Pin Function
14, 15, 19, 20, 21	NC	No internal connection.
16, 17	PWM[1:2]_MAIN	PWM outputs for main rail VR of Channel 1 and 2.
18	DRVEN_SET	Set DRVEN output function at PS4. Set to 5V DRVEN is floating, and set to GND DRVEN is low at PS4.
22	PWM_AUXI	PWM outputs for auxiliary rail VR.
23	TSEN_AUXI	Thermal sense input for AUXI rail VR.
24	FB_AUXI	Negative input of the error amplifier. This pin is for auxiliary rail VR output voltage feedback to controller.
25	RGND_AUXI	Return ground for auxiliary rail VR. This pin is the negative node of the differential remote voltage sensing.
26	COMP_AUXI	Auxiliary rail VR compensation. This pin is error amplifier output pin.
27	VSEN_AUXI	Auxiliary VR voltage sense input. This pin is connected to the terminal of Main VR output voltage.
28	ISENN_AUXI	Negative current sense input of single-phase auxiliary Rail.
29	ISENP_AUXI	Positive current sense input of single-phase auxiliary Rail.
30	IMON_AUXI	Auxiliary rail VR current monitor output. This pin outputs a voltage proportional to the output current.
31	$\overline{\text{VR\_HOT}}$	Thermal monitor output, this pin is active low.
32	VDIO	VR and CPU data transmission interface.
33	$\overline{\text{ALERT}}$	SVID alert. (Active low)
34	VCLK	Synchronous clock from the CPU.
35	DRVEN	External driver enable control. Connecting to driver enable pin.
36	PWM_SA	PWM outputs for VCCSA VR.
37	EN	VR enable control input.
38	VR_READY	VR ready indicator.
39	IMON_SA	VCCSA rail VR current monitor output. This pin outputs a voltage proportional to the output current.
40	ISENP_SA	Positive current sense input of single-phase VCCSA rail VR.
41	ISENN_SA	Negative current sense input of single-phase VCCSA rail VR.
42	VREF06/PSET	Fixed 0.6V output reference voltage. This voltage is used to offset the output voltage of IMON pin. Between this pin and GND must be placed a exact 0.47 $\mu$ F decoupling capacitor and 3.9 $\Omega$ resistor.
43	COMP_SA	VCCSA rail VR compensation. This pin is error amplifier output pin.
44	RGND_SA	Return ground for VCCSA rail VR. This pin is the negative node of the differential remote voltage sensing.
45	FB_SA	Negative input of the error amplifier. This pin is for VCCSA rail VR output voltage feedback to controller.

Pin No	Pin Name	Pin Function
46	PSYS	System Input Power Monitor. Place the PSYS resistor as close to the IC as possible.
47	VSEN_MAIN	Main VR voltage sense input. This pin is connected to the terminal of MAIN VR output Voltage.
48	RGND_MAIN	Return ground for main rail VR. This pin is the negative node of the differential remote voltage sensing.
49 (Exposed Pad)	GND	Ground. The exposed pad must be soldered to a large PCB and connected to GND for maximum power dissipation.

**Functional Block Diagram**



## Operation

The RT3602AE adopts G-NAVP™ (Green Native AVP) which is Richtek's proprietary topology derived from finite DC gain of EA amplifier with current mode control, making it easy to set the droop to meet all Intel CPU requirements of AVP (Adaptive Voltage Positioning).

The G-NAVP™ controller is one type of current mode constant on-time control with DC offset cancellation. The approach can not only improve DC offset problem for increasing system accuracy but also provide fast transient response. When current feedback signal reaches COMP signal, the RT3602AE generates an on-time width to achieve PWM modulation.

### TON GEN/Driver Interface PWMx

Generate the sequentially according to the phase control signal from the Loop Control/Protection Logic. Pulse width is determined by current balance result and pin setting. Once quick response mechanism is triggered, VR will allow all PWM to turn on at the same time. PWM status is also controlled by Protection Logic. Different protections may cause different PWM status (Both High-Z or LG turn-on).

### SVID Interface/Configuration Registers/Control Logic

The interface receives the SVID signal from CPU and sends the relative signals to Loop Control/Protection Logic for loop control to execute the action by CPU. The registers save the pin setting data from ADC output. The Control Logic controls the ADC timing, generates the digital code of the VID for VSEN voltage.

### Loop Control/Protection Logic

It controls the power on sequence, the protection behavior, and the operational phase number.

### MUX and ADC

The MUX supports the inputs from SET1, SET2, SET3, IMON\_MAIN, IMON\_AUXI, TSEN\_MAIN and TSEN\_AUXI. The ADC converts these analog signals to digital codes for reporting or performance adjustment.

### Current Balance

Each phase current sense signal is sent to the current balance circuit which adjusts the on-time of each phase to optimize current sharing.

### Offset Cancellation

Cancel the current/voltage ripple issue to get the accurate VSEN.

### UVLO

Detect the VCC voltage and issue POR signal as they are high enough.

### DAC

Generate an analog signal according to the digital code generated by Control Logic.

### Soft-Start & Slew Rate Control

Control the Dynamic VID slew rate of VSEN according to the SetVID fast or SetVID slow.

### Error Amp

Error amplifier generates COMP\_MAIN/COMP\_AUXI/COMP\_SA signal by the difference between output of MAIN/AUXI/SA rail and FB\_MAIN/FB\_AUXI/FB\_SA.

### PWM CMP

The PWM comparator compares COMP signal and current feedback signal to generate a signal for TON trigger.

### IMON Filter

IMON Filter is used for average sum current signal by analog RC filter.

**Table 1. IMVP8 VID Code Table**

VID7	VID6	VID5	VID4	VID3	VID2	VID1	VID0	HEX	Voltage (V)
0	0	0	0	0	0	0	1	01	0.25
0	0	0	0	0	0	1	0	02	0.255
0	0	0	0	0	0	1	1	03	0.26
0	0	0	0	0	1	0	0	04	0.265
0	0	0	0	0	1	0	1	05	0.27
0	0	0	0	0	1	1	0	06	0.275
0	0	0	0	0	1	1	1	07	0.28
0	0	0	0	1	0	0	0	08	0.285
0	0	0	0	1	0	0	1	09	0.29
0	0	0	0	1	0	1	0	0A	0.295
0	0	0	0	1	0	1	1	0B	0.3
0	0	0	0	1	1	0	0	0C	0.305
0	0	0	0	1	1	0	1	0D	0.31
0	0	0	0	1	1	1	0	0E	0.315
0	0	0	0	1	1	1	1	0F	0.32
0	0	0	1	0	0	0	0	10	0.325
0	0	0	1	0	0	0	1	11	0.33
0	0	0	1	0	0	1	0	12	0.335
0	0	0	1	0	0	1	1	13	0.34
0	0	0	1	0	1	0	0	14	0.345
0	0	0	1	0	1	0	1	15	0.35
0	0	0	1	0	1	1	0	16	0.355
0	0	0	1	0	1	1	1	17	0.36
0	0	0	1	1	0	0	0	18	0.365
0	0	0	1	1	0	0	1	19	0.37
0	0	0	1	1	0	1	0	1A	0.375
0	0	0	1	1	0	1	1	1B	0.38
0	0	0	1	1	1	0	0	1C	0.385
0	0	0	1	1	1	0	1	1D	0.39
0	0	0	1	1	1	1	0	1E	0.395
0	0	0	1	1	1	1	1	1F	0.4
0	0	1	0	0	0	0	0	20	0.405
0	0	1	0	0	0	0	1	21	0.41
0	0	1	0	0	0	1	0	22	0.415
0	0	1	0	0	0	1	1	23	0.42
0	0	1	0	0	1	0	0	24	0.425

VID7	VID6	VID5	VID4	VID3	VID2	VID1	VID0	HEX	Voltage (V)
0	0	1	0	0	1	0	1	25	0.43
0	0	1	0	0	1	1	0	26	0.435
0	0	1	0	0	1	1	1	27	0.44
0	0	1	0	1	0	0	0	28	0.445
0	0	1	0	1	0	0	1	29	0.45
0	0	1	0	1	0	1	0	2A	0.455
0	0	1	0	1	0	1	1	2B	0.46
0	0	1	0	1	1	0	0	2C	0.465
0	0	1	0	1	1	0	1	2D	0.47
0	0	1	0	1	1	1	0	2E	0.475
0	0	1	0	1	1	1	1	2F	0.48
0	0	1	1	0	0	0	0	30	0.485
0	0	1	1	0	0	0	1	31	0.49
0	0	1	1	0	0	1	0	32	0.495
0	0	1	1	0	0	1	1	33	0.5
0	0	1	1	0	1	0	0	34	0.505
0	0	1	1	0	1	0	1	35	0.51
0	0	1	1	0	1	1	0	36	0.515
0	0	1	1	0	1	1	1	37	0.52
0	0	1	1	1	0	0	0	38	0.525
0	0	1	1	1	0	0	1	39	0.53
0	0	1	1	1	0	1	0	3A	0.535
0	0	1	1	1	0	1	1	3B	0.54
0	0	1	1	1	1	0	0	3C	0.545
0	0	1	1	1	1	0	1	3D	0.55
0	0	1	1	1	1	1	0	3E	0.555
0	0	1	1	1	1	1	1	3F	0.56
0	1	0	0	0	0	0	0	40	0.565
0	1	0	0	0	0	0	1	41	0.57
0	1	0	0	0	0	1	0	42	0.575
0	1	0	0	0	0	1	1	43	0.58
0	1	0	0	0	1	0	0	44	0.585
0	1	0	0	0	1	0	1	45	0.59
0	1	0	0	0	1	1	0	46	0.595
0	1	0	0	0	1	1	1	47	0.6
0	1	0	0	1	0	0	0	48	0.605
0	1	0	0	1	0	0	1	49	0.61

VID7	VID6	VID5	VID4	VID3	VID2	VID1	VID0	HEX	Voltage (V)
0	1	0	0	1	0	1	0	4A	0.615
0	1	0	0	1	0	1	1	4B	0.62
0	1	0	0	1	1	0	0	4C	0.625
0	1	0	0	1	1	0	1	4D	0.63
0	1	0	0	1	1	1	0	4E	0.635
0	1	0	0	1	1	1	1	4F	0.64
0	1	0	1	0	0	0	0	50	0.645
0	1	0	1	0	0	0	1	51	0.65
0	1	0	1	0	0	1	0	52	0.655
0	1	0	1	0	0	1	1	53	0.66
0	1	0	1	0	1	0	0	54	0.665
0	1	0	1	0	1	0	1	55	0.67
0	1	0	1	0	1	1	0	56	0.675
0	1	0	1	0	1	1	1	57	0.68
0	1	0	1	1	0	0	0	58	0.685
0	1	0	1	1	0	0	1	59	0.69
0	1	0	1	1	0	1	0	5A	0.695
0	1	0	1	1	0	1	1	5B	0.7
0	1	0	1	1	1	0	0	5C	0.705
0	1	0	1	1	1	0	1	5D	0.71
0	1	0	1	1	1	1	0	5E	0.715
0	1	0	1	1	1	1	1	5F	0.72
0	1	1	0	0	0	0	0	60	0.725
0	1	1	0	0	0	0	1	61	0.73
0	1	1	0	0	0	1	0	62	0.735
0	1	1	0	0	0	1	1	63	0.74
0	1	1	0	0	1	0	0	64	0.745
0	1	1	0	0	1	0	1	65	0.75
0	1	1	0	0	1	1	0	66	0.755
0	1	1	0	0	1	1	1	67	0.76
0	1	1	0	1	0	0	0	68	0.765
0	1	1	0	1	0	0	1	69	0.77
0	1	1	0	1	0	1	0	6A	0.775
0	1	1	0	1	0	1	1	6B	0.78
0	1	1	0	1	1	0	0	6C	0.785
0	1	1	0	1	1	0	1	6D	0.79
0	1	1	0	1	1	1	0	6E	0.795

VID7	VID6	VID5	VID4	VID3	VID2	VID1	VID0	HEX	Voltage (V)
0	1	1	0	1	1	1	1	6F	0.8
0	1	1	1	0	0	0	0	70	0.805
0	1	1	1	0	0	0	1	71	0.81
0	1	1	1	0	0	1	0	72	0.815
0	1	1	1	0	0	1	1	73	0.82
0	1	1	1	0	1	0	0	74	0.825
0	1	1	1	0	1	0	1	75	0.83
0	1	1	1	0	1	1	0	76	0.835
0	1	1	1	0	1	1	1	77	0.84
0	1	1	1	1	0	0	0	78	0.845
0	1	1	1	1	0	0	1	79	0.85
0	1	1	1	1	0	1	0	7A	0.855
0	1	1	1	1	0	1	1	7B	0.86
0	1	1	1	1	1	0	0	7C	0.865
0	1	1	1	1	1	0	1	7D	0.87
0	1	1	1	1	1	1	0	7E	0.875
0	1	1	1	1	1	1	1	7F	0.88
1	0	0	0	0	0	0	0	80	0.885
1	0	0	0	0	0	0	1	81	0.89
1	0	0	0	0	0	1	0	82	0.895
1	0	0	0	0	0	1	1	83	0.9
1	0	0	0	0	1	0	0	84	0.905
1	0	0	0	0	1	0	1	85	0.91
1	0	0	0	0	1	1	0	86	0.915
1	0	0	0	0	1	1	1	87	0.92
1	0	0	0	1	0	0	0	88	0.925
1	0	0	0	1	0	0	1	89	0.93
1	0	0	0	1	0	1	0	8A	0.935
1	0	0	0	1	0	1	1	8B	0.94
1	0	0	0	1	1	0	0	8C	0.945
1	0	0	0	1	1	0	1	8D	0.95
1	0	0	0	1	1	1	0	8E	0.955
1	0	0	0	1	1	1	1	8F	0.96
1	0	0	1	0	0	0	0	90	0.965
1	0	0	1	0	0	0	1	91	0.97
1	0	0	1	0	0	1	0	92	0.975
1	0	0	1	0	0	1	1	93	0.98

VID7	VID6	VID5	VID4	VID3	VID2	VID1	VID0	HEX	Voltage (V)
1	0	0	1	0	1	0	0	94	0.985
1	0	0	1	0	1	0	1	95	0.99
1	0	0	1	0	1	1	0	96	0.995
1	0	0	1	0	1	1	1	97	1
1	0	0	1	1	0	0	0	98	1.005
1	0	0	1	1	0	0	1	99	1.01
1	0	0	1	1	0	1	0	9A	1.015
1	0	0	1	1	0	1	1	9B	1.02
1	0	0	1	1	1	0	0	9C	1.025
1	0	0	1	1	1	0	1	9D	1.03
1	0	0	1	1	1	1	0	9E	1.035
1	0	0	1	1	1	1	1	9F	1.04
1	0	1	0	0	0	0	0	A0	1.045
1	0	1	0	0	0	0	1	A1	1.05
1	0	1	0	0	0	1	0	A2	1.055
1	0	1	0	0	0	1	1	A3	1.06
1	0	1	0	0	1	0	0	A4	1.065
1	0	1	0	0	1	0	1	A5	1.07
1	0	1	0	0	1	1	0	A6	1.075
1	0	1	0	0	1	1	1	A7	1.08
1	0	1	0	1	0	0	0	A8	1.085
1	0	1	0	1	0	0	1	A9	1.09
1	0	1	0	1	0	1	0	AA	1.095
1	0	1	0	1	0	1	1	AB	1.1
1	0	1	0	1	1	0	0	AC	1.105
1	0	1	0	1	1	0	1	AD	1.11
1	0	1	0	1	1	1	0	AE	1.115
1	0	1	0	1	1	1	1	AF	1.12
1	0	1	1	0	0	0	0	B0	1.125
1	0	1	1	0	0	0	1	B1	1.13
1	0	1	1	0	0	1	0	B2	1.135
1	0	1	1	0	0	1	1	B3	1.14
1	0	1	1	0	1	0	0	B4	1.145
1	0	1	1	0	1	0	1	B5	1.15
1	0	1	1	0	1	1	0	B6	1.155
1	0	1	1	0	1	1	1	B7	1.16
1	0	1	1	1	0	0	0	B8	1.165

VID7	VID6	VID5	VID4	VID3	VID2	VID1	VID0	HEX	Voltage (V)
1	0	1	1	1	0	0	1	B9	1.17
1	0	1	1	1	0	1	0	BA	1.175
1	0	1	1	1	0	1	1	BB	1.18
1	0	1	1	1	1	0	0	BC	1.185
1	0	1	1	1	1	0	1	BD	1.19
1	0	1	1	1	1	1	0	BE	1.195
1	0	1	1	1	1	1	1	BF	1.2
1	1	0	0	0	0	0	0	C0	1.205
1	1	0	0	0	0	0	1	C1	1.21
1	1	0	0	0	0	1	0	C2	1.215
1	1	0	0	0	0	1	1	C3	1.22
1	1	0	0	0	1	0	0	C4	1.225
1	1	0	0	0	1	0	1	C5	1.23
1	1	0	0	0	1	1	0	C6	1.235
1	1	0	0	0	1	1	1	C7	1.24
1	1	0	0	1	0	0	0	C8	1.245
1	1	0	0	1	0	0	1	C9	1.25
1	1	0	0	1	0	1	0	CA	1.255
1	1	0	0	1	0	1	1	CB	1.26
1	1	0	0	1	1	0	0	CC	1.265
1	1	0	0	1	1	0	1	CD	1.27
1	1	0	0	1	1	1	0	CE	1.275
1	1	0	0	1	1	1	1	CF	1.28
1	1	0	1	0	0	0	0	D0	1.285
1	1	0	1	0	0	0	1	D1	1.29
1	1	0	1	0	0	1	0	D2	1.295
1	1	0	1	0	0	1	1	D3	1.3
1	1	0	1	0	1	0	0	D4	1.305
1	1	0	1	0	1	0	1	D5	1.31
1	1	0	1	0	1	1	0	D6	1.315
1	1	0	1	0	1	1	1	D7	1.32
1	1	0	1	1	0	0	0	D8	1.325
1	1	0	1	1	0	0	1	D9	1.33
1	1	0	1	1	0	1	0	DA	1.335
1	1	0	1	1	0	1	1	DB	1.34
1	1	0	1	1	1	0	0	DC	1.345
1	1	0	1	1	1	0	1	DD	1.35

VID7	VID6	VID5	VID4	VID3	VID2	VID1	VID0	HEX	Voltage (V)
1	1	0	1	1	1	1	0	DE	1.355
1	1	0	1	1	1	1	1	DF	1.36
1	1	1	0	0	0	0	0	E0	1.365
1	1	1	0	0	0	0	1	E1	1.37
1	1	1	0	0	0	1	0	E2	1.375
1	1	1	0	0	0	1	1	E3	1.38
1	1	1	0	0	1	0	0	E4	1.385
1	1	1	0	0	1	0	1	E5	1.39
1	1	1	0	0	1	1	0	E6	1.395
1	1	1	0	0	1	1	1	E7	1.4
1	1	1	0	1	0	0	0	E8	1.405
1	1	1	0	1	0	0	1	E9	1.41
1	1	1	0	1	0	1	0	EA	1.415
1	1	1	0	1	0	1	1	EB	1.42
1	1	1	0	1	1	0	0	EC	1.425
1	1	1	0	1	1	0	1	ED	1.43
1	1	1	0	1	1	1	0	EE	1.435
1	1	1	0	1	1	1	1	EF	1.44
1	1	1	1	0	0	0	0	F0	1.445
1	1	1	1	0	0	0	1	F1	1.45
1	1	1	1	0	0	1	0	F2	1.455
1	1	1	1	0	0	1	1	F3	1.46
1	1	1	1	0	1	0	0	F4	1.465
1	1	1	1	0	1	0	1	F5	1.47
1	1	1	1	0	1	1	0	F6	1.475
1	1	1	1	0	1	1	1	F7	1.48
1	1	1	1	1	0	0	0	F8	1.485
1	1	1	1	1	0	0	1	F9	1.49
1	1	1	1	1	0	1	0	FA	1.495
1	1	1	1	1	0	1	1	FB	1.5
1	1	1	1	1	1	0	0	FC	1.505
1	1	1	1	1	1	0	1	FD	1.51
1	1	1	1	1	1	1	0	FE	1.515
1	1	1	1	1	1	1	1	FF	1.52

## Absolute Maximum Ratings (Note 1)

- VCC to GND ----- -0.3V to 6.5V
- RGND to GND ----- -0.3V to 0.3V
- VIN to GND ----- -0.3V to 28
- PVCC to GND ----- -0.3V to 6.5V
- Other Pins ----- -0.3V to (V<sub>CC</sub> + 0.3V)
- Power Dissipation, P<sub>D</sub> @ T<sub>A</sub> = 25°C
  - WQFN-48L 6x6 ----- 3.73W
- Package Thermal Resistance (Note 2)
  - WQFN-48L 6x6, θ<sub>JA</sub> ----- 26.8°C/W
  - WQFN-48L 6x6, θ<sub>JC</sub> ----- 1.3°C/W
- Junction Temperature ----- 150°C
- Lead Temperature (Soldering, 10 sec.) ----- 260°C
- Storage Temperature Range ----- -65°C to 150°C
- ESD Susceptibility (Note 3)
  - HBM (Human Body Model) ----- 2kV

## Recommended Operating Conditions (Note 4)

- Supply Voltage, VIN ----- 4.5V to 24V
- Supply Voltage, VCC ----- 4.5V to 5.5V
- Driver Supply Voltage, PVCC ----- 4.5V to 5.5V
- Junction Temperature Range ----- -40°C to 125°C
- Ambient Temperature Range ----- -40°C to 85°C

## Electrical Characteristics

(V<sub>CC</sub> = 5V, T<sub>A</sub> = 25°C, unless otherwise specified)

Parameter	Symbol	Test Conditions	Min	Typ	Max	Unit
<b>Supply Input</b>						
Supply Voltage	V <sub>CC</sub>		4.5	5	5.5	V
Driver Supply Voltage	V <sub>PVCC</sub>		4.5	--	5.5	V
Supply Current	I <sub>VCC</sub>	V <sub>EN</sub> = 1.05V, No Switching	--	9	15	mA
Supply Current at PS4	I <sub>VCC_PS4</sub>	V <sub>EN</sub> = 1.05V, No Switching	--	0.2	0.25	
Shutdown Current	I <sub>SHDN</sub>	V <sub>EN</sub> = 0V	--	10	20	μA
<b>Reference and DAC</b>						
DAC Accuracy	V <sub>FB</sub>	VDAC = 0.75V – 1.52V	-0.5%	0	0.5%	% of VID
		VDAC = 0.5V – 0.745V	-8	0	8	mV
		VDAC = 0.25V – 0.495V	-10	0	10	
<b>Slew Rate</b>						
Dynamic VID Slew Rate	SR	Set VID Fast	30	34	38	mV/μs
		Set VID Slow, set slow = 1/2 Fast	15	17	19	

Parameter	Symbol	Test Conditions	Min	Typ	Max	Unit
<b>EA Amplifier</b>						
DC Gain	ADC	$R_L = 47k\Omega$	70	80	--	dB
Gain-Bandwidth Product	GBW	$C_{LOAD} = 5pF$	--	5	--	MHz
Input Offset	VEAOF5		-3	--	3	mV
Slew Rate	SREA	$C_{LOAD} = 10pF$ (Gain= -4, $R_F = 47k\Omega$ , $V_{OUT} = 0.5V$ to $-3V$ )	--	5	--	V/ $\mu$ s
Output Voltage Range	V <sub>COMP</sub>	$R_L = 47k\Omega$	0.3	--	3.6	V
Max Source/Sink Current	I <sub>OUTEA</sub>	$V_{COMP} = 2V$	--	5	--	mA
<b>Current Sensing Amplifier</b>						
Input Offset Voltage	V <sub>OSCS</sub>		-0.4	--	0.4	mV
Impedance at Positive Input	R <sub>ISENxP</sub>		1	--	--	M $\Omega$
Current Mirror Gain	A <sub>MIRROR</sub>	I <sub>MON</sub> /I <sub>SENxN</sub>	0.97	1	1.03	A/A
Input Range	V <sub>ISEN_IN</sub>	$V_{DAC} = 1.1V$ , I <sub>SENP_x</sub> - I <sub>SENN_x</sub>	-40	--	40	mV
<b>TON Setting</b>						
On-Time Setting	t <sub>ON</sub>	$V_{IN} = 10V$ , $V_{DAC} = 1V$ , Freq. = 400k	--	250	--	ns
Minimum Off time	t <sub>OFF</sub>	$V_{DAC} = 1$	--	180	300	ns
<b>Protections</b>						
Under-Voltage Lockout Threshold	V <sub>UVLO</sub>	Falling edge	3.9	4.1	4.2	V
	$\Delta V_{UVLO}$	Rising edge hysteresis	100	170	250	mV
Over-Voltage Protection Threshold	V <sub>OV</sub>	Respect to VID voltage	VID + 300	VID + 350	VID + 400	mV
		Lower limit to 1V	1300	1350	1400	mV
Under-Voltage Protection Threshold	V <sub>UV</sub>	Respect to VID voltage	-400	-350	-300	mV
						mV
Negative Voltage Protection Threshold	V <sub>NV</sub>		-100	-50	--	mV
<b>VRON and VR_READY</b>						
VRON Threshold	V <sub>IH</sub>	Respect to 1V, 70%	0.7	--	--	V
	V <sub>IL</sub>	Respect to 1V, 30%	--	--	0.3	V
Leakage Current of VRON			-1	--	1	$\mu$ A
PGOOD Pull Low Voltage	V <sub>PGOOD</sub>	I <sub>VR_Ready</sub> = 10mA	--	--	0.13	V
<b>Serial VID and VR_HOT</b>						
VCLK, VDIO	V <sub>IH</sub>	Respect to INTEL Spec. with 50mV hysteresis	0.65	--	--	V
	V <sub>IL</sub>		--	--	0.45	
Leakage Current of VCLK, VDIO, ALERT and VR_HOT	I <sub>LEAK_IN</sub>		-1	--	1	$\mu$ A

Parameter	Symbol	Test Conditions	Min	Typ	Max	Unit
VDIO, $\overline{\text{ALERT}}$ and $\overline{\text{VR\_HOT}}$ Pull Low Voltage		I <sub>VDIO</sub> = 10mA	--	--	0.13	V
		I $\overline{\text{ALERT}}$ = 10mA				
		I $\overline{\text{VR\_HOT}}$ = 10mA				
<b>VREF</b>						
VREF06	V <sub>REF</sub>		0.595	0.6	0.605	V
<b>ADC</b>						
Digital IMON Set	V <sub>IMON</sub>	V <sub>IMON</sub> – V <sub>IMON_INI</sub> = 0.8V, MAIN rail 2 phase application	--	255	--	Decimal
		V <sub>IMON</sub> – V <sub>IMON_INI</sub> = 0.4V, single phase application	--	255	--	
Update Period	t <sub>IMON</sub>		--	125	--	μs
TSEN Threshold for Tmp_Zone[7] Transition	V <sub>TSEN</sub>	100°C	--	1.092	--	V
TSEN Threshold for Tmp_Zone[6] Transition		97°C	--	1.132	--	
TSEN Threshold for Tmp_Zone[5] Transition		94°C	--	1.176	--	
TSEN Threshold for Tmp_Zone[4] Transition		91°C	--	1.226	--	
TSEN Threshold for Tmp_Zone[3] Transition		88°C	--	1.283	--	
TSEN Threshold for Tmp_Zone[2] Transition		85°C	--	1.346	--	
TSEN Threshold for Tmp_Zone[1] Transition		82°C	--	1.418	--	
TSEN Threshold for Tmp_Zone[0] Transition		75°C	--	1.624	--	
Update Period	t <sub>TSEN</sub>		--	100	--	μs
<b>PWM Driving Capability</b>						
PWM_x	R <sub>PWMsr</sub>		--	20	--	Ω
	R <sub>PWMsk</sub>		--	10	--	
<b>ITSEN</b>						
TSEN Source Current	I <sub>TSEN</sub>	TSEN = 1.6V	79.2	80	80.8	μA

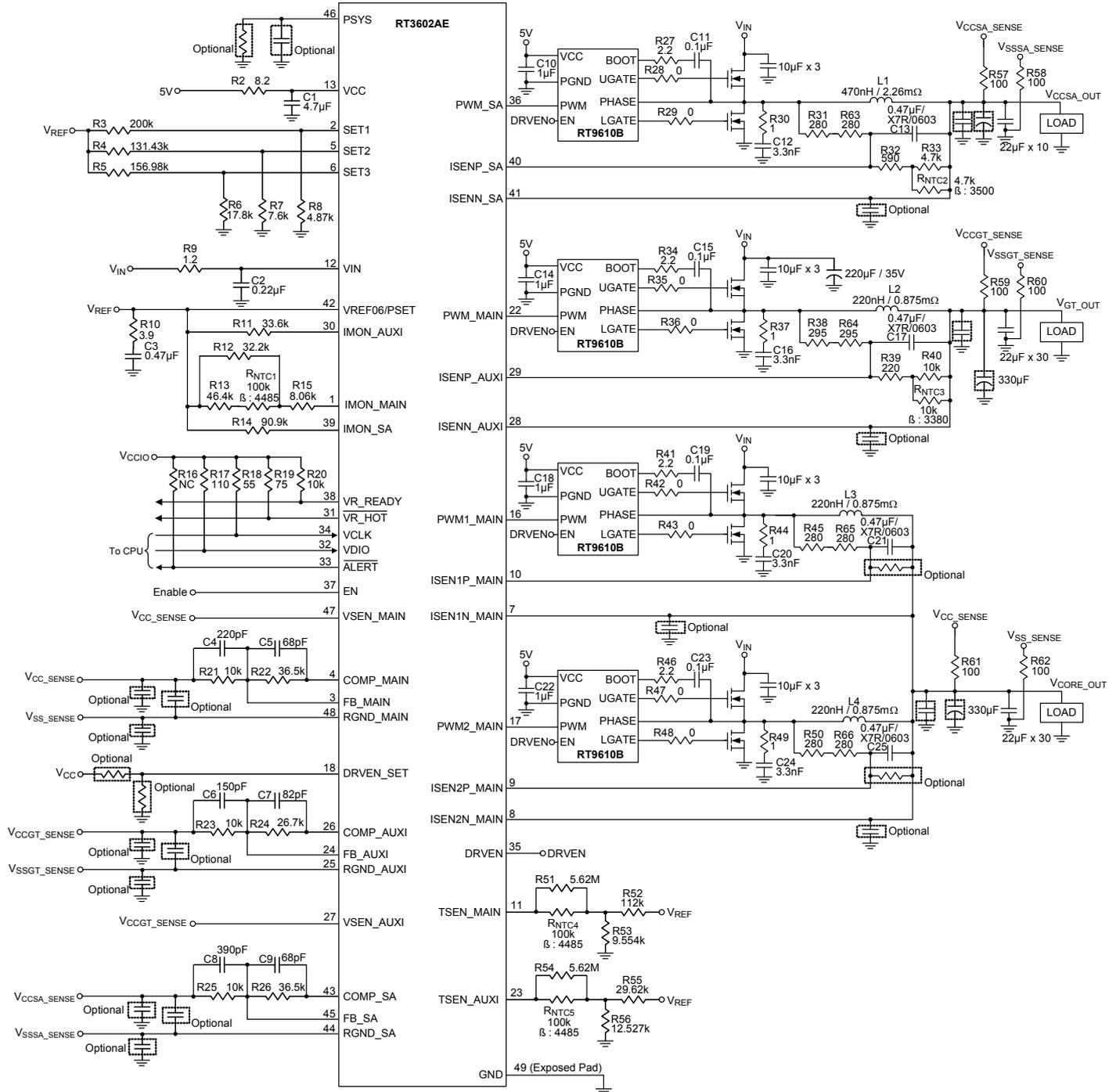
**Note 1.** Stresses beyond those listed “Absolute Maximum Ratings” may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions may affect device reliability.

**Note 2.** θ<sub>JA</sub> is measured under natural convection (still air) at T<sub>A</sub> = 25°C with the component mounted on a high effective-thermal-conductivity four-layer test board on a JEDEC 51-7 thermal measurement standard. θ<sub>JC</sub> is measured at the exposed pad of the package.

**Note 3.** Devices are ESD sensitive. Handling precaution is recommended.

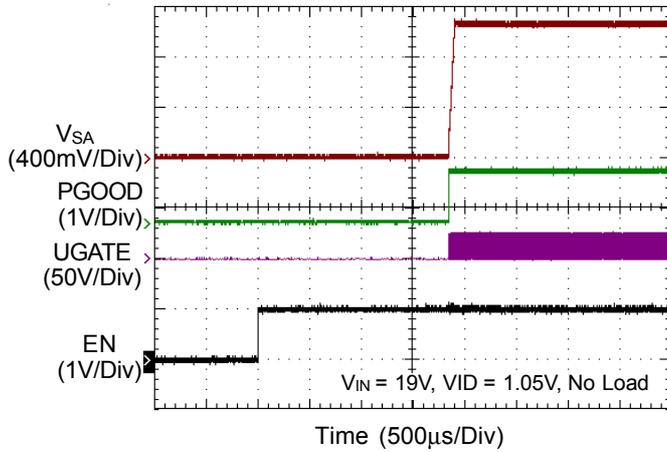
**Note 4.** The device is not guaranteed to function outside its operating conditions.

**Typical Application Circuit**

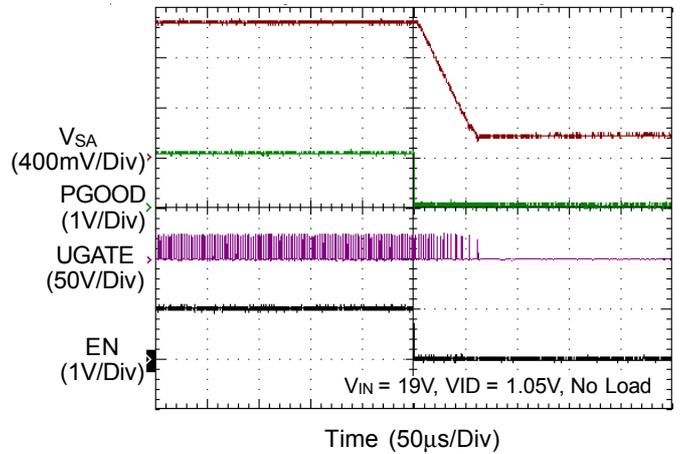


Typical Operating Characteristics

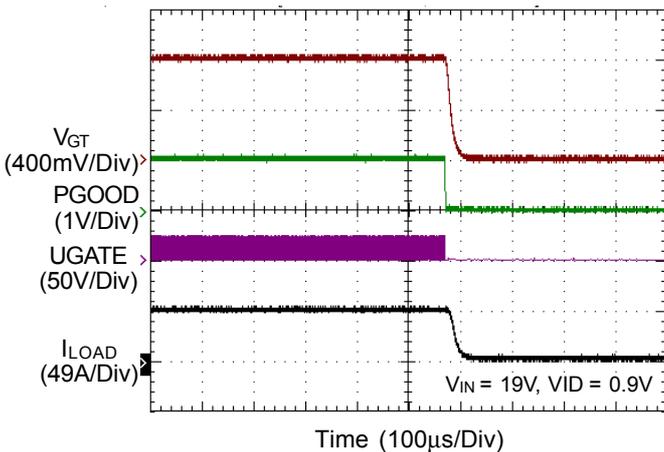
VR Power On from EN



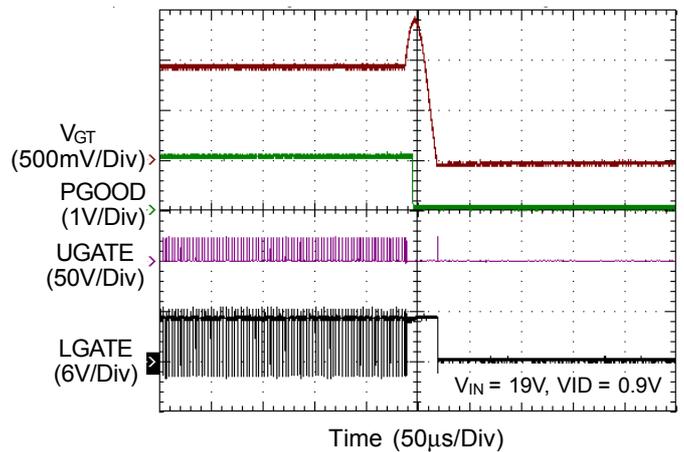
VR Power Off from EN



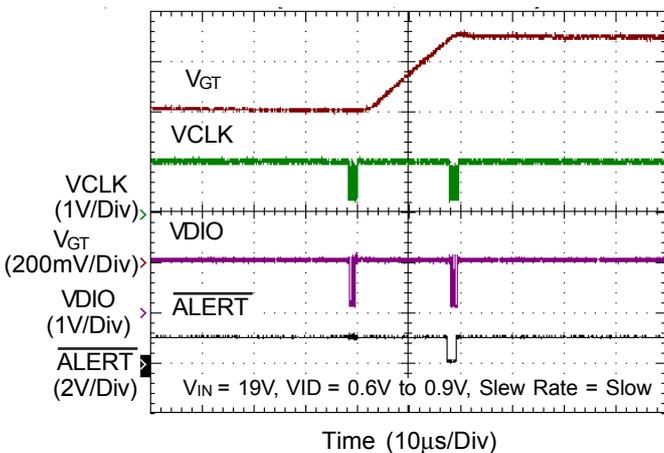
GT VR OCP



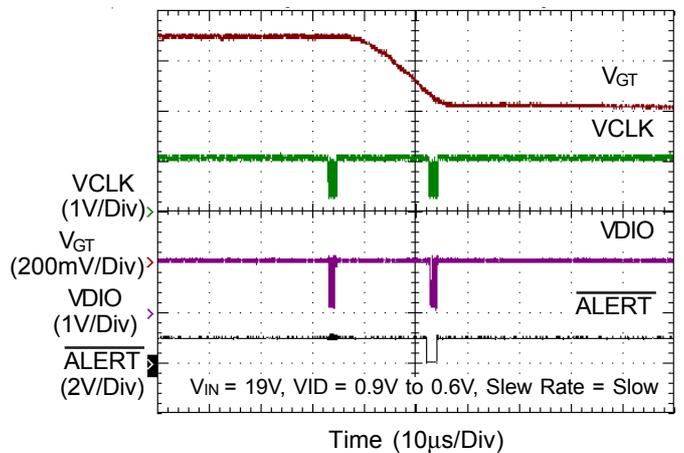
GT VR OVP



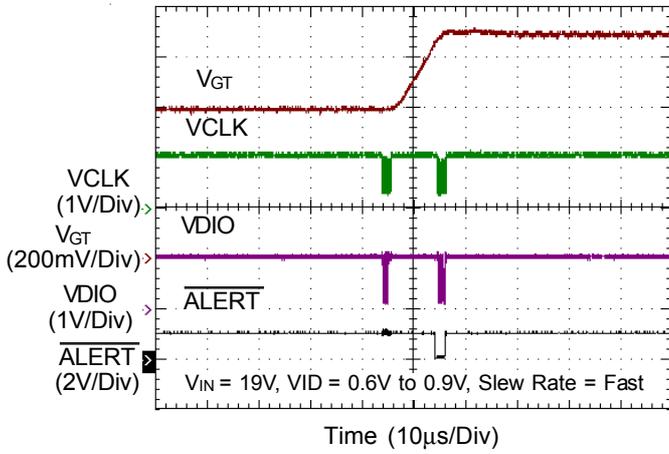
GT VR Dynamic VID Up



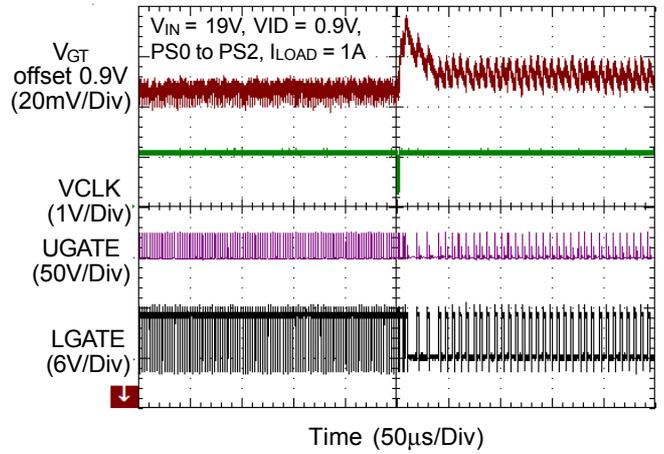
GT VR Dynamic VID Down



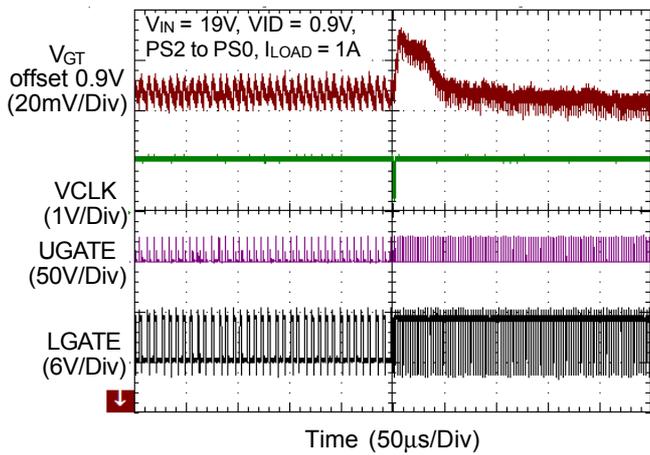
GT VR Dynamic VID Up



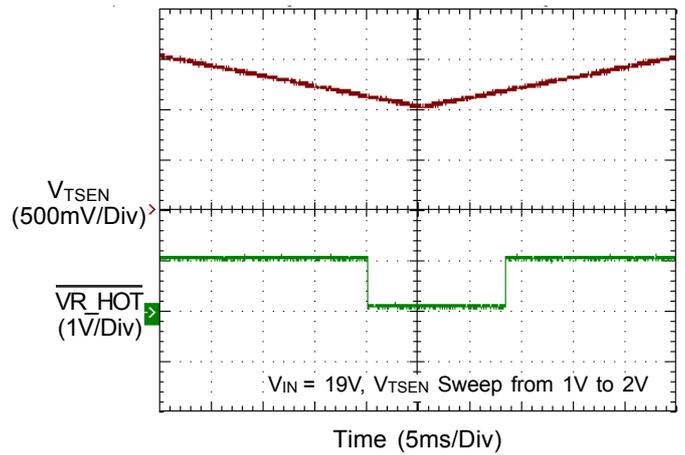
GT VR Mode Transient



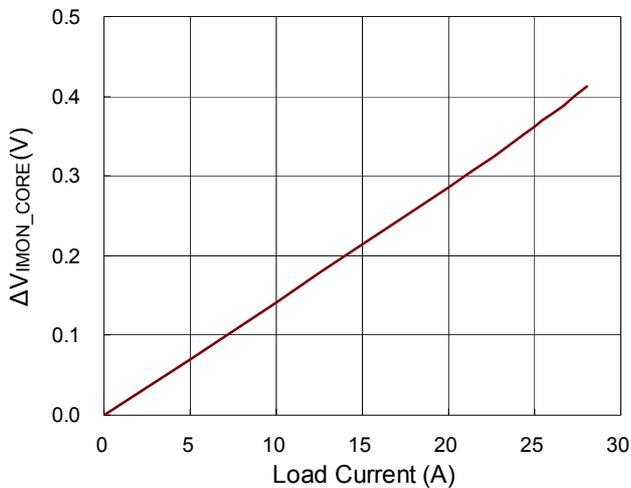
GT VR Mode Transient



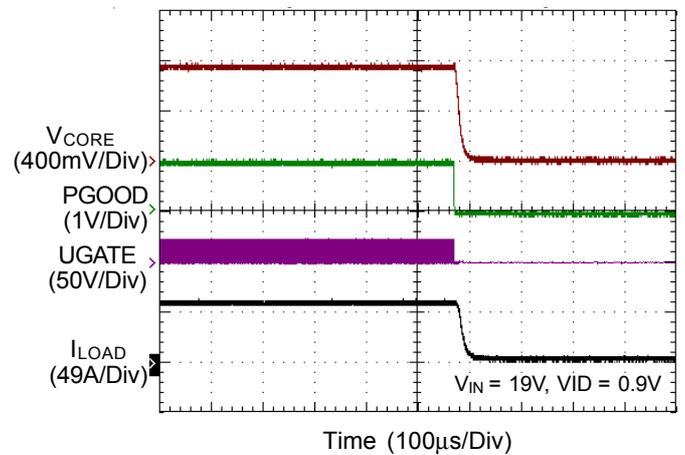
GT VR Thermal Monitoring



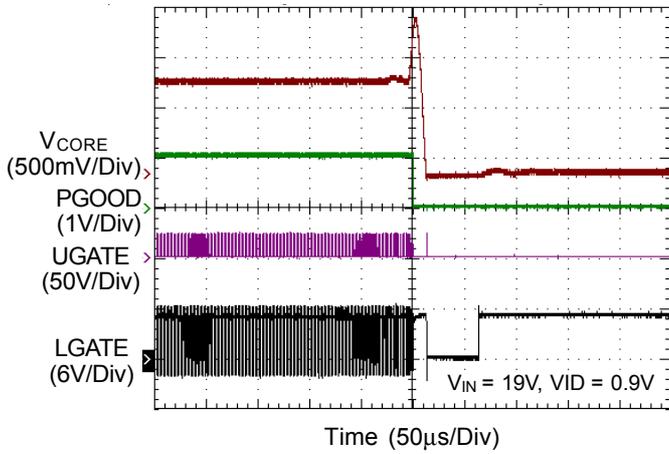
$\Delta V_{MON\_CORE}$  vs. Load Current



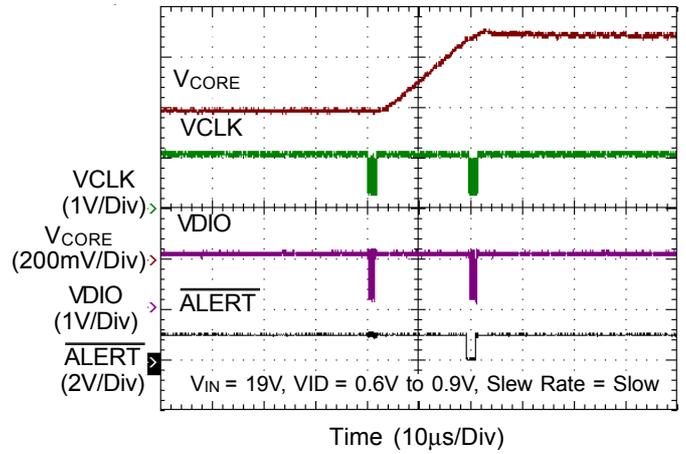
CORE VR OCP



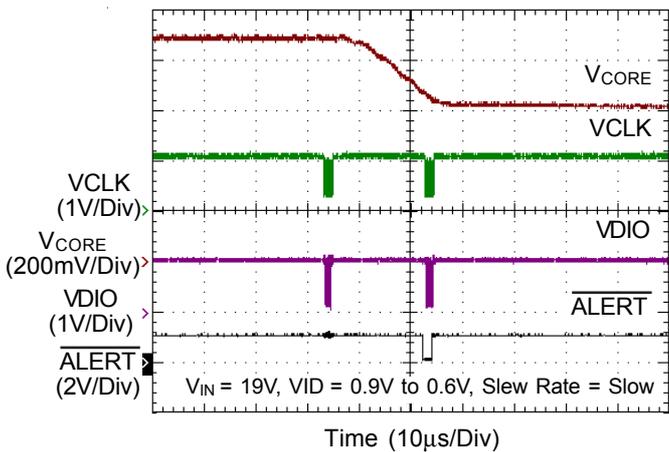
CORE VR OVP



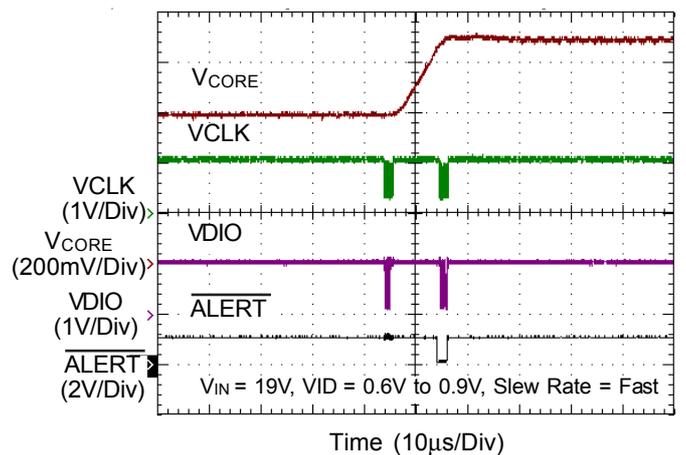
CORE VR Dynamic VID Up



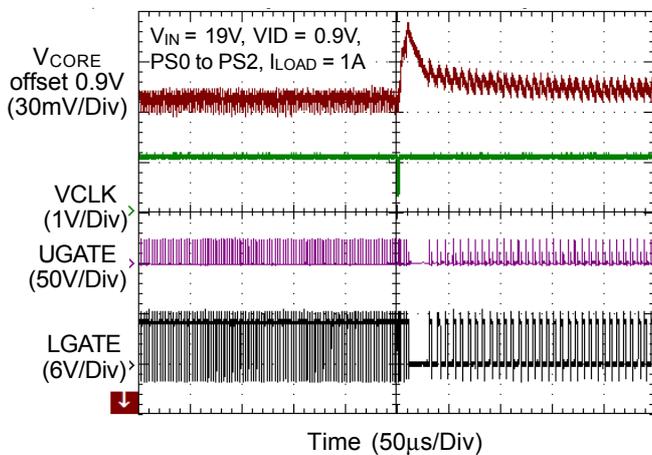
CORE VR Dynamic VID Down



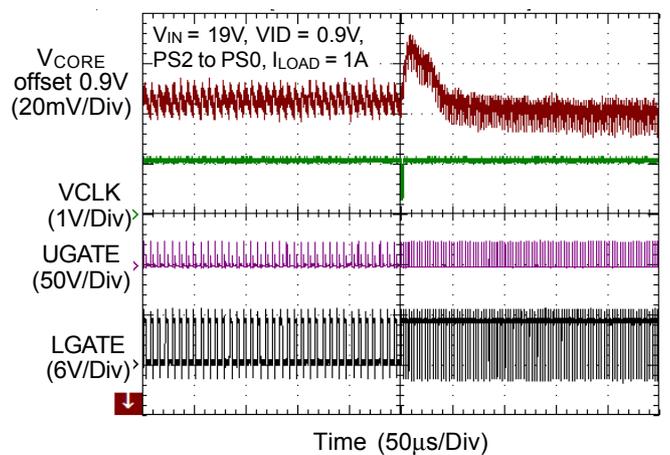
CORE VR Dynamic VID Up



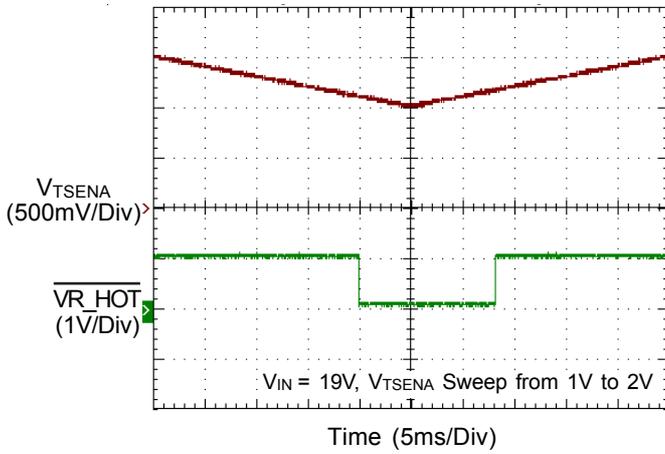
CORE VR Mode Transient



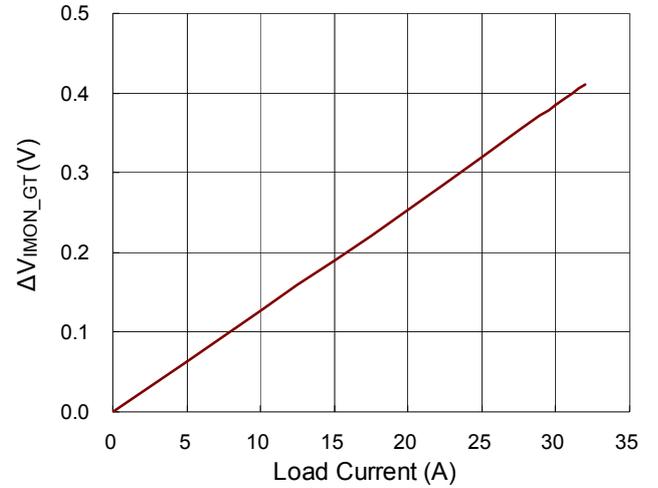
CORE VR Mode Transient



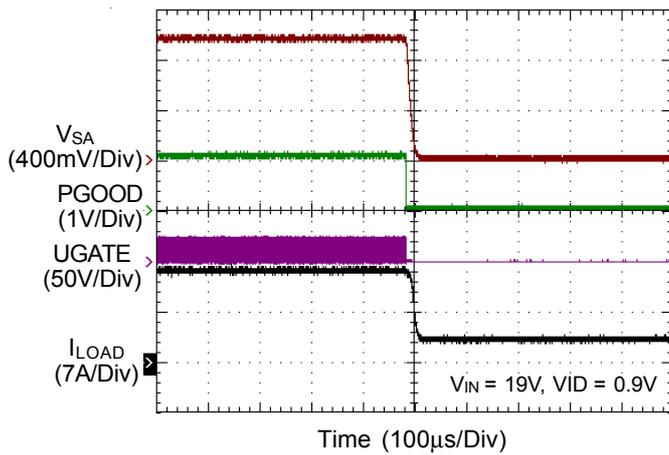
**CORE VR Thermal Monitoring**



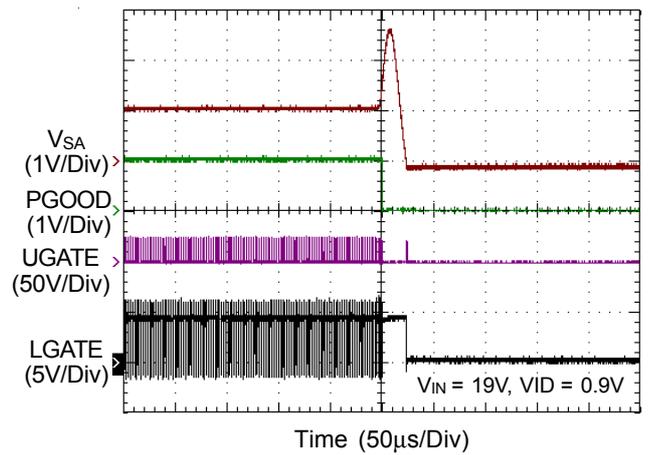
**$\Delta V_{MON\_GT}$  vs. Load Current**



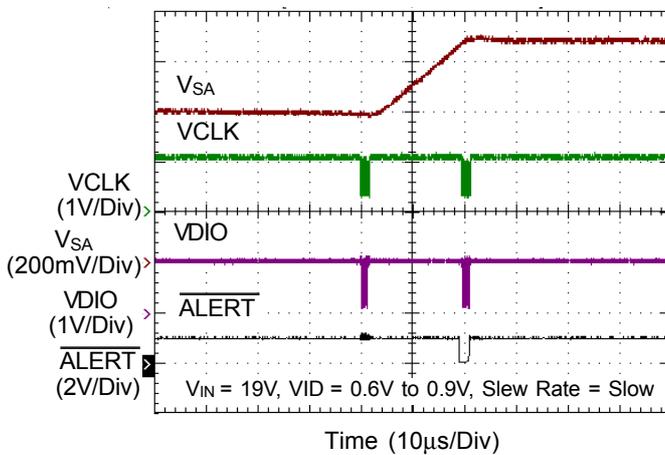
**SA VR OCP**



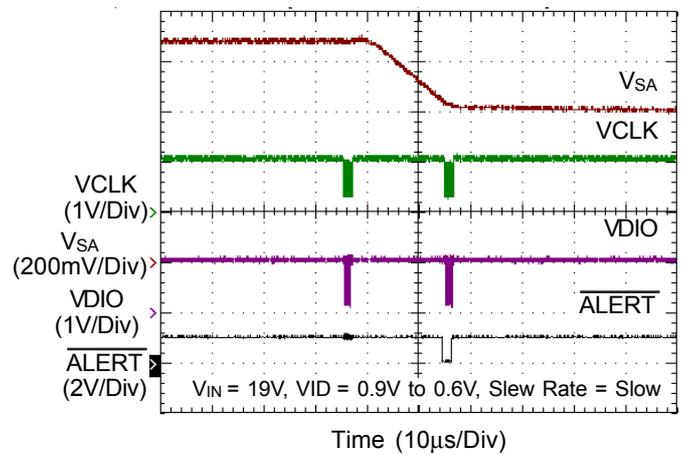
**SA VR OVP**



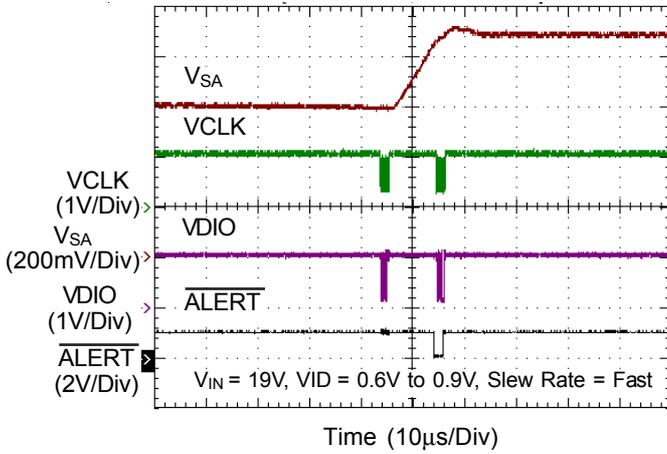
**SA VR Dynamic VID Up**



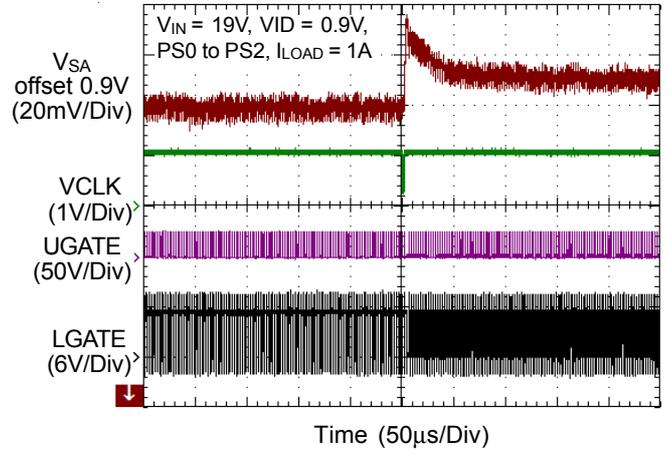
**SA VR Dynamic VID Down**



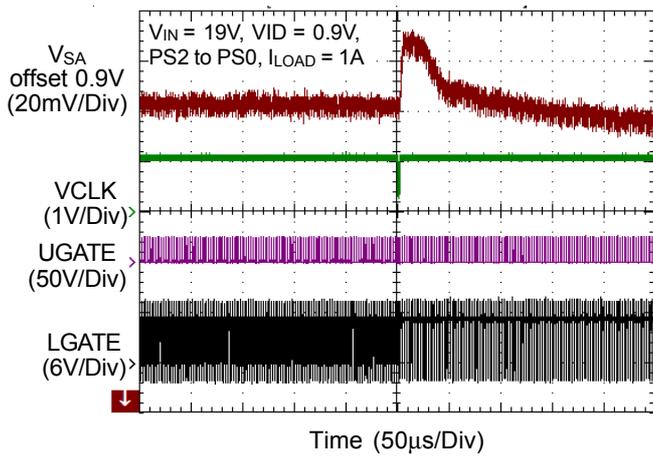
SA VR Dynamic VID Up



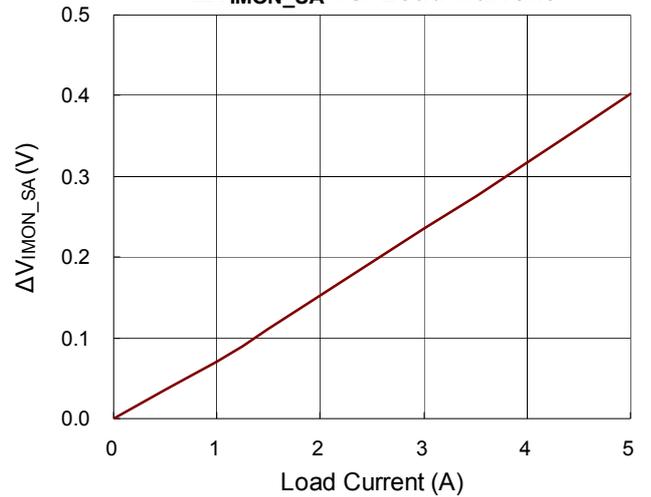
SA VR Mode Transient



SA VR Mode Transient



$\Delta V_{MON\_SA}$  vs. Load Current



## Applications information

The RT3602AE includes three voltage rails : a single phase synchronous Buck controller, the MAIN VR, a 2/1 multiphase synchronous Buck controller, the auxiliary VR, and a single phase synchronous Buck controller, the VCCSA VR, designed to meet Intel IMVP8 compatible CPUs specification with a serial SVID control interface. The controller uses an ADC to implement all kinds of settings to save total pin number for easy use and increasing PCB space utilization. The RT3602AE is used in notebooks, desktop computers and servers.

### General loop Function

#### G-NAVP™ Control Mode

The RT3602AE adopts the G-NAVP™ controller, which is a current mode constant on-time control with DC offset cancellation. The approach can not only improve DC offset problem for increasing system accuracy but also provide fast transient response. When current feedback signal reaches comp signal, the RT3602AE generates an on-time width to achieve PWM modulation. Figure 1 shows the basic G-NAVP™ behavior waveforms in continuous conduct mode (CCM).

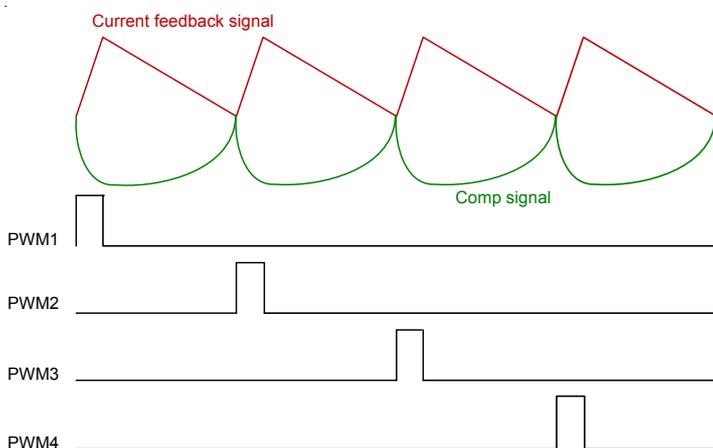


Figure 1 (a). G-NAVP™ Behavior Waveforms in CCM in Steady State

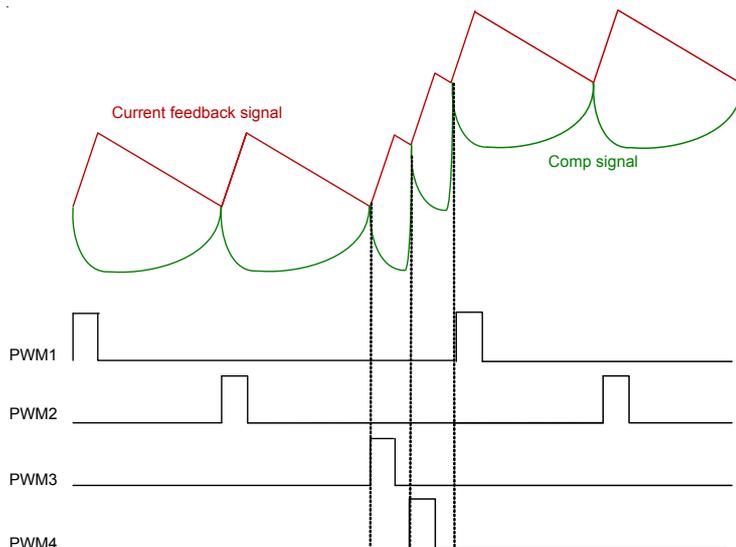


Figure 1 (b). G-NAVP™ Behavior Waveforms in CCM in Load Transient.

#### Diode Emulation Mode (DEM)

As well-known, the dominate power loss is switching related loss during light load, hence VR needs to be operated in asynchronous mode (or called discontinuous conduct mode, DCM) to reduce switching related loss since switching frequency is dependent on loading in the asynchronous mode. The RT3602AE can operate in diode emulation mode (DEM) to improve light load efficiency. In DEM operation, the behavior of low-side MOSFET(s) needs to work like a diode, that is, the low-side MOSFET(s) will be turned on when the phase voltage is a negative value, i.e. the inductor current follows from Source to Drain of low-side MOSFET(s). And the low-side MOSFET(s) will be turned off when phase voltage is a positive value, i.e. reversed current is not allowed. Figure 2 shows the control behavior in DEM. Figure 3 shows the G-NAVP™ operation in DEM to illustrate the control behaviors. When the load decreases, the discharge time of output capacitors increases during UGATE and LGATE are turned off. Hence, the switching frequency and switching loss will be reduced to improve efficiency in light load condition.

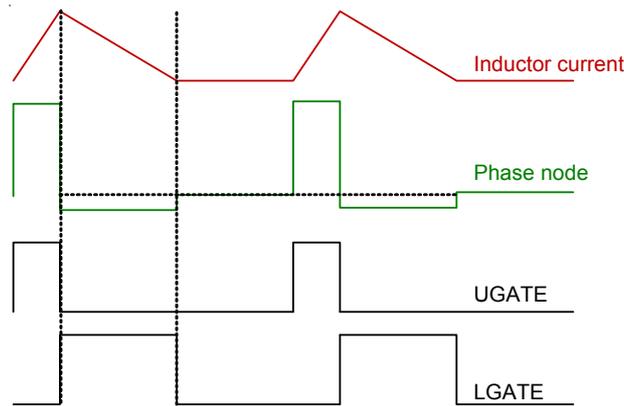


Figure 2. Diode Emulation Mode (DEM) in Steady State

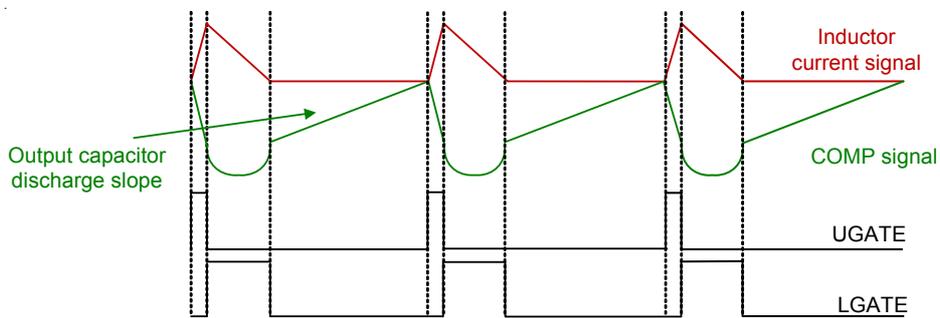


Figure 3. (a)

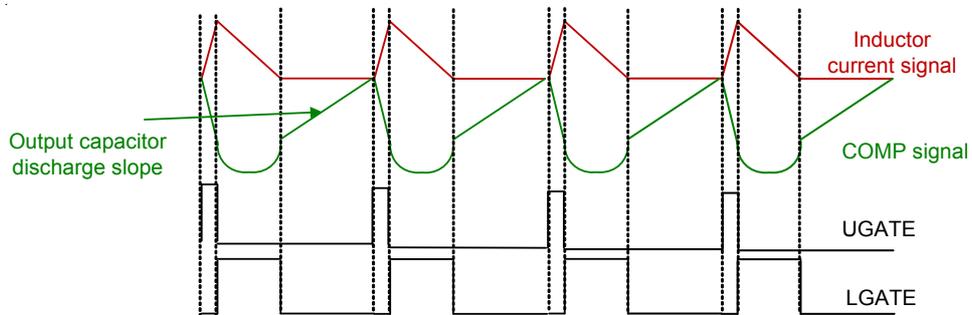


Figure 3. (b)

Figure 3. G-NAVPTM Operation in DEM. (a) : The load is lighter, output capacitor discharge slope is smaller and the switching frequency is lower. (b) : The load is increasing, output capacitor discharge slope is increased and switching frequency is increased, too.

**Phase Interleaving Function**

The RT3602AE is a multi-output controller, the AUXI rail of the IC has a phase interleaving function, 180 degree phase shift for 2-phase operation which can help reduce output voltage ripple and EMI problem.

**Multi-Function Pin Setting Mechanism**

For reducing total pin number of package, SET [1:3], TSEN\_MAIN and TSEN\_AUXI pins adopt the multi-function pin setting mechanism in the RT3602AE. Figure 4 illustrates this operating mechanism for SET [1:3]. The voltage at VREF pin will be pulled up to 3.2V after power ready (POR). First, external voltage divider is used to set the Function1, and then internal current source 80µA is used to set the Function2. The setting voltage of Function1 and Function2 can be represented as

$$V_{Function1} = \frac{R2}{R1+R2} \times 3.2V$$

$$V_{Function2} = 80\mu A \times \frac{R1 \times R2}{R1+R2}$$

All function setting will be done within 500µs after power ready (POR), and the voltage at VREF pin will be fixed to 0.6V after all function setting over.

If  $V_{Function1}$  and  $V_{Function2}$  are determined, R1 and R2 can be calculated as follows :

$$R1 = \frac{3.2V \times V_{Function2}}{80\mu A \times V_{Function1}}$$

$$R2 = \frac{R1 \times V_{Function1}}{3.2V - V_{Function1}}$$

Connecting a R3 resistor from SETx pin or SETAx pin to the middle node of voltage divider can help to fine tune the set voltage of Function 2, which does not affect the set voltage of Function1. The Figure 5 shows the setting method and the set voltage of Function 1 and Function2 can be represented as :

$$V_{Function1} = \frac{R2}{R1+R2} \times 3.2V$$

$$V_{Function2} = 80\mu A \times \left( R3 + \frac{R1 \times R2}{R1+R2} \right)$$

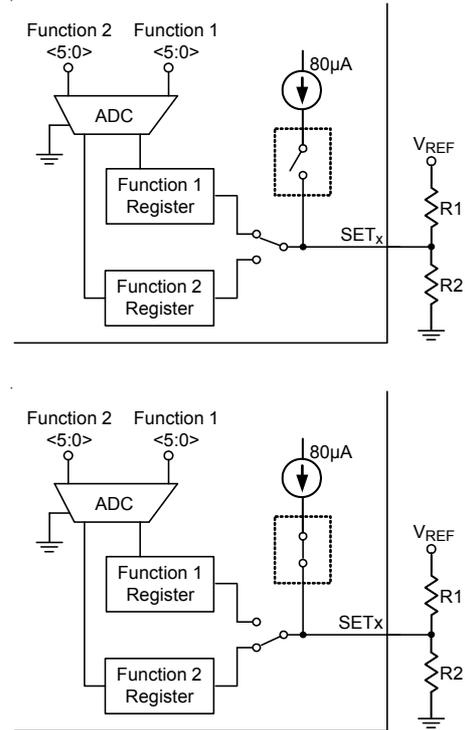


Figure 4. Multi-Function Pin Setting Mechanism for SET [1:3]

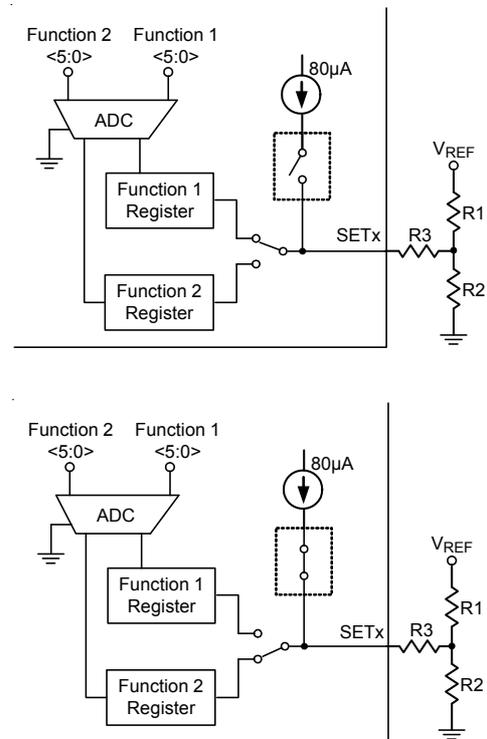


Figure 5. Multi-Function Pin Setting Mechanism with a R3 Resistor to Fine Tune the Set Voltage of Function2

Figure 6 shows operating mechanism for TSEN\_MAIN and TSEN\_AUX1 pins. There is only voltage divider Function to program VR. The internal current source is used to thermal sensing. The Function for program VR can be represented as

$$V_{\text{Function1}} = \frac{R2}{R1+R2} \times 3.2V$$

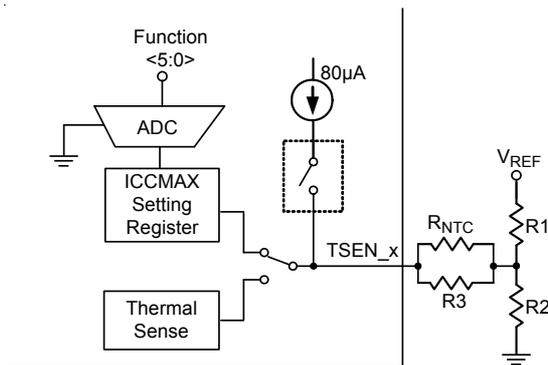


Figure 6. Multi-Function Pin Setting Mechanism for TSEN\_MAIN and TSEN\_AUX1

By the way, Function1 of SET1 and SET2 pins are used to program QR threshold and QR width for MAIN and AUX1 rails, respectively. Function1 of SET3 pin is used to setting force-non-zero VBOOT, SA rail Ton factor, and SA rail DVID threshold. Function2 of SET1 and SET2 pins are used to program Ton factor, Ki gain and anti-overshoot functions for MAIN and AUX1 rails. Function2 of SET3 can be setting DVID threshold for MAIN and AUX1 rails. TSEN\_MAIN pin is used to set ICCMAX and zero load-line for SA rail. TSEN\_AUX1 is used to program ICCMAX of AUX1 and SA rails. In addition, Richtek provide a Microsoft Excel-based spreadsheet to help design SETx, TSEN\_MAIN and TSEN\_AUX1 resistor network.

### TSEN\_MAIN, TSEN\_AUX1 and VR\_HOT

The VR\_HOT signal is an open-drain signal which is used for VR thermal protection. When the sensed voltage in each TSEN pin is less than 1.092, the VR\_HOT signal will be pulled-low to notify CPU that the thermal protection needs to work. According to Intel VR definition, VR\_HOT signal needs acting if VR power chain temperature exceeds 100°C. Placing an NTC thermistor at the hottest

area in the VR power chain and its connection is shown in Figure 7, to design the TSEN network so that  $V_{\text{TSEN}} = 1.092V$  at 100°C. The resistance accuracy of TSEN network is recommended to be 1% or higher.

$$V_{\text{TSEN}_X} = 80\mu A \times \left[ R1 // \left( R2 + R_{\text{NTC}(100^\circ\text{C})} \right) \right]$$

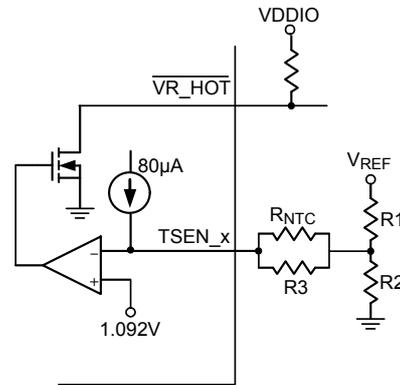


Figure 7. VR\_HOT Circuit

### Power Ready (POR) Detection

During start-up, the RT3602AE detects the voltage at the voltage input pins :  $V_{\text{CC}}$  and EN. When  $V_{\text{CC}} > 4.45V$ , the RT3602AE recognizes the power state of system to be ready (POR = high) and waits for enable command at the EN pin. After POR = high and  $V_{\text{EN}} > 0.7V$ , the RT3602AE enters start-up sequence. If  $V_{\text{CC}}$  drops below low threshold (POR = low), the RT3602AE enters power down sequence and all functions will be disabled. Normally, connecting system voltage  $V_{\text{TT}}$  (1.05V) to the EN pin is recommended. 2ms (max) after the chip has been enabled, the SVID circuitry will be ready. All the protection latches (OVP, OCP, UVP) will be cleared only by  $V_{\text{CC}}$ . The condition of  $V_{\text{EN}} = \text{low}$  will not clear these latches. Figure 8 and Figure 9 show the POR detection and the timing chart for POR process, respectively.

### Under-Voltage Lockout (UVLO)

During normal operation, if the voltage at the VCC pin drops below POR threshold 4.14V (min), the VR triggers UVLO. The UVLO protection forces all high-side MOSFETs and low-side MOSFETs off by shutting down internal PWM logic drivers.

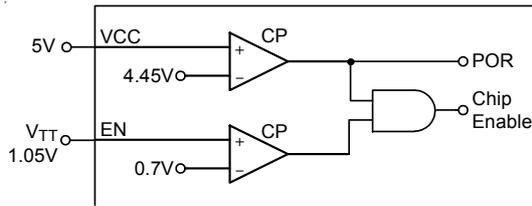


Figure 8. POR Detection

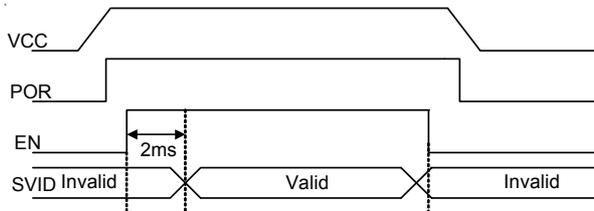


Figure 9. Timing Chart for POR Process

**Phase Disable (Before POR)**

The number of active phases is determined by the internal circuitry that monitors the ISENxN voltages during startup. Normally, the AUX1 rail operates as a 2-phase PWM controller. Pulling ISEN2N to VCC programs a 1-phase operation. Before POR, VR detects whether the voltage of ISEN2N is higher than “VCC – 1V” to decide how many phases should be active. Phase selection is only active during POR. When POR = high, the number of active phases is determined and latched. The unused ISENxP pins are recommended to be connected to VCC and unused PWM pins can be left floating.

**Switching Frequency Setting**

The RT3602AE is one kind of constant on-time control. The patented CCRCOT (Constant Current Ripple COT) technology can generate an adaptive on-time with input voltage and VID code to obtain a constant current ripple, so that the output voltage ripple can be controlled nearly like a constant as different input and output voltages change.

The Ton equation can be classified as below two regions

$$V_{DAC} \geq 0.9$$

$$t_{ON} = \frac{1.2\mu \times V_{DAC}}{k_{TON} \times (V_{IN} - V_{DAC})} + 15n$$

$$V_{DAC} < 0.9$$

$$t_{ON} = \frac{1.08\mu}{k_{TON} \times (V_{IN} - V_{DAC})} + 15n$$

where  $k_{TON}$  is a coefficient which can be selected by SET[1:3] pins for each VR rail. Table 3 and Table 6 show the  $k_{TON}$  coefficient and  $k_i$  gain setting for each VR rail on the SET[1:3] pins.

Table 2. SET[1 to 2] Pins Setting for QR\_TH and QRWIDTH

$V_{SET[1 \text{ and } 2]_V} = 3.2 \times \frac{R1 \times R2}{R1 + R2}$				QRTH_X(mV)	QRWIDTH_X (% of On-Time)
Min	Typ	Max	Unit		
10.02444	25.02444	40.02444	mV	Disable	160%
60.07331	75.07331	90.07331	mV		130%
110.1222	125.1222	140.1222	mV		100%
160.1711	175.1711	190.1711	mV		70%
210.2199	225.2199	240.2199	mV	10	160%
260.2688	275.2688	290.2688	mV		130%
310.3177	325.3177	340.3177	mV		100%
360.3666	375.3666	390.3666	mV		70%
410.4154	425.4154	440.4154	mV	15	160%
460.4643	475.4643	490.4643	mV		130%
510.5132	525.5132	540.5132	mV		100%
560.5621	575.5621	590.5621	mV		70%
610.6109	625.6109	640.6109	mV	20	160%
660.6598	675.6598	690.6598	mV		130%
710.7087	725.7087	740.7087	mV		100%
760.7576	775.7576	790.7576	mV		70%
810.8065	825.8065	840.8065	mV	25	160%
860.8553	875.8553	890.8553	mV		130%
910.9042	925.9042	940.9042	mV		100%
960.9531	975.9531	990.9531	mV		70%
1011.002	1026.002	1041.002	mV	30	160%
1061.051	1076.051	1091.051	mV		130%
1111.1	1126.1	1141.1	mV		100%
1161.149	1176.149	1191.149	mV		70%
1211.197	1226.197	1241.197	mV	35	160%
1261.246	1276.246	1291.246	mV		130%
1311.295	1326.295	1341.295	mV		100%
1361.344	1376.344	1391.344	mV		70%
1411.393	1426.393	1441.393	mV	40	160%
1461.442	1476.442	1491.442	mV		130%
1511.491	1526.491	1541.491	mV		100%
1561.54	1576.54	1591.54	mV		70%

**Table 3. SET3 Pin Setting for Force-Non-Zero-VBOOT, k<sub>TON</sub>, and DVID\_TH**

$V_{SET3\_V} = 3.2 \times \frac{R1 \times R2}{R1+R2}$				Force-Non-Zero VBOOT	TONSET_SA	DVID_SA (mV)
Min	Typ	Max	Unit			
10.02444	25.02444	40.02444	mV	VBOOT for hardware test	0.6	15
60.07331	75.07331	90.07331	mV			30
110.1222	125.1222	140.1222	mV			60
160.1711	175.1711	190.1711	mV			Disable
210.2199	225.2199	240.2199	mV		0.8	15
260.2688	275.2688	290.2688	mV			30
310.3177	325.3177	340.3177	mV			60
360.3666	375.3666	390.3666	mV			Disable
410.4154	425.4154	440.4154	mV		1.1	15
460.4643	475.4643	490.4643	mV			30
510.5132	525.5132	540.5132	mV			60
560.5621	575.5621	590.5621	mV			Disable
610.6109	625.6109	640.6109	mV		0.4	15
660.6598	675.6598	690.6598	mV			30
710.7087	725.7087	740.7087	mV			60
760.7576	775.7576	790.7576	mV			Disable
810.8065	825.8065	840.8065	mV	INTEL VBOOT	0.6	15
860.8553	875.8553	890.8553	mV			30
910.9042	925.9042	940.9042	mV			60
960.9531	975.9531	990.9531	mV			Disable
1011.002	1026.002	1041.002	mV		0.8	15
1061.051	1076.051	1091.051	mV			30
1111.1	1126.1	1141.1	mV			60
1161.149	1176.149	1191.149	mV			Disable
1211.197	1226.197	1241.197	mV		1.1	15
1261.246	1276.246	1291.246	mV			30
1311.295	1326.295	1341.295	mV			60
1361.344	1376.344	1391.344	mV			Disable
1411.393	1426.393	1441.393	mV		0.4	15
1461.442	1476.442	1491.442	mV			30
1511.491	1526.491	1541.491	mV			60
1561.54	1576.54	1591.54	mV			Disable

For better efficiency of the given load range, the maximum switching frequency is suggested to be :

$$F_{SW(MAX)} = \frac{VID1 + \frac{I_{ccTDC}}{N} \cdot \left( DCR + \frac{R_{ON\_LS,max}}{n_{LS}} - N \cdot R_{LL} \right)}{\left[ V_{IN(MAX)} + \frac{I_{ccTDC}}{N} \cdot \left( \frac{R_{ON\_LS,max}}{n_{LS}} - \frac{R_{ON\_HS,max}}{n_{HS}} \right) \right] \cdot (T_{ON} - T_D + T_{ON,VAR}) + \frac{I_{ccTDC}}{N} \cdot \left( \frac{R_{ON\_LS,max}}{n_{LS}} \right) \cdot T_D}$$

where  $F_{SW(MAX)}$  is the maximum switching frequency, VID1 is the typical VID of application,  $V_{IN(MAX)}$  is the maximum application input voltage,  $I_{ccTDC}$  is the thermal design current of application, N is the phase number. The  $R_{ON\_HS,max}$  is the maximum equivalent high-side  $R_{DS(ON)}$ , and  $n_{HS}$  is the number of high-side MOSFETs ;  $R_{ON\_LS,max}$  is the maximum equivalent low-side  $R_{DS(ON)}$ , and  $n_{LS}$  is the number of low-side MOSFETs.  $T_D$  is the summation of the high-side MOSFET delay time and the rising time,  $T_{ON,VAR}$  is the  $T_{ON}$  variation value. DCR is the inductor DCR, and  $R_{LL}$  is the loadline setting. In addition, Richtek provides a Microsoft Excel-based spreadsheet to help design the  $R_{TON}$  for the RT3602AE.

When load increases, on-time keeps constant. The off-time width will be reduced so that loading can load more power from input terminal to regulate output voltage. Hence, the loading current usually increases in case the switching frequency also increases. Higher switching frequency operation can reduce power components' size and PCB space, trading off the whole efficiency since switching related loss increases, vice versa.

**Current Sense**

In the RT3602AE, the current signal is used for load-line setting and over-current protection (OCP). The inductor current sense method adopts the lossless current sensing for allowing high efficiency as illustrated in Figure 10. If RC network time constant matches inductor time constant  $L_x/DCR_x$ , an expected load transient waveform can be designed. If  $R_x C_x$  network time constant is larger than inductor time constant  $L_x/DCR_x$ ,  $V_{CORE}$  waveform has a sluggish droop during load transient. If  $R_x C_x$  network is smaller than inductor time constant  $L_x/DCR_x$ , a worst  $V_{CORE}$  waveform will sag to create an undershooting to fail the specification.  $R_x$  is highly recommended as two 0603 size resistors in series to enhance the  $I_{OUT}$  reporting accuracy.  $C_x$  is suggested X7R type for the application.

Figure 11 shows the variety  $R_x C_x$  constant corresponding to the output waveforms.

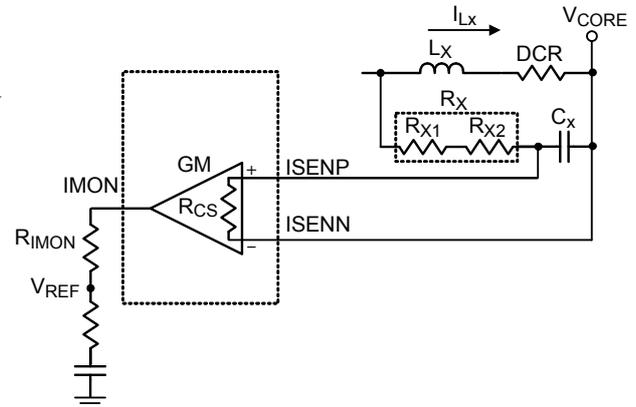


Figure 10. Lossless Current Sense Method for Single Phase

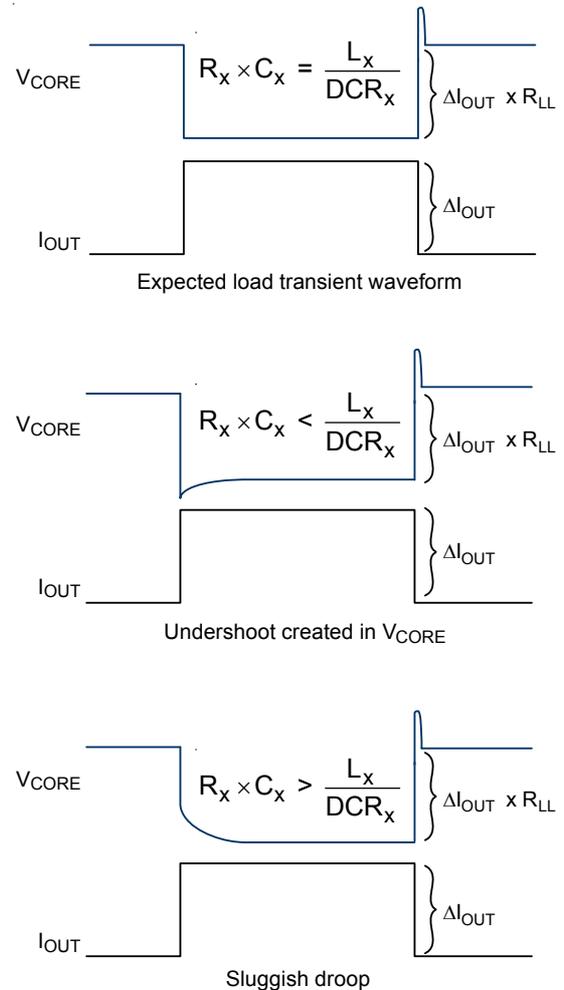


Figure 11. All Kind of  $R_x C_x$  Constants



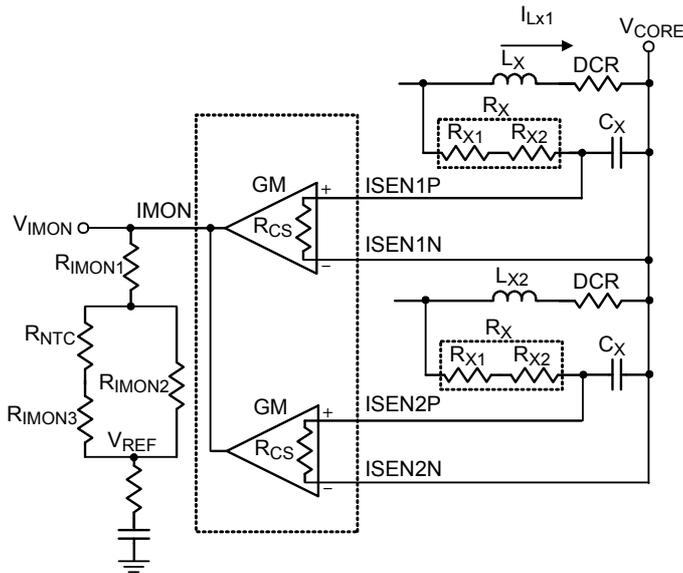


Figure 14. Thermal Compensation method for dual Phase

The current sense network equation is as follows :

$$V_{IMON} - V_{ref} = \frac{\sum_{X=1}^2 I_{LX} \times DCR}{R_{CS}} \times \{R_{IMON1} + [R_{IMON2} // (R_{IMON3} + R_{NTC})]\}$$

Please note that  $V_{IMON}$  is equal to 1V for single phase application and  $V_{IMON}$  is equal to 1.4V for dual phase application under ICCMAX condition.

A resistor network with NTC thermistor compensation connecting between IMON pin and VREF pin is used to compensate the positive temperature coefficient of inductor DC. The design flow is as follows :

Step1: Given the three temperature  $T_L$ ,  $T_R$  and  $T_H$ , at which are compensated.

Step 2 : Three equations can be listed as

$$\frac{DCR(T_L)}{R_{CS}} = \sum_{i=1}^2 I_{Li} \times R_{IMON}(T_L) = 0.4$$

$$\frac{DCR(T_R)}{R_{CS}} = \sum_{i=1}^2 I_{Li} \times R_{IMON}(T_R) = 0.4$$

$$\frac{DCR(T_H)}{R_{CS}} = \sum_{i=1}^2 I_{Li} \times R_{IMON}(T_H) = 0.4$$

Where :

(1) The relationship between DCR and temperature is as follows :

$$DCR(T) = DCR(25^\circ C) \times [1 + 0.00393(T - 25)]$$

(2)  $R_{IMON}(T)$  is the equivalent resistor of the resistor network with a NTC thermistor

$$R_{IMON}(T) = R_{IMON1} + \{R_{IMON2} // [R_{IMON3} + R_{NTC}(T)]\}$$

And the relationship between NTC and temperature is as follows :

$$R_{NTC}(T) = R_{NTC}(25^\circ C) \times e^{\beta \left( \frac{1}{T} - \frac{1}{298} \right)}$$

$\beta$  is in the NTC thermistor datasheet.

Step 3 : Three equation and three unknowns,  $R_{IMON1}$ ,  $R_{IMON2}$  and  $R_{IMON3}$  can be calculated out unique solution.

$$R_{IMON1} = K_{TR} - \frac{R_{IMON2} \times (R_{NTCTR} + R_{IMON3})}{R_{IMON2} + R_{NTCTR} + R_{IMON3}}$$

$$R_{IMON2} = \sqrt{[K_{R3}^2 + K_{R3}(R_{NTCTL} + R_{NTCTR}) + R_{NTCTL}R_{NTCTR}] \alpha_{TL}}$$

$$R_{IMON3} = -R_{IMON2} + K_{R3}$$

Where :

$$\alpha_{TH} = \frac{K_{TH} - K_{TR}}{R_{NTCTH} - R_{NTCTR}}$$

$$\alpha_{TL} = \frac{K_{TL} - K_{TR}}{R_{NTCTL} - R_{NTCTR}}$$

$$K_{R3} = \frac{(\alpha_{TH} / \alpha_{TL}) R_{NTCTH} - R_{NTCTL}}{1 - (\alpha_{TH} / \alpha_{TL})}$$

$$K_{TL} = \frac{0.4}{\frac{DCR(T_L)}{R_{CS}} \times ICCMAX}$$

$$K_{TR} = \frac{0.4}{\frac{DCR(T_R)}{R_{CS}} \times ICCMAX}$$

$$K_{TH} = \frac{0.4}{\frac{DCR(T_H)}{R_{CS}} \times ICCMAX}$$

**Current Monitor, IMON**

For each VR rail, the RT3602AE includes a current monitor (IMON) function which can be used to detect over-current protection and maximum processor current ICCMAX, and also sets a part of current gain in the load-line setting. It produces an analog voltage proportional to output current between the IMON and VREF pins.

**Load-Line (Droop) Setting**

The G-NAVP™ topology can set load-line (droop) via the current loop and voltage loop, the load-line is a slope between load current ICC and output voltage Vsen as shown in Figure 15. Figure 16 shows the voltage control and current loop for MAIN and SA rails. By using both loops, the load-line (droop) can be set easily. The load-line set equation for MAIN and SA is :

$$R_{LL} = \frac{A_I}{A_V} = \frac{\frac{k_i}{2} \times \frac{DCR}{R_{CS}} \times R_{OUT}}{\frac{R_2}{R_1}} = \frac{\frac{k_i}{2} \times DCR}{\frac{R_2}{R_1}} \text{ (m}\Omega\text{)}$$

where R<sub>OUT</sub> = R<sub>CS</sub>

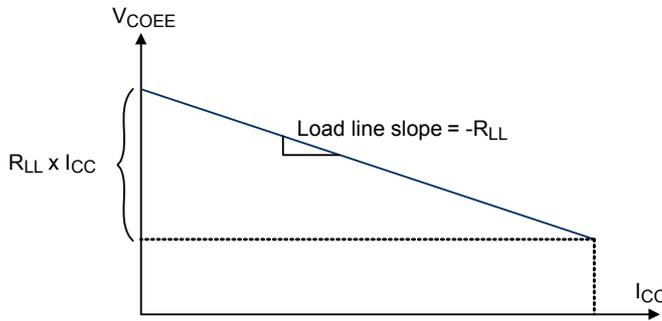


Figure 15. Load-Line (Droop)

Figure 17 shows the voltage control and current loop for AUXI rail. By using both loops, the load-line (droop) can be set easily. The load-line set equation for AUXI is :

$$R_{LL} = \frac{A_I}{A_V} = \frac{\frac{k_i}{2} \times \frac{DCR}{R_{CS}} \times R_{IMON}}{\frac{R_2}{R_1}}$$

Where R<sub>CS</sub> = 2.15kΩ

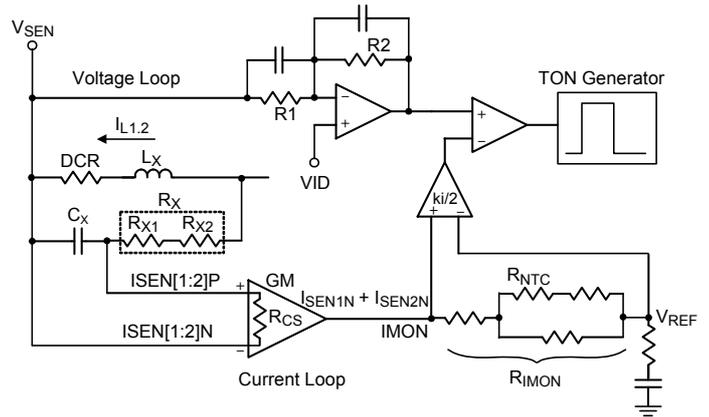


Figure 17. Voltage Loop and Current Loop for AUXI

The ki gain can be selected by SET [1:3] pins for individual rail.

**Compensator Design**

The compensator of the RT3602AE doesn't need a complex type II or type III compensator to optimize control loop performance. It can adopt a simple type I compensator (one pole, one zero) in the G-NAVP™ topology to achieve constant output impedance design for Intel IMVP8 ACLL specification. The one pole one zero compensator is shown as Figure 18. The transfer function of compensator should be design as following transfer function to achieve constant output impedance, i.e. Z<sub>o</sub>(s) = load-line slope in the entire frequency range :

$$G_{CON}(S) \approx \frac{A_I}{R_{LL}} \frac{1 + \frac{s}{\omega \times f_{sw}}}{1 + \frac{s}{\omega_{ESR}}}$$

where A<sub>I</sub> is current loop gain, R<sub>LL</sub> is load-line, f<sub>sw</sub> is switching frequency and ω<sub>ESR</sub> is a pole that should be located at 1/(C<sub>OUT</sub> × ESR). Then, the C<sub>1</sub> and C<sub>2</sub> should be designed as follows :

$$C_1 = \frac{1}{R_1 \times \pi \times f_{sw}} \quad C_2 = \frac{C_{OUT} \times ESR}{R_2}$$

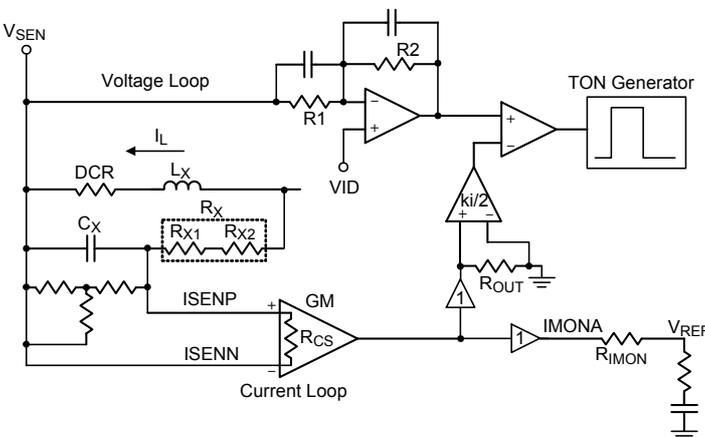


Figure 16. Voltage Loop and Current Loop for MAIN and SA Rails

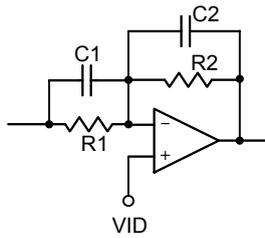


Figure 18. Type I compensator

**Differential Remote Sense Setting**

The VR provides differential remote-sense inputs to eliminate the effects of voltage drops along the PC board traces, CPU internal power routes and socket contacts for MAIN and AUX1 rails. The CPU contains on-die sense pins, V<sub>CC\_SENSE</sub> and V<sub>SS\_SENSE</sub>. Connect RGND to V<sub>SS\_SENSE</sub> and connect FB to V<sub>CC\_SENSE</sub> with a resistor to build the negative input path of the error amplifier as shown in Figure 19. The V<sub>DAC</sub> and the precision voltage reference are referred to RGND for accurate remote sensing.

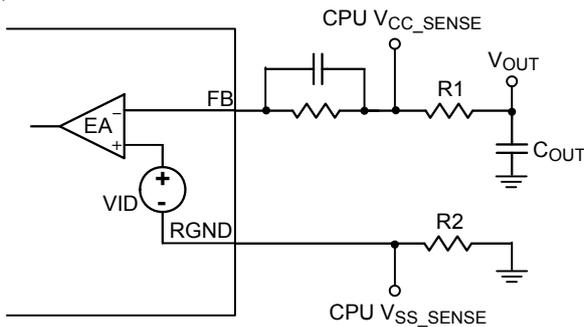


Figure 19. Remote Sensing Circuit

**Maximum Processor Current Setting, I<sub>MAX</sub>**

The maximum processor current I<sub>MAX</sub> for each VR rail can be set by TSEN\_MAIN and TSEN\_AUX1 pins. Each VR I<sub>MAX</sub> register is set by an external voltage divider with the multi-function mechanism. Table 4 and Table 5 show the each VR I<sub>MAX</sub> setting on TSEN\_MAIN and TSEN\_AUX1 pins.

**System Input Power Monitor, PSYS**

The IC provides PSYS function to monitor total platform system power and the obtained information will be provided directly to the CPU via the SVID interface. The PSYS function can be described as in Figure 20. When the maximum PSYS voltage V<sub>PSYS</sub> = 3.2V, the RT3602AE will generate an 8-bit code, FF, which will be stored in the 1Bh register. To choose the resistor value R, for example, if the maximum current from the PSYS "Meter" I = 320μA in conjunction with V<sub>PSYS</sub> = 3.2V and R = V<sub>PSYS</sub> / I = 10kΩ can be obtained.

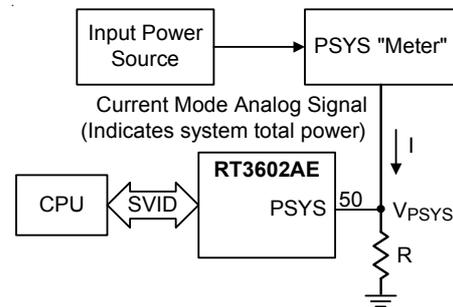


Figure 20. PSYS Function Block Diagram

**Table 4. TSEN\_AUX1 Setting for IMAX\_MAIN and SA Zero Load-Line**

$V_{TSEN\_AUX1} = 3.2 \times \frac{R1 \times R2}{R1+R2}$				<b>IMAX_MAIN (A)</b>				<b>SA_0LL</b>
<b>Min</b>	<b>Typ</b>	<b>Max</b>	<b>Unit</b>	1-Phase	1-Phase POCP	2-Phase	2-Phase POCP	
49.5484	50.0489	50.5494	mV	16	48	29	43.5	Disable
148.645	150.147	151.648	mV					Enable
247.742	250.244	252.747	mV	18	54	33	49.5	Disable
346.839	350.342	353.846	mV					Enable
445.935	450.44	454.944	mV	20	60	37	55.5	Disable
545.032	550.538	556.043	mV					Enable
644.129	650.635	657.142	mV	21	63	40	60	Disable
743.226	750.733	758.24	mV					Enable
842.323	850.831	859.339	mV	22	66	44	66	Disable
941.419	950.929	960.438	mV					Enable
1040.52	1051.03	1061.54	mV	23	69	46	69	Disable
1139.61	1151.12	1162.64	mV					Enable
1238.71	1251.22	1263.73	mV	24	72	48	72	Disable
1337.81	1351.32	1364.83	mV					Enable
1436.9	1451.42	1465.93	mV	25	75	49	73.5	Disable
1536	1551.52	1567.03	mV					Enable
1635.1	1651.61	1668.13	mV	26	52	50	50	Disable
1734.19	1751.71	1769.23	mV					Enable
1833.29	1851.81	1870.33	mV	27	54	52	52	Disable
1932.39	1951.91	1971.43	mV					Enable
2031.48	2052	2072.52	mV	28	56	53	53	Disable
2130.58	2152.1	2173.62	mV					Enable
2229.68	2252.2	2274.72	mV	29	58	55	55	Disable
2328.77	2352.3	2375.82	mV					Enable
2427.87	2452.39	2476.92	mV	30	60	57	57	Disable
2526.97	2552.49	2578.02	mV					Enable
2626.06	2652.59	2679.12	mV	31	62	59	59	Disable
2725.16	2752.69	2780.22	mV					Enable
2824.26	2852.79	2881.31	mV	33	66	61	61	Disable
2923.35	2952.88	2982.41	mV					Enable
3022.45	3052.98	3083.51	mV	35	70	64	64	Disable
3121.55	3153.08	3184.61	mV					Enable

Table 5. TSEN\_MAIN Setting for IMAX\_AUXI and IMAX\_SA

$V_{TSEN\_MAIN} = 3.2 \times \frac{R1 \times R2}{R1+R2}$				IMAX_AUXI (A)		IMAX_SA (A)	
Min	Typ	Max	Unit	IMAX	POCP	IMAX	POCP
49.5484	50.0489	50.5494	mV	16	48	3	18
148.645	150.147	151.648	mV			4	24
247.742	250.244	252.747	mV			5	30
346.839	350.342	353.846	mV			6	36
445.935	450.44	454.944	mV	18	54	3	18
545.032	550.538	556.043	mV			4	24
644.129	650.635	657.142	mV			5	30
743.226	750.733	758.24	mV			6	36
842.323	850.831	859.339	mV	20	60	3	18
941.419	950.929	960.438	mV			4	24
1040.52	1051.03	1061.54	mV			5	30
1139.61	1151.12	1162.64	mV			6	36
1238.71	1251.22	1263.73	mV	22	66	3	18
1337.81	1351.32	1364.83	mV			4	24
1436.9	1451.42	1465.93	mV			5	30
1536	1551.52	1567.03	mV			6	36
1635.1	1651.61	1668.13	mV	24	48	3	18
1734.19	1751.71	1769.23	mV			4	24
1833.29	1851.81	1870.33	mV			5	30
1932.39	1951.91	1971.43	mV			6	36
2031.48	2052	2072.52	mV	26	52	3	18
2130.58	2152.1	2173.62	mV			4	24
2229.68	2252.2	2274.72	mV			5	30
2328.77	2352.3	2375.82	mV			6	36
2427.87	2452.39	2476.92	mV	29	58	3	18
2526.97	2552.49	2578.02	mV			4	24
2626.06	2652.59	2679.12	mV			5	30
2725.16	2752.69	2780.22	mV			6	36
2824.26	2852.79	2881.31	mV	35	70	3	18
2923.35	2952.88	2982.41	mV			4	24
3022.45	3052.98	3083.51	mV			5	30
3121.55	3153.08	3184.61	mV			6	36

**Dynamic VID (DVID) Compensation**

When VID transition event occurs, a charge current will be generated in the loop to cause DVID performance is deteriorated by this induced charge current, the phenomenon is called droop effect. The droop effect is shown in Figure 21. When VID up transition occurs, the output capacitor will be charged by inductor current. Since current signal is sensed in inductor, an induced charge current will appear in control loop. The induced charge current will produce a voltage drop in R1 to cause output voltage to have a droop effect. Due to this, VID transition performance will be deteriorated.

The RT3602AE provides a DVID compensation function. By the DVID compensation to cancel the real induced charge current signal and the virtual charge current signal is defined in Figure 22. Figure 23 shows the operation of cancelling droop effect. A virtual charge current signal is established first and then VID signal plus virtual charge current signal to be generated on the FB pin. Hence, an induced charge current signal flows to R1 and is cancelled to reduce droop effect.

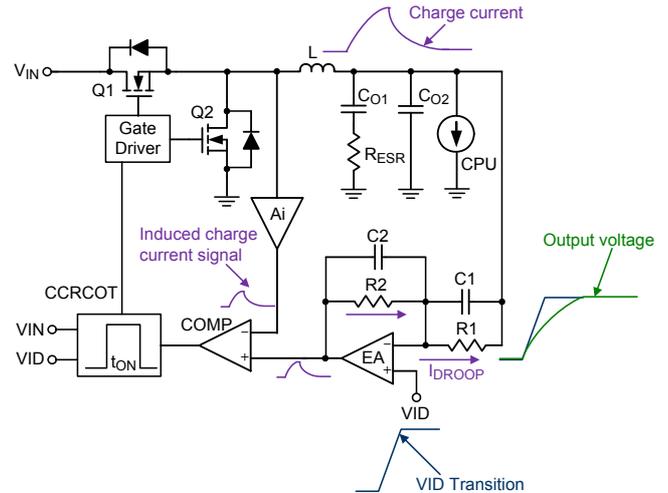


Figure 21. Droop Effect in VID transition

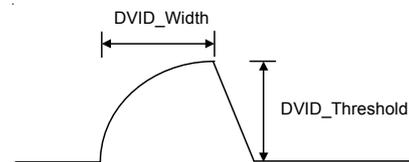


Figure 22. Definition of Virtual Charge Current Signal

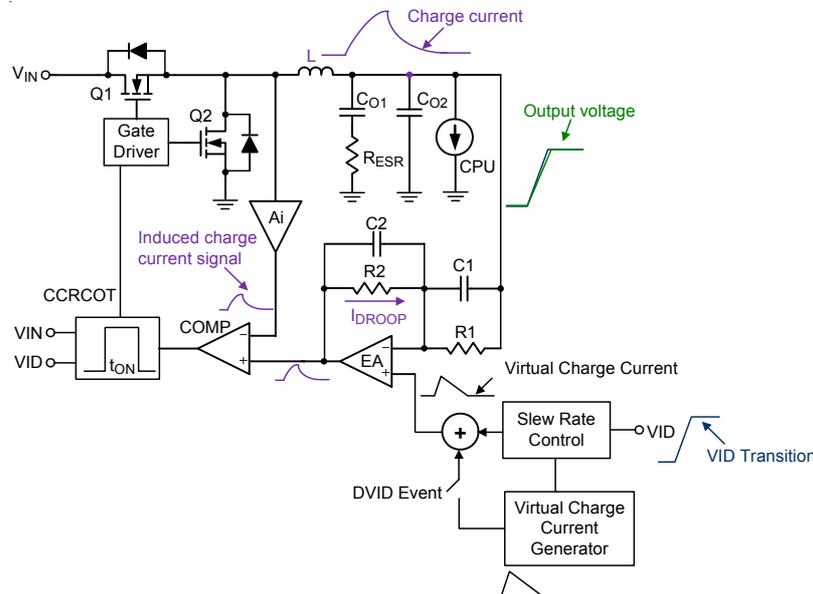


Figure 23. DVID Compensation

Table 3 and Table 7 show the each VR DVID threshold setting on TSEN\_MAIN and TSEN\_AUXI pins. The each VR DVID width is equal to 2 $\mu$ s. For example, VR IMAXs are 35A, 6A and 31A for MAIN rail, SA rail and AUXI rail, respectively. The  $V_{TSEN\_MAIN}$  and  $V_{TSEN\_AUXI}$  need to be set as 2.65V and 3.15V, respectively. Please note that a high accuracy resistor is needed for this setting, <1% error tolerance is recommended.

### Ramp Compensation

The G-NAVP™ topology is one type of ripple based control that has fast transient response and can lower BOM cost. However, ripple based control usually has no good noise immunity. The RT3602AE provides the ramp compensation to increase noise immunity and reduce jitter at the switching node. Figure 24 shows the ramp compensation.

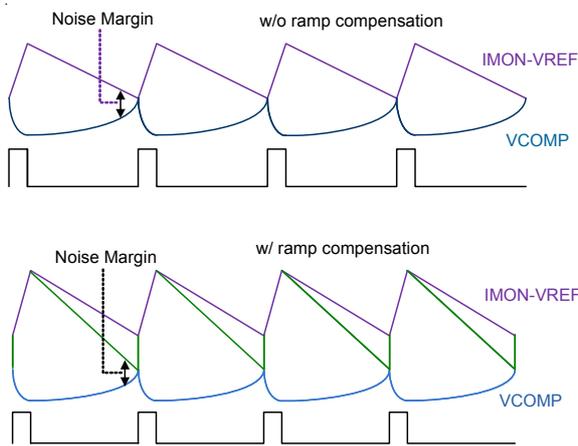


Figure 24. Ramp Compensation

### Quick Response (QR) Mechanism

When the transient load step-up becomes quite large, it is difficult for loop response to meet the energy transfer. Hence, that output voltage generate undershoot to fail specification. The RT3602AE has Quick Response (QR) mechanism being able to improve this issue. It adopts a nonlinear control mechanism which can disable interleaving function and simultaneously turn on all UGATE one pulse at instantaneous step-up transient load to restrain the output voltage drooping. Figure 25 shows the QR behavior.

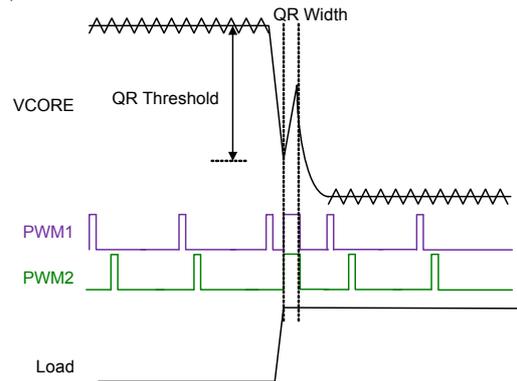


Figure 25. Quick Response Mechanism

The output voltage signal behavior needs to be detected so that QR mechanism can be triggered. The output voltage signal is via a remote sense line to connect at the VSEN pin which is shown in Figure 26. The QR mechanism needs to set QR width and QR threshold. Both definitions are shown in Figure 24. A proper QR mechanism set can meet different applications. The SET1 and SET2 pins can set QR threshold and QR width by internal current source 80uA with multi-function pin setting mechanism for MAIN and AUXI VR rails. Table 2 shows the QR\_TH and QR\_WIDTH for MAIN and AXUI VR rails on the SET[1 to 2] pins.

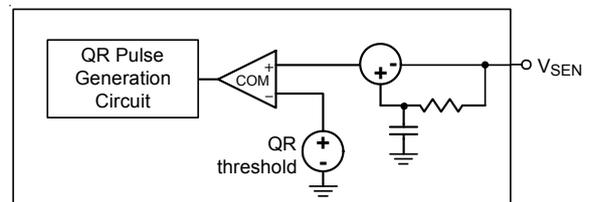


Figure 26. Simplified QR Trigger schematic

Table 6. SET[1 to 2] pins setting for k<sub>TON</sub>, ki and ANTIOVS

$V_{SET[1\ to\ 2]_I} = 80\mu A \times \frac{R2}{R1+R2}$				TONSET_X	AI_X		ANTIOVS_X
Min	Typ	Max	Unit		AUXI	MAIN	
60.07331	75.07331	90.07331	mV	0.6	20	1	Disable
160.1711	175.1711	190.1711	mV				Enable
260.2688	275.2688	290.2688	mV		80	2	Disable
360.3666	375.3666	390.3666	mV				Enable
460.4643	475.4643	490.4643	mV	0.8	20	1	Disable
560.5621	575.5621	590.5621	mV				Enable
660.6598	675.6598	690.6598	mV		80	2	Disable
760.7576	775.7576	790.7576	mV				Enable
860.8553	875.8553	890.8553	mV	1	20	1	Disable
960.9531	975.9531	990.9531	mV				Enable
1061.051	1076.051	1091.051	mV		80	2	Disable
1161.149	1176.149	1191.149	mV				Enable
1261.246	1276.246	1291.246	mV	0.4	20	1	Disable
1361.344	1376.344	1391.344	mV				Enable
1461.442	1476.442	1491.442	mV		80	2	Disable
1561.54	1576.54	1591.54	mV				Enable

For example, 35mV QR threshold and 1.3 x TON QR width are set. According to Table 2, the set voltage should be between 1.261V and 1.291V. Please note that a high accuracy resistor is needed for this setting accuracy, <1% error tolerance is recommended.

**Zero Load-Line Setting and Anti-overshoot function**

The TSEN\_MAIN can be enabled/disabled zero-load-line function for SA rail. The SET1 and SET2 pins can be enabled/disabled anti-overshoot function for MAIN and AUXI rails.

When DVID slew rate increases, loop response is difficult to meet energy transfer so that output voltage generates overshoot to fail specification. The RT3602AE has anti-overshoot function being able to help improve this issue. The VR will turn off low-side MOSFET when output voltage ramps up to the target VID (ALERT signal be pulled low). This function also can improve the overshoot during the load transient condition. When anti-overshoot function is triggered, the UGATE and LGATE signal will be masked to reduce the overshoot amplitude.

In order to increase high power density performance, Dr.MOS is popular to use in VR application. In PS4 mode the Dr.MOS is required to enter power saving mode. So the RT3602AE provide DRVEN\_SET pin for different Dr.MOS. When DRVEN\_SET is set to VCC, DRVEN is floating at PS4 mode. Moreover, the DRVEN is pull to low at DRVEN\_SET connected to GND.

Table 7. SET3 Pin Setting for DVIDTH

$V_{SET3\_I} = 80\mu A \times \frac{R1 \times R2}{R1+R2}$				DVIDTH_MAIN (mV)	DVIDTH_AUXI (mV)
Min	Typ	Max	Unit		
60.07331	75.07331	90.07331	mV	15	15
160.1711	175.1711	190.1711	mV		30
260.2688	275.2688	290.2688	mV		60
360.3666	375.3666	390.3666	mV		Disable
460.4643	475.4643	490.4643	mV	30	15
560.5621	575.5621	590.5621	mV		30
660.6598	675.6598	690.6598	mV		60
760.7576	775.7576	790.7576	mV		Disable
860.8553	875.8553	890.8553	mV	60	15
960.9531	975.9531	990.9531	mV		30
1061.051	1076.051	1091.051	mV		60
1161.149	1176.149	1191.149	mV		Disable
1261.246	1276.246	1291.246	mV	Disable	15
1361.344	1376.344	1391.344	mV		30
1461.442	1476.442	1491.442	mV		60
1561.54	1576.54	1591.54	mV		Disable

**Over-Current Protection**

The RT3602AE has dual OCP mechanism. One is named SUM-OCP, the other is called SPIKE-OCP. The over current protection (OCP) forces high-side MOSFET and low-side MOSFET off by shutting down internal PWM logic drivers. The RT3602AE provides SUM-OCP which is 160% of IMON\_04. IMON\_04 is the current that makes ( $V_{IMON} - V_{REF} = 0.4V$ ). When output current is higher than the SUM-OCP threshold, SUM-OCP is latched with a 40µs delay time to prevent false trigger. Besides, the SUM-OCP function is masked when dynamic VID transient occurs and after dynamic VID transition, SUM-OCP is masked for 80µs. The other one is SPIKE-OCP which should trip when the output current exceeds SPIKE\_OCP threshold during first DVID. SPIKE\_OCP threshold is dependent on IMAX level as shown in Table 4 and Table 5. When output current is higher than the SPIKE-OCP threshold, SPIKE-OCP is latched with a 1µs delay time to prevent false trigger.

**Output Over-Voltage Protection**

An OVP condition is detected when the VSEN pin is 350mV more than VID. When OVP is detected, the high-side gate voltage UGATEx is pulled low and the low-side gate voltage LGATEx is pulled high. OVP is latched with a 0.5us delay- to prevent false trigger.

**Negative Voltage Protection**

Since the OVP latch continuously turns on all low-side MOSFETs of the VR, the VR will suffer negative output voltage. When the VSEN detects a voltage below -0.07V after triggering OVP, the VR triggers NVP to turn off all low-side MOSFETs of the VR while the high-side MOSFETs remain off. After triggering NVP, if the output voltage rises above 0V, the OVP latch restarts to turn on all low-side MOSFETs. Therefore, the output voltage may bounce between 0V and -0.07V due to OVP latch and NVP triggering. The NVP function will be active only after OVP is triggered.

**Under-Voltage Protection**

When the VSEN pin voltage is 350mV less than VID, UVP will be latched. When UVP latched, the both UGATE<sub>x</sub> and LGATE<sub>x</sub> are pulled low. A 3μs delay is used in UVP detection circuit to prevent false trigger. Besides, the UVP function is masked when dynamic VID transient occurs and after dynamic VID transition, UVP is masked for 80μs.

**Design Step :**

The RT3602AE Excel based design tool is available. Users can contact your Richtek representative to get the spreadsheet. Three MAIN design procedures of the RT3602AE design, first step is loop design, second step is pin setting design, and the last step is protection settings. The following design example is to explain the RT3602AE design procedure :

**AUXI VR**

	V <sub>AUXI</sub> Specification
Input Voltage	19V
No. of Phase	1
Normal VID	1.35V
ICCMAX	35
ICC-Dyn	28
Load-Line	2.1mΩ
Fast Slew Rate	37.5mV/μs
MAX Switching Frequency	700kHz

The output filter requirements of VRTB specification are as follows :

Output Inductor : 220nH/0.875mΩ

Output Ceramic Capacitor: 47μF (6pcs)

Output Ceramic Capacitor: 10μF (9pcs)

Loop Design :

- On time setting: Using the specification, then can get that t<sub>ON</sub> is 108ns.

The k<sub>TON</sub> parameter can be calculated after the on-time is decided.

$$t_{ON} = \frac{1.2\mu \times V_{DAC}}{k_{TON} \times (V_{IN} - V_{DAC})} + 15n$$

Choosing the nearest on-time setting k<sub>TON</sub> = 1.1

- Current sensor adopts lossless RC filter to sense current signal in DCR. For getting an expected load transient waveform R<sub>X</sub>C<sub>X</sub> time constant needs to match L<sub>X</sub>/DCR<sub>X</sub>. C<sub>X</sub> = 0.47μF, R<sub>NTC</sub> = 10kΩ and R<sub>P</sub> = 10kΩ are set, then

$$R_{EQU} = R_S + (R_P // R_{NTC})$$

$$\frac{L_X}{DCR} = C_X \times \frac{R_{EQU} \times R_X}{R_{EQU} + R_X}$$

By using the design tool, R<sub>S</sub> and R<sub>X</sub> can be determined, are equal to 220Ω and 590Ω, respectively.

- IMON resistor network design :

$$R_{IMON} = \frac{\Delta V_{IMON} \times 2.15k}{ICCMAX \times DCR \times \frac{R_{EQU}}{R_X + R_{EQU}}} = 31.25k\Omega$$

- Load-line design : 2.1mΩ droop is requirement, because DCR and k<sub>i</sub> are decided to 0.875mΩ and 20, respectively. The voltage loop A<sub>v</sub> gain is also can be determined by following equation :

$$R_{LL} = \frac{A_i}{A_v} = \frac{\frac{k_i \times DCR}{2}}{\frac{R_2}{R_1}}$$

R<sub>1</sub> = 10kΩ is usually decided and here R<sub>2</sub> is chosen to 37.4kΩ.

- Typical compensator design can use the following equations to design C<sub>1</sub> and C<sub>2</sub> values

$$C_1 = \frac{1}{R_1 \times \pi \times F_{SW}} \approx 45.5pF$$

$$C_2 = \frac{C_{OUT} \times ESR}{R_1} \approx 33pF$$

For Intel platform, in order to induce the band width to enhance transient performance to meet Intel's criterion, the zero location can be designed close to 1/10 of the switching frequency or less than the 1/10 of switching frequency.

## SA VR

	V <sub>SA</sub> Specification
Input Voltage	19V
No. of Phase	1
Normal VID	1.05V
ICCMAX	6
ICC-Dyn	3
Load-Line	10.3mΩ
Fast Slew Rate	37.5mV/μs
MAX Switching Frequency	800kHz

The output filter requirements of VRTB specification are as follows :

Output Inductor: 820nH/6.7mΩ

Output Ceramic Capacitor: 47μF (4pcs)

Output Ceramic Capacitor: 10μF (8pcs)

Loop Design :

- On time setting : Using the specification, then can get that t<sub>ON</sub> is 96ns.

The k<sub>TON</sub> parameter can be calculated after the on-time is decided.

$$t_{ON} = \frac{1.2\mu \times V_{DAC}}{k_{TON} \times (V_{IN} - V_{DAC})} + 15n$$

Choosing the nearest on-time setting k<sub>TON</sub> = 1.1

Current sensor adopts lossless RC filter to sense current signal in DCR. For getting an expected load transient waveform R<sub>X</sub>C<sub>X</sub> time constant needs to match L<sub>X</sub>/DCR<sub>X</sub>. C<sub>X</sub> = 0.47μF, R<sub>NTC</sub> = 4.7kΩ and R<sub>p</sub> = 4.7kΩ are set, then

$$R_{EQU} = R_S + (R_P // R_{NTC})$$

$$\frac{L_X}{DCR} = C_X \times \frac{R_{EQU} \times R_X}{R_{EQU} + R_X}$$

By using the design tool, R<sub>S</sub> and R<sub>X</sub> can be determined, are equal to 165Ω and 280Ω, respectively.

- IMON resistor network design :

$$R_{IMON} = \frac{\Delta V_{IMON} \times 2.15k}{ICCMAX \times DCR \times \frac{R_{EQU}}{R_X + R_{EQU}}} = 23.79k\Omega$$

- Load-line design : 10.3mΩ droop is requirement, because DCR and k<sub>i</sub> are decided to 6.7mΩ and 20, respectively. The voltage loop A<sub>v</sub> gain is also can be determined by following equation :

$$R_{LL} = \frac{A_i}{A_v} = \frac{\frac{k_i}{2} \times DCR}{\frac{R_2}{R_1}}$$

R<sub>1</sub> = 10kΩ is usually decided and here R<sub>2</sub> is chosen to 58.5kΩ.

Typical compensator design can use the following equations to design C<sub>1</sub> and C<sub>2</sub> values

$$C_1 = \frac{1}{R_1 \times \pi \times F_{SW}} \approx 45.5pF$$

$$C_2 = \frac{C_{OUT} \times ESR}{R_2} \approx 56pF$$

For Intel platform, in order to induce the band width to enhance transient performance to meet Intel's criterion, the zero location can be designed close to 1/10 of the switching frequency or less than the 1/10 of switching frequency.

## MAIN VR

	V <sub>MAIN</sub> Specification
Input Voltage	19V
No. of Phase	1
Normal VID	1.35V
ICCMAX	31
ICC-Dyn	28
Load-Line	3.1mΩ
Fast Slew Rate	37.5mV/μs
MAX Switching Frequency	700kHz

The output filter requirements of VRTB specification are as follows :

Output Inductor: 220nH/0.875mΩ

Output Bulk Capacitor: 330μF/2V.4.5mΩ (1pcs)

Output Ceramic Capacitor: 47μF (6pcs)

Output Ceramic Capacitor: 22μF (7pcs)

Output Ceramic Capacitor: 10μF (2pcs)

Loop Design :

- On time setting: Using the specification, then can get that  $t_{ON}$  parameter can be calculated after the on-time is decided.

$$t_{ON} = \frac{1.2\mu \times V_{DAC}}{k_{TON} \times (V_{IN} - V_{DAC})} + 15n$$

Choosing the nearest on-time setting  $k_{TON} = 1.1$

- Current sensor adopts lossless RC filter to sense current signal in DCR. For getting an expected load transient waveform  $R_X C_X$  time constant needs to match  $L_X / DCR_X$ .  $C_X = 0.47\mu F$  is set, then

$$R_X = \frac{L_X}{1\mu F \times DCR_X} = 530\Omega$$

- IMON resistor network design :  $T_L = 25^\circ C$ ,  $T_R = 50^\circ C$  and  $T_H = 100^\circ C$  are decided, NTC thermistor =  $100k\Omega @ 25^\circ C$ ,  $\beta = 4485$  and  $ICCMAX = 31A$ .  $R_{IMON1} = 16.74k\Omega$ ,  $R_{IMON2} = 17.35k\Omega$  and  $R_{IMON3} = 9.16k\Omega$  can be decided. The  $R_{EQ}(25^\circ C) = 31.78k\Omega$ .
- Load-line design:  $3.1m\Omega$  droop is requirement, because DCR and  $k_i$  are decided to  $0.875m\Omega$  and  $2$ , respectively. The voltage loop  $A_v$  gain is also can be determined by following equation :

$$R_{LL} = \frac{A_i}{A_v} = \frac{\frac{k_i}{2} \times \frac{DCR}{R_{CS}} \times R_{IMON}}{\frac{R_2}{R_1}}$$

$R_1 = 10k\Omega$  is usually decided and here  $R_2$  is chosen to  $42.2k\Omega$ .

- Typical compensator design can use the following equations to design  $C_1$  and  $C_2$  values

$$C_1 = \frac{1}{R_1 \times \pi \times F_{SW}} \approx 45.5pF$$

$$C_2 = \frac{C_{OUT} \times ESR}{R_2} \approx 55pF$$

For intel platform, in order to induce the band width to enhance transient performance to meet intel's criterion, the zero location can be designed close to  $1/10$  of the switching frequency or less than the  $1/10$  of switching frequency.

Pin Setting Design :

SET1 resistor network design : From above designs, parameters of  $k_{TON\_AUXI}$  and  $k_{L\_AUXI}$  are  $1.1$  and  $20$ , respectively. The  $AUXI\_QR\_TH$  is set to disable and  $AUXI\_QR\_Width$  is designed as  $0.7 \times T_{ON}$ . And anti-overshoot function is disabled for  $AUXI$  rail. By using the information, the two equation can be listed by using multi-function pin setting mechanism :

$$3.2 \times \frac{R_2}{R_1 + R_2} = 175.17mV$$

$$80\mu \times \frac{R_1 \times R_2}{R_1 + R_2} = 975.9mV$$

$R_1 = 222.86k\Omega$  and  $R_2 = 12.91k\Omega$ .

- SET2 resistor network design : From above designs, parameters of  $k_{TON\_MAIN}$  and  $k_{L\_MAIN}$  are  $1.1$  and  $2$ , respectively. The  $MAIN\_QR\_TH$  is set to  $15mV$  and  $MAIN\_QR\_Width$  is designed as  $0.7 \times T_{ON}$ . And anti-overshoot function is disabled for  $MAIN$  rail. By using the information, the two equation can be listed by using multi-function pin setting mechanism :

$$3.2 \times \frac{R_2}{R_1 + R_2} = 575.56mV$$

$$80\mu \times \frac{R_1 \times R_2}{R_1 + R_2} = 1176.14mV$$

$R_1 = 81.74k\Omega$  and  $R_2 = 17.93k\Omega$ .

- SET3 resistor network design: From above designs, parameter of  $k_{TON\_SA}$  is  $1.1$ . The  $DVID$  thresholds are  $60mV$ ,  $15mV$ , and  $60mV$  for  $MAIN$ ,  $AUXI$ , and  $SA$  rail. The force-non-zero  $VBOOT$  is setting as Intel  $VBOOT$ . By using the information, the two equation can be listed by using multi-function pin setting mechanism :

$$3.2 \times \frac{R_2}{R_1 + R_2} = 1326.3mV$$

$$80\mu \times \frac{R_1 \times R_2}{R_1 + R_2} = 875.86mV$$

$R_1 = 26.4k\Omega$  and  $R_2 = 18.7k\Omega$ .

- TSEN\_AUXI resistor network design : The  $ICCMAX$  of  $MAIN$  rail is designed as  $31A$ . And zero load-line function for  $SA$  rail is disabled. By using the information, the

equation can be shown as below :

$$3.2 \times \frac{R2}{R1+R2} = 2.65V$$

- TSEN\_MAIN resistor network design : The ICCMAXs are designed as 35A and 6A for AUX1 and SA rail. By using the information, the equation can be listed by using multi-function pin setting mechanism :

$$3.2 \times \frac{R2}{R1+R2} = 3.15V$$

Protection Settings :

- OVP/UVP protections: When the VSEN pin voltage is 350mV higher than VID, the OVP will be latched. When the VSEN pin voltage is 350mV lower than VID, the UVP will be latched.
- TSEN and  $\overline{VR\_HOT}$  design : Using the following equation to calculate related resistances for  $\overline{VR\_HOT}$  setting.

$$V_{TSEN} = 80\mu \times (R3//R_{NTC}) + (R1//R2)$$

Choosing  $R1 = 100k\Omega$  and an NTC thermistor  $R_{NTC(25^\circ C)} = 100k\Omega$  and its  $\beta = 4485$ . When temperature is  $100^\circ C$ , the  $R_{NTC(100^\circ C)} = 4.85k\Omega$ . According to TSEN pins for multi-function mechanism, three equations can be got as following for MAIN VR rail :

$$V_{TSEN\_Main(25^\circ C)} = 80\mu \times (R3//R_{NTC(25^\circ C)}) + (R1//R2) = 1.624V$$

$$V_{TSEN\_Main(100^\circ C)} = 80\mu \times (R3//R_{NTC(100^\circ C)}) + (R1//R2) = 1.092V$$

$$3.2 \times \frac{R2}{R1+R2} = 2.65V$$

$R1 = 8.94k\Omega$ ,  $R2 = 600.45k\Omega$  and  $R3 = 5618.685k\Omega$ .

Three equations can be got as following for AUX1 VR rail:

$$V_{TSEN\_AUX1(25^\circ C)} = 80\mu \times (R3//R_{NTC(25^\circ C)}) + (R1//R2) = 1.624V$$

$$V_{TSEN\_AUX1(100^\circ C)} = 80\mu \times (R3//R_{NTC(100^\circ C)}) + (R1//R2) = 1.092V$$

$$3.2 \times \frac{R2}{R1+R2} = 3.15V$$

$R1 = 8.94k\Omega$ ,  $R2 = 63k\Omega$  and  $R3 = 5618.685k\Omega$ .

## Thermal Considerations

The junction temperature should never exceed the absolute maximum junction temperature  $T_{J(MAX)}$ , listed under Absolute Maximum Ratings, to avoid permanent damage to the device. The maximum allowable power dissipation depends on the thermal resistance of the IC package, the PCB layout, the rate of surrounding airflow, and the difference between the junction and ambient temperatures. The maximum power dissipation can be calculated using the following formula :

$$P_{D(MAX)} = (T_{J(MAX)} - T_A) / \theta_{JA}$$

where  $T_{J(MAX)}$  is the maximum junction temperature,  $T_A$  is the ambient temperature, and  $\theta_{JA}$  is the junction-to-ambient thermal resistance.

For continuous operation, the maximum operating junction temperature indicated under Recommended Operating Conditions is  $125^\circ C$ . The junction-to-ambient thermal resistance,  $\theta_{JA}$ , is highly package dependent. For a WQFN-48L 6x6 package, the thermal resistance,  $\theta_{JA}$ , is  $26.8^\circ C/W$  on a standard JEDEC 51-7 high effective-thermal-conductivity four-layer test board. The maximum power dissipation at  $T_A = 25^\circ C$  can be calculated as below :

$$P_{D(MAX)} = (125^\circ C - 25^\circ C) / (26.8^\circ C/W) = 3.73W \text{ for a WQFN-48L 6x6 package.}$$

The maximum power dissipation depends on the operating ambient temperature for the fixed  $T_{J(MAX)}$  and the thermal resistance,  $\theta_{JA}$ . The derating curves in Figure 27 allows the designer to see the effect of rising ambient temperature on the maximum power dissipation.

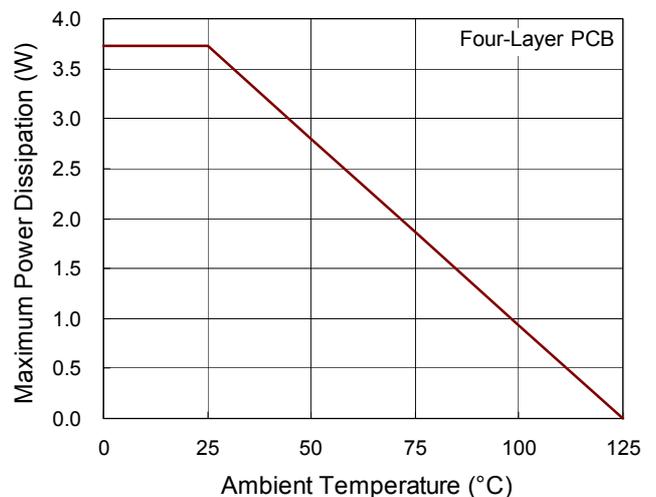
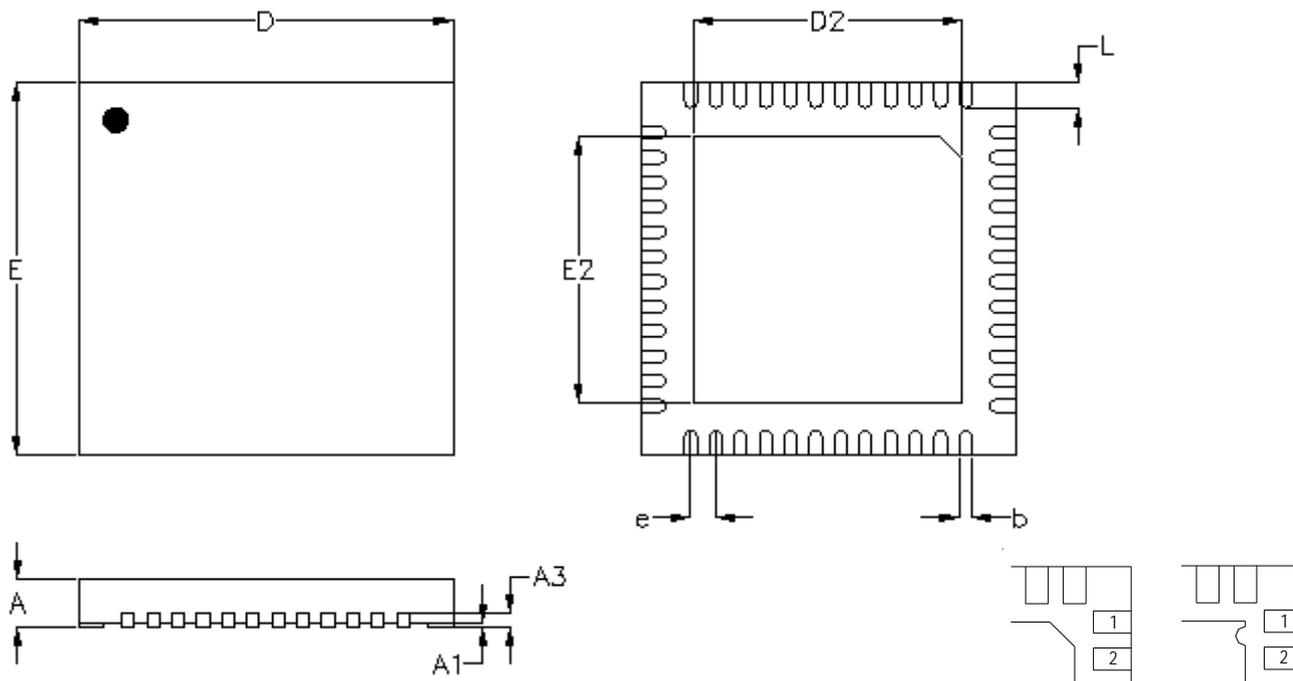


Figure 27. Derating Curve of Maximum Power Dissipation

**Outline Dimension**



**DETAIL A**

Pin #1 ID and Tie Bar Mark Options

Note : The configuration of the Pin #1 identifier is optional, but must be located within the zone indicated.

Symbol	Dimensions In Millimeters		Dimensions In Inches		
	Min.	Max.	Min.	Max.	
A	0.700	0.800	0.028	0.031	
A1	0.000	0.050	0.000	0.002	
A3	0.175	0.250	0.007	0.010	
b	0.150	0.250	0.006	0.010	
D	5.950	6.050	0.234	0.238	
D2	Option 1	4.250	4.350	0.167	0.171
	Option 2	4.350	4.450	0.171	0.175
E	5.950	6.050	0.234	0.238	
E2	Option 1	4.250	4.350	0.167	0.171
	Option 2	4.350	4.450	0.171	0.175
e	0.400		0.016		
L	0.350	0.450	0.014	0.018	

**W-Type 48L QFN 6x6 Package**

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