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## Contact us

Tel: +86-755-8981 8866 Fax: +86-755-8427 6832

Email & Skype: info@chipsmall.com Web: www.chipsmall.com

Address: A1208, Overseas Decoration Building, #122 Zhenhua RD., Futian, Shenzhen, China



## FEATURES

- Integrated 6.8V/0.8A Buck Regulator provides bias to Control and Driver IC(s)
- Adjustable switching frequency from 250 KHz up to 1.5MHz per phase based on the synchronization SCLK input
- Sink and source tracking capability
- Margining via SVID for both rails
- Pre-bias compatible
- Soft Stop capability
- 0.5% overall system set point accuracy
- Voltage Mode Modulation for excellent transient performance
- Single NTC thermistor for current reporting, OC Threshold, and Load Line thermal compensation
- Complete protection including over-current, over-voltage, over-temperature, open remote sense and open control loop
- Thermally enhanced 48L 7mm x 7mm MLPQ package
- RoHS compliant

## DESCRIPTION

The IR3531 control IC provides all the necessary control, communication and protection to support compact dual output power solutions up to 210W. The IR3531 can be combined with either discrete IR3535 driver ICs and Direct Fets™ or our IR35XX family of footprint compatible and scalable PowIRstages™ which integrate the MOSFETs and driver into the same package.

The IR3531 provides overall system control and current sharing while the Driver IC or power stages senses per-phase current locally and communicates it to the Control IC. The IR3531 has tri-state PWM outputs to allow diode emulation during light load events.

The IR3531 provides a high performance transient solution through classic voltage mode control and our non-linear transient solutions, Turbo™ and Body Braking™. Turbo™ automatically turns on all phases to minimize load turn-on transients while Body Braking™ automatically turns off the low-side MOSFET to help dissipate stored inductor energy at load turn-off.

## BASIC APPLICATION CIRCUIT

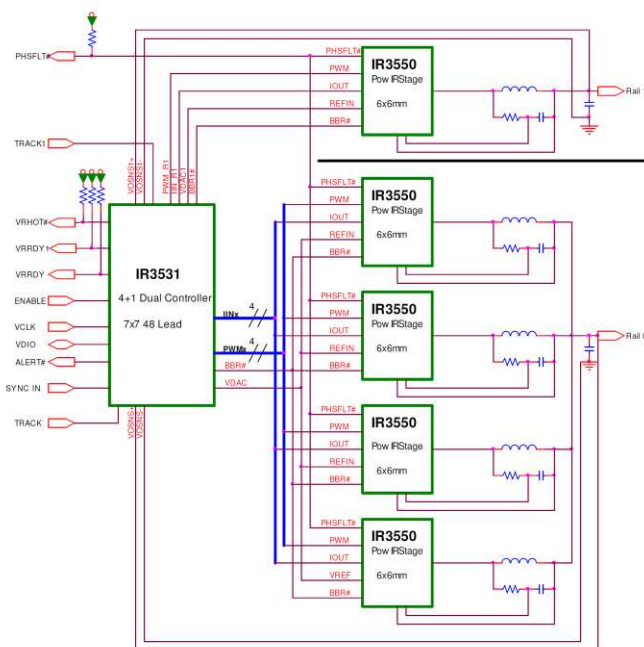


Figure 1: IR3531 Basic Application Circuit, showing a 4+1 Configuration

## PIN DIAGRAM

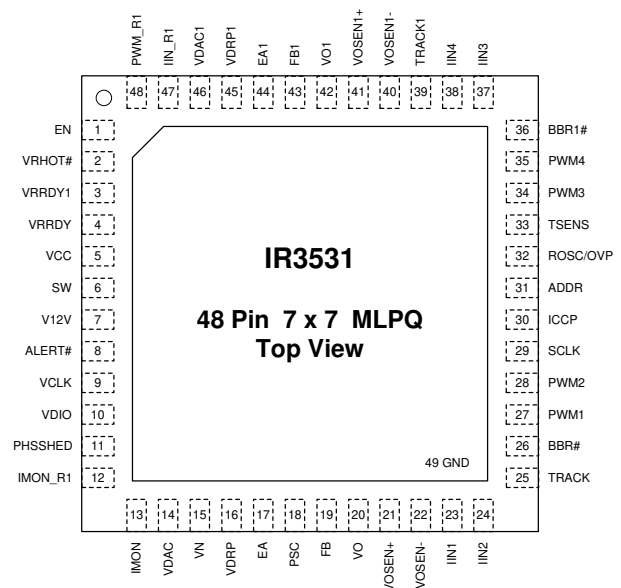
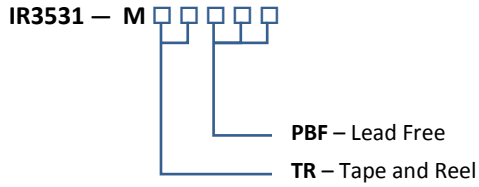


Figure 2: IR3531 Package Top View

**ORDERING INFORMATION**



Package	Tape & Reel Qty	Part Number
48 Lead MLPQ (7x7 mm body)	100	IR3531-MPBF
48 Lead MLPQ (7x7 mm body)	3000	IR3531-MTRPBF <sup>1</sup>

Note <sup>1</sup>: Samples only.

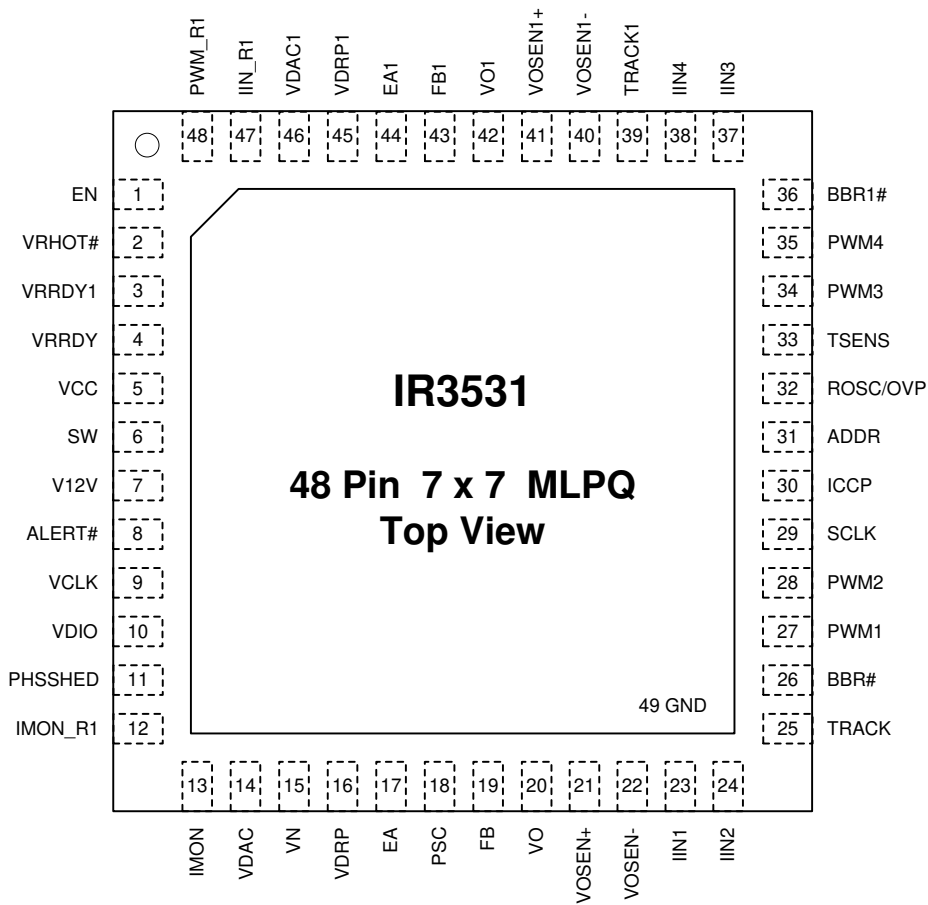


Figure 3: Package Top View, Enlarged



**FUNCTIONAL BLOCK DIAGRAM**

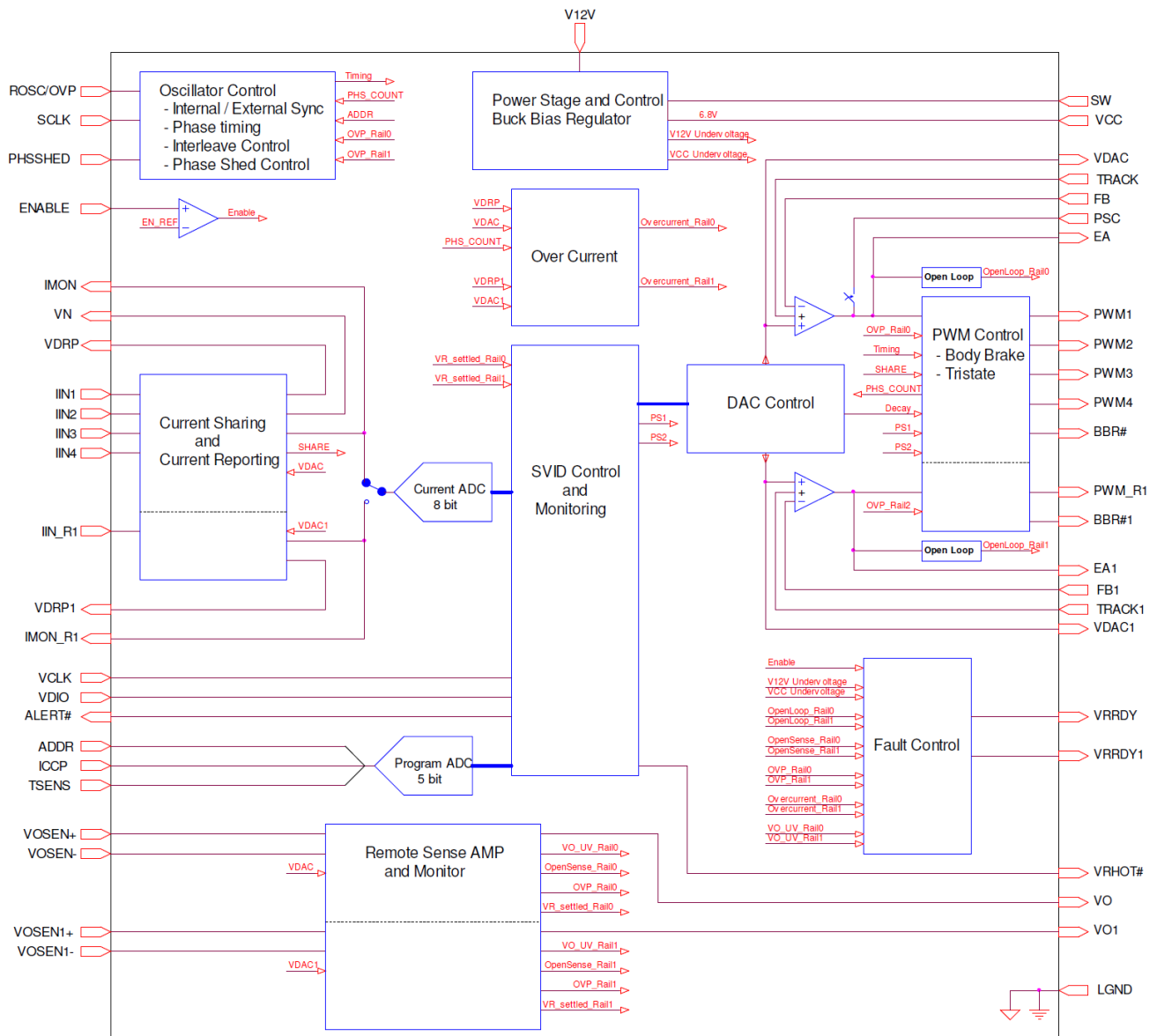


Figure 4: IR3531 Block Diagram

**TYPICAL APPLICATION DIAGRAM**

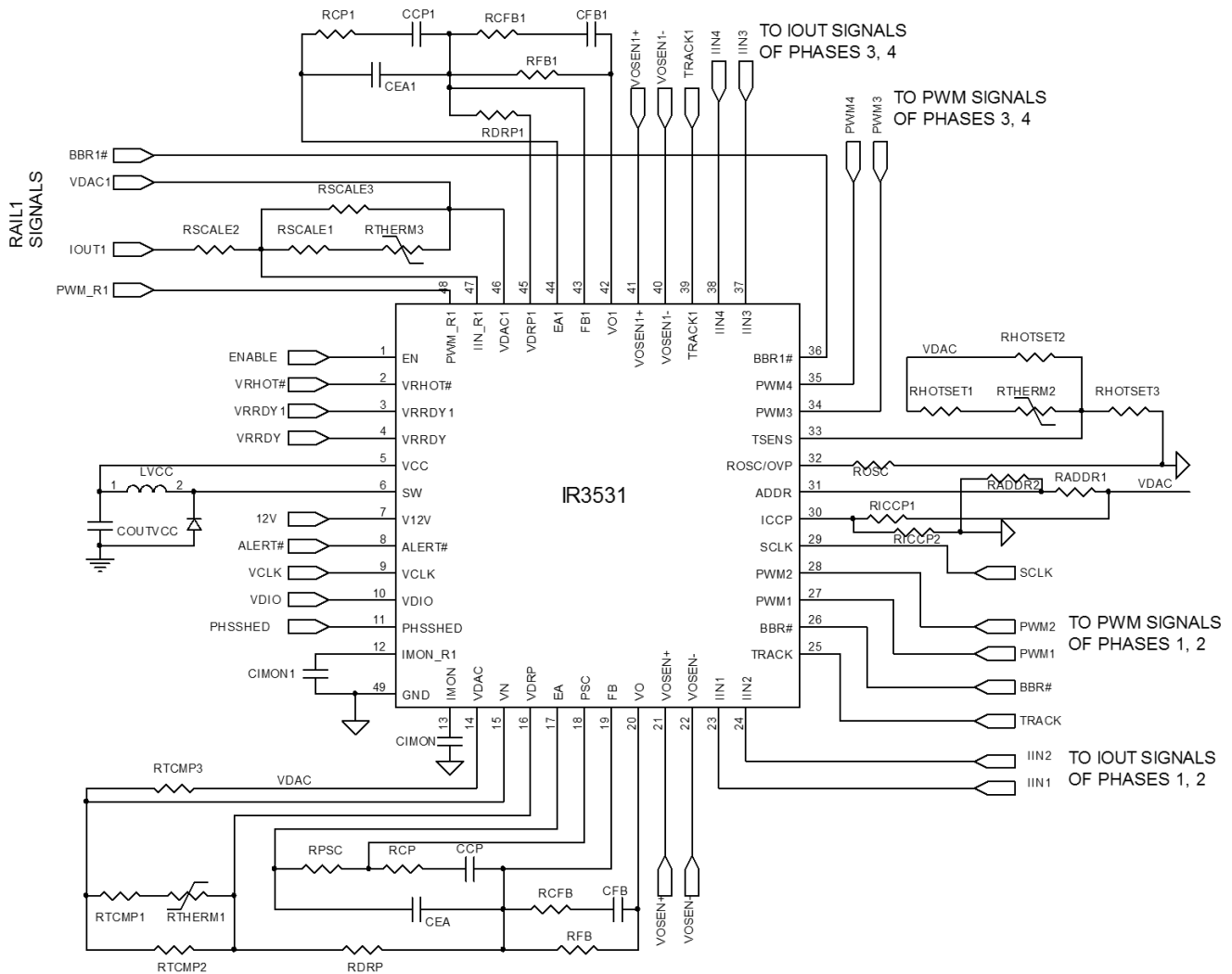


Figure 5: IR3531 Typical Application Diagram

## PIN DESCRIPTIONS

PIN #	PIN NAME	PIN DESCRIPTION
1	EN	Enable input. Grounding this pin shuts down the voltage regulators. Do not float this pin as the logic state will be undefined.
2	VRHOT#	Open collector output of the VRHOT# comparator which drives low if Rail0 temperature exceeds the programmed threshold. Connect external pull-up to bias.
3	VDRRY1	Open collector output that drives low during startup and under any external fault condition for Rail1 regulator. Connect external pull-up to bias.
4	VDRRY	Open collector output that drives low during startup and under any external fault condition for Rail0 regulator. Connect external pull-up to bias.
5	VCC	Bias buck regulator output, feedback pin, and bias input for internal circuitry.
6	SW	Switching node for bias buck regulator.
7	V12V	Power Supply input supply rail.
8	ALERT#	Output pin for SVID Alert# interrupt. Open collector output that drives low to notify the master.
9	VCLK	SVID Clock Input. Clock is a high impedance input pin. It is driven by the open collector output of a microprocessor and requires a pull-up resistor.
10	VDIO	SVID Data Input/Output. High impedance input when address, command or data bits are shifted in, open drain output when acknowledging or sending data back to the microprocessor. Pin requires a pull up resistor.
11	PHSSHED	Analog signal that represents the number of phases to be disabled. 0% to 25% VCC, no phases disabled. 25% to 50% VCC, disable 1 phase. 50% to 75% VCC, disable 2 phases. 75% to 100% VCC, disable 3 phases (if available).
12	IMON_R1	Voltage at this pin is proportional to Rail1 load current. It is also the input to the ADC for output current register.
13	IMON	Voltage at this pin is proportional to Rail0 load current. It is also the input to the ADC for output current register.
14	VDAC	Voltage Regulator Rail 0 reference voltage programmed by SVID. VDAC is also used as the A/D reference during power up for pins ADDR/PSN, TSENS and ICCP.
15	VN	Node for DCR thermal compensation network.
16	VDRP	Buffered, scaled and thermally compensated current signal for Rail0. Connect an external resistor to FB to program converter output impedance.
17	EA	Output of the error amplifier for Rail0.
18	PSC	Node for Power Savings mode compensation input.
19	FB	Inverting input to the Error Amplifier for Rail0.
20	VO	Remote sense amplifier output for Rail0.
21	VOSEN+	Rail0 remote sense amplifier input. Connect to output at the load.
22	VOSEN-	Rail0 remote sense amplifier input. Connect to ground at the load.
23, 24, 37, 38	IIN1-4	Current signals from the driver IC-s of Rail0.
25	TRACK	External tracking reference for Rail0.
26	BBR#	Body-braking™ bus for Rail0 driver ICs to disable synchronous switches.
27, 28, 34, 35	PWM1-4	PWM outputs for Rail0. Each output is connected to the input of the driver IC. Connecting the PWMx output to LGND disables the phase, allowing the IR3531 to operate as a 1, 2, 3, or 4 phase controller.
29	SCLK	Synchronization clock input. Program ROSC using ROSC vs. Frequency to match the SCLK frequency.

PIN #	PIN NAME	PIN DESCRIPTION
30	ICCP	Program maximum load current for both Rail0 and Rail1.
31	ADDR	Programs SVID address for Rail0 and Rail1, discrete or coupled inductor operation for Rail0, enable/disable turbo function for Rail0.
32	ROSC/OVP	Connect a resistor to LGND to program oscillator frequency. Oscillator frequency equals switching frequency per phase. ROSC/OVP pin is pulled up to VCC when an over voltage event occurs.
33	TSENS	Pin for thermal network that senses the temperature of Rail0 and Rail1.
36	BBR1#	Body-braking™ bus for Rail1 driver ICs to disable synchronous switches.
39	TRACK1	External tracking reference for Rail1.
40	VOSEN1-	Rail1 remote sense amplifier input. Connect to ground at the load.
41	VOSEN1+	Rail1 remote sense amplifier input. Connect to output at the load.
42	VO1	Remote sense amplifier output for Rail1.
43	FB1	Inverting input to the Error Amplifier for Rail1.
44	EA1	Output of the error amplifier for Rail1.
45	VDRP1	Buffered, scaled and thermally compensated current signal for Rail1. Connect an external resistor to FB1 to program converter output impedance.
46	VDAC1	Buffered Rail1 reference voltage. Voltage can be margined via SVID.
47	IIN_R1	Current signal from Rail1 driver IC.
48	PWM_R1	PWM output for Rail1.
49	GND	Local Ground for internal circuitry and IC substrate connection.

## ABSOLUTE MAXIMUM RATINGS

Storage Temperature Range	-65°C To 150°C
Operating Junction Temperature	0°C To 150°C
ESD Rating	HBM Class 1C JEDEC Standard
MSL Rating	2
Reflow Temperature	260°C

Stresses beyond those listed under “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 are not implied.

PIN Number	PIN NAME	V <sub>MAX</sub>	V <sub>MIN</sub>	I <sub>SOURCE</sub>	I <sub>SINK</sub>
1	EN	3.5V	-0.3V	25mA	1mA
2	VRHOT#	VCC	-0.3V	1mA	50mA
3	VDRRY1	VCC	-0.3V	1mA	20mA
4	VDRRY	VCC	-0.3V	1mA	20mA
5	VCC	8V	-0.3V	1mA	20mA
6	SW	16V	-1.0V	3A	1mA
7	V12V	16V	-0.5V	1mA	1.5A
8	ALERT#	3.5V	-0.3V	1mA	50mA
9	VCLK	3.5V	-0.3V	1mA	1mA
10	VDIO	3.5V	-0.3V	1mA	50mA
11	PHSSHED	VCC	-0.3V	1mA	1mA
12	IMON_R1	3.5V	-0.3V	25mA	1mA
13	IMON	3.5V	-0.3V	25mA	1mA
14	VDAC	3.5V	-0.3V	5mA	35mA
15	VN	VCC	-0.3V	1mA	1mA
16	VDRP	VCC	-0.3V	35mA	1mA
17	EA	VCC	-0.3V	35mA	5mA
18	PSC	VCC	-0.3V	1mA	1mA
19	FB	VCC	-0.3V	1mA	1mA
20	VO	VCC	-0.3V	35mA	5mA
21	VOSEN+	VCC	-0.5V	5mA	1mA
22	VOSEN-	1.0V	-0.5V	5mA	1mA
23	IIN1	VCC	-0.3V	1mA	1mA
24	IIN2	VCC	-0.3V	1mA	1mA
25	TRACK	VCC	-0.3V	1mA	1mA
26	BBR#	VCC	-0.3V	1mA	5mA
27	PWM1	VCC	-0.3V	1mA	5mA



PIN Number	PIN NAME	V <sub>MAX</sub>	V <sub>MIN</sub>	I <sub>SOURCE</sub>	I <sub>SINK</sub>
28	PWM2	VCC	-0.3V	1mA	5mA
29	SCLK	3.5V	-0.3V	1mA	5mA
30	ICCP	3.5V	-0.3V	1mA	1mA
31	ADDR	3.5V	-0.3V	1mA	1mA
32	ROSC	VCC	-0.3V	1mA	1mA
33	TSEN	3.5V	-0.3V	1mA	1mA
34	PWM3	VCC	-0.3V	1mA	5mA
35	PWM4	VCC	-0.3V	1mA	5mA
36	BBR1#	VCC	-0.3V	1mA	5mA
37	IIN3	VCC	-0.3V	1mA	1mA
38	IIN4	VCC	-0.3V	1mA	1mA
39	TRACK1	VCC	-0.3V	1mA	1mA
40	VOSEN1-	1.0V	-0.5V	5mA	1mA
41	VOSEN1+	VCC	-0.5V	5mA	1mA
42	VO1	VCC	-0.5V	35mA	5mA
43	FB1	VCC	-0.3V	1mA	1mA
44	EA1	VCC	-0.3V	35mA	5mA
45	VDRP1	VCC	-0.3V	35mA	1mA
46	VDAC1	3.5V	-0.3V	1mA	35mA
47	IIN_R1	VCC	-0.3V	1mA	1mA
48	PWM_R1	VCC	-0.3V	1mA	1mA
49	GND	N/A	N/A	20mA	1mA

## ELECTRICAL SPECIFICATIONS

### RECOMMENDED OPERATING CONDITIONS FOR RELIABLE OPERATION WITH MARGIN

The electrical characteristics table lists the spread of values guaranteed within the recommended operating conditions. Typical values represent the median values, which are related to 25°C. Unless otherwise specified, these specifications apply over:  $-0.3V \leq VOSEN- \leq 0.3V$ ,  $7.75K\Omega \leq RO SC \leq 50.0 K\Omega$

Recommended V12V Range	10.8V	12	13.2V	V
Recommended VCC Range	6.6	6.8	7.0	V
VOSEN- and VOSEN1- to LGND offset	-0.3	0	0.3	V
ROSC Resistor Programming Range	7.75		50	K $\Omega$
Recommended Operating Junction Temperature	0	T <sub>J</sub>	100	°C

## ELECTRICAL CHARACTERISTICS

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNIT
<b>VDAC Reference</b>						
System Set-Point Accuracy	SETACC	VID $\geq$ 1V	-0.5	-	0.5	%
		$0.8 \leq$ VID < 1V	-5	-	+5	mV
		$0.25V \leq$ VID < 0.8V	-8	-	+8	mV
Slew Rate – Fast Mode	VIDFAST		15	20	25	mV/ $\mu$ s
Slew Rate – Slow Mode	VIDSLOW		3.75	5	6.25	mV/ $\mu$ s
Default VBOOT Rail 0	VBOOT0	Note 3	-	1.5	-	V
Default VBOOT Rail 1	VBOOT1	Note 3	-	1.5	-	V
<b>Oscillator (Note 4)</b>						
ROSC Voltage	VROSC	ROSC = 24.5 K $\Omega$	0.570	0.595	0.620	V
<b>VDAC Buffer Amplifier</b>						
Input Offset Voltage	DACOFF	V(VDAC, VDAC1) – VID code + VID offset, $0.25V \leq$ V(VDAC, VDAC1) $\leq$ 1.52V, < 1mA load	-15	0	15	mV
Source Current	DACSRC	$0.25V \leq$ V(VDAC1) $\leq$ 1.52V	0.3	0.44	0.6	mA
		$0.25V \leq$ V(VDAC) $\leq$ 1.52V	0.9	1.65	2.4	
Sink Current	DACSINK	$0.5V \leq$ V(VDAC1) $\leq$ 1.52V	2	13	20	mA
		V(VDAC1) = 0.25V	0.5	1.5	2	
		$0.5V \leq$ V(VDAC) $\leq$ 1.52V	3	15	30	
		V(VDAC) = 0.25V	0.5	1.5	3	
Unity Gain Bandwidth			-	3.5	-	MHz
Slew Rate			-	1.5	-	V/ $\mu$ s
<b>Thermal Compensation Amplifier (VDRP)</b>						
Output Offset Voltage	VDRPOUTOFF	$0V \leq$ V(IIN) – V(VDAC) $\leq$ 1.52V, $0.25V \leq$ V(VDAC) $\leq$ 1.52V,	-14	0	14	mV

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNIT
		Req/R2 = 2				
Source Current	VDRPSRC	$0.25V \leq V(\text{VDAC}) \leq 1.52V$	3	8	15	mA
Sink Current	VDRPSNK	$0.5V \leq V(\text{VDRP}) \leq 1.52V$	0.2	0.4	0.7	mA
		$V(\text{VDRP}) = 0.25V$	0.175	0.25	0.4	
Unity Gain Bandwidth		Req/R2 = 2, Note 1	2	4.5	7	MHz
Slew Rate			-	5.5	-	V/ $\mu$ s
VN Bias Current		$V(\text{VN}) = 2V$	-2	0	2	$\mu$ A
<b>Power Savings Mode Operation</b>						
PS2/PS3 Turn-on Threshold	PS2THRSH	VID = 250 mV	250	350	385	mV
		VID = 1.52 V	2	2.15	2.26	V
PS2/PS3 Pulse Width Rail0	PS2COT0	VID = 250 mV, SF = 500 kHz	60	151	200	ns
		VID = 1.52 V, SF = 500 kHz	220	409	480	
PS2/PS3 Pulse Width Rail1	PS2COTMIN1	VID = 250 mV, SF = 500 kHz	50	100	200	ns
	PS2COTMAX1	VID = 1.52 V, SF = 500 kHz	220	358	480	
PS Mode Enter Delay	PS1DELAY	PS0 to PS1 only	-	8	-	PWM Cycle
<b>Enable Input</b>						
Rising Threshold	ENRISE		625	650	675	mV
Falling Threshold	ENFALL		575	600	625	mV
Hysteresis	ENHYST		25	50	75	mV
Bias Current	ENBIAS	$0V \leq V(\text{ENABLE}) \leq 3.3V$	-5	0	5	$\mu$ A
Blanking Time		Noise Pulse < 100ns will not register an ENABLE state change. Note 1	75	250	400	ns
<b>IMONx Current Report Amplifier</b>						
Output Offset Voltage	IMONOFF	$V(\text{VDRP}) - V(\text{VDAC}) = 0, 225, 450, 900\text{mV}$	15	50	90	mV
Unity Gain Bandwidth		Note 1	-	1	-	MHz
Input Filter Time Constant			-	1	-	$\mu$ s
Max Output Voltage	IMONMAX		1.00	1.09	1.145	V
Current Report A/D Accuracy	IMONACC	$V(\text{VDRP}) - V(\text{VDAC}) = 900\text{mV}$	-2	0	2	%
<b>Rail1 VDRP Amplifier</b>						
Output Offset Voltage	VDRP1OFF	$0V \leq V(\text{IIN\_R1}) - V(\text{VDAC1}) \leq 0.2V$ $0.25V \leq V(\text{IIN\_R1}) - V(\text{VDAC1}) \leq 1.52V$	-75	0	75	mV
Source Current	VDRP1SRC	$0.25V \leq V(\text{VDAC1}) \leq 1.52V$	3	8	15	mA
Sink Current	VDRP1SNK	$0.5V \leq V(\text{VDRP1}) \leq 1.52V$	0.2	0.4	0.6	mA
		$V(\text{VDRP1}) = 0.25V$	0.175	0.25	0.375	
Closed Loop Gain		Note 1	-	9	-	V/V
Unity Gain Bandwidth		Note 1	0.8	1.5	3	MHz
Slew Rate		Note 1	-	5.5	-	V/ $\mu$ s
<b>Error Amplifier</b>						

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNIT
Input Offset Voltage		Note 2 (test mode only)	-	0	-	mV
FB Bias Current			-1	0	1	μA
DC Gain		Note 1	100	110	120	dB
Unity Gain Bandwidth		Note 1	20	30	40	MHz
Slew Rate		Note 1	7	12	20	V/μs
Sink Current	EASRC		0.40	0.85	1.35	mA
Source Current	EASNK		5	8	12	mA
Maximum Voltage	EAMAX	Measure V(VCC) – V(EA), V(EA1)	500	925	1100	mV
Minimum Voltage	EAMIN		-	120	250	mV
Open Voltage Loop Detection Threshold	EAOPENTHR	Measure V(VCCx) - V(EA), V(EA1), Relative to Error Amplifier maximum voltage	100	300	1100	mV
Open Loop Detection Delay	EAOPENDEL	V(EA), V(EA1) = V(VCC) to VRRDY = low	-	8	-	PWM
PS2 Clamp Voltage	EAPS2CLMP	With respect to VDAC	-240	-70	-10	mV
<b>Phase Firing Comparators</b>						
Input Offset	KEEPOFF		-30	0	30	mV
Propagation Delay	KEEPDEL		-	-	320	ns
<b>Phase Shedding Comparators</b>						
Bias Current	PHSDBIAS		-2	0	2	μA
Threshold	PHSDTHRS	Comparator 1	1.3	1.7	2.0	V
		Comparator 2	3.0	3.4	3.85	
		Comparator 3	4.8	5.1	5.55	
<b>PWM Comparator</b>						
PWM Ramp Slope	PWMSLP	V12V= 12V	42	52.5	57	mV/ %DC
Minimum Pulse Width	PWMMIN	Note 1		55	70	ns
Input Offset Voltage	PWMOFF	Note 1	-5	0	5	mV
<b>Share Adjust Amplifier</b>						
Input Offset Voltage	SAAOFF	Note 1	-3	0	3	mV
Gain	SAAGAIN	CSIN+ = CSIN- = DACIN, Note 1	4	5.0	6	V/V
Unity Gain Bandwidth		Note 1	4	8.5	17	kHz
Maximum PWM Ramp Floor Voltage	MINFLOOR	IOUT = DACIN – 200mV Measure relative to floor voltage	100	180	220	mV
Minimum PWM Ramp Floor Voltage	MAXFLOOR	IOUT = DACIN + 200mV Measure relative to floor voltage	-220	-160	-100	mV
<b>Over Voltage Protection (OVP) Comparators</b>						
Threshold at Power-up	OVPPOP		1.615	1.65	1.67	V
Threshold during Normal Operation	OVPTHR	Compare to VID Voltage + VID offset	100	130	150	mV
Propagation Delay to OVP	OVPPROP	Measure time from V(FB), V(FB1) > VID voltage + VID offset (250mV overdrive) to V(PWM) transition to > 0.5 * V(VCC)	-	90	180	ns

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNIT
<b>Turbo Circuit</b>						
Activation Threshold Voltage	TURBACT Note 1	Compare to EA, Note 1	-	390	-	mV
Turbo Comparator Hysteresis	TURBHYST Note 1	Note 1	-	90	-	mV
Filter Time Constant	TURBTIME Note 1	Note 1	-	8	-	μs
Turbo Pulse Width	TURBPW	500kHz 600mV Peak sine wave on EAIN, measure GATEH pulse width	115	230	280	ns
Peak Detect Reset Time Constant	TURBRESET		-	400	-	ns
<b>Over-Current Comparator</b>						
Input Filter Time Constant			-	2	-	μs
Over-Current Threshold	OCTHRSH	VDRP-VDAC, VDRP1-VDAC1	0.94	1.08	1.18	V
OC Threshold PSI Reduction Factor	OCPSI	PSI mode, 4ph to 2ph, 2ph to 1ph	450	540	610	mV
		PSI mode, 3ph to 1ph	310	360	410	
		3ph to 2ph	640	720	800	
		PSI mode, 4ph to 1ph	220	270	310	
		4ph to 3ph	690	800	900	
OC Delay Time	OCDELAY	Delay to OC shutdown	225	256	285	μs
OC Hiccup Time		Relaxation Delay	-	4096	-	μs
<b>VCC Undervoltage</b>						
VCC UVL Start	VCCSTART		5.5	5.85	6.4	V
VCC UVL Stop	VCCSTOP		4.85	5.2	5.65	V
VCC UVL Hysteresis	VCCHYST		515	650	830	mV
<b>VRRDY Output</b>						
Output Voltage	VRRDYLO	I(VRRDY, VDRRY1) = 4mA	-	150	300	mV
Leakage Current	VRRDYLEAK	V(VRRDY, VDRRY1) = 5.5V	-	0	10	μA
VCC Activation Voltage	VRRDYVCC	I(VDRRY, VDRRY1) = 4mA, <300mV	1	2	3.6	V
VO-VDAC Undervoltage Threshold	VOUVRISE	Reference to VDAC	-340	-290	-230	mV
<b>Open Sense Line Detection</b>						
Sense Line Detection Active Comparator Threshold Voltage	OPENACT		100	150	200	mV
Sense Line Detection Active Comparator Offset Voltage	OPENOFF	$V(VO) < [V(VOSEN+) - V(LGND)] / 2$	25	60	80	mV
VOSEN+ Open Sense Line Comparator Threshold	OPENCOMP+	Compare to V(VCC)	82	90	92	%
VOSEN- Open Sense Line Comparator Threshold	OPENCOMP-		0.36	0.40	0.44	V
Sense Line Detection Source Currents	OPENSRC	V(VO) = 100mV	200	500	700	μA
<b>VCC Buck Regulator</b>						
VCC Output Voltage	VCC100	100–400 mA load current	6.5	6.8	7.1	V



PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNIT
Switch Node Rise Time	SWRISE	Note 1	-	5	-	ns
Switch Node Fall Time	SWFALL	Note 1	-	15	-	ns
<b>A/D Program Inputs</b>						
ADDR Pin Bias Current	ADDRBIAS		-2	0	2	μA
ICCP Pin Bias Current	ICCPBIAS		-2	0	2	μA
TSENS Pin Bias Current	TSENBIAS		-2	0	2	μA
A/D Comparator Offset	ADOFFSET		-5	0	5	mV
<b>V12V Undervoltage</b>						
VCC V12V Start	VCCSTART		8.8	9.6	10.2	V
VCC V12V Stop	VCCSTOP		7.8	8.6	9.2	V
VCC V12V Hysteresis	VCCHYST		0.8	1	1.3	V
<b>SerialVID</b>						
ALERT#, VDIO Buffer On Resistance	ALERTRES		-	-	14.3	Ω
ALERT#, VDIO Leakage Current	ALERTLEAK		-10	0	10	μA
VCLK Bias Current	VCLKBIAS		-1	0	1	μA
VDIO Bias Current	VDIOBIAS		-1	0	1	μA
Transmit Data Prop Delay	XMITDELAY	VCLK rising to VDIO change	4	6	12	ns
Comparator Threshold	SVIDTHRSH	VCLK, VDIO rising	500	590	650	mV
		VCLK, VDIO falling	450	515	650	
Comparator Hysteresis	SVIDHYST		50	75	-	mV
Link States Reset Timer	SVIDTIME		200	-	600	ns
<b>PWMx Outputs</b>						
Source Resistance	PWMSRCR		50	144	500	Ω
Sink Resistance	PWMSNKR		75	117	290	Ω
Tri-state Source Impedance	PWMTRIZ		2.0	5.4	7.5	KΩ
Tri-state Bias Current	PWMTRIBIAS	V(PWMx) = 1.65V	-5	0	5	μA
Tri-state Active Pull-up	PWMTRIPUP	V(PWMx) while sourcing 100 μA to GND	0.5	1	1.2	V
Disable Comparator Threshold	PWMDISTHR		0.4	0.6	0.9	V
PWM High Voltage	PWMHIGH	I(PWM) = -1mA, measure VCC-PWM	-	-	1	V
PWM Low Voltage	PWMLOW	I(PWM) = -1mA	-	-	1	V
<b>Body Braking Comparator</b>						
Threshold Voltage with EAIN Decreasing	BBRTHRFBLL	Measure relative to floor voltage	-300	-200	-110	mV
Threshold Voltage with EAIN Increasing	BBRTHRRISE	Measure relative to floor voltage	-200	-100	-10	mV
Hysteresis	BBRTHRHS		70	105	130	mV
Propagation Delay	BBRDELAY	VCC = 5V Measure time from EAIN < V(DACIN) (200mV overdrive) to GATEL transition to < 4V.	30	65	90	ns
BBR1# Source Resistance	BBRSRCRES		20	40	75	Ω

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNIT
BBR1# Sink Resistance	BBRSNKRES		10	35	60	Ω
BBR1# High Voltage	BBRHIGH	I(BBR1#) = -1mA, measure V(VCC) – V(BBR1#)	0	0.4	0.8	V
BBR1# Low Voltage	BBRLOW	I(BBR1#) = 1mA	0	0.35	0.8	V
<b>Remote Sense Differential Amplifier</b>						
Unity Gain Bandwidth	RSABW	Note 1	1.5	3.2	4.5	mV
Input Offset Voltage	RSAOFF	0.25V ≤ V(VOSEN+) - V(VOSEN-) ≤ 1.52V, 0.25V ≤ V(VOSEN1+) - V(VOSEN1-) ≤ 1.52V	-5	0	5	mV
Sink Current	RSASINK	0.5V ≤ V(VOSEN+) - V(VOSEN-) ≤ 1.52V, 0.5V ≤ V(VOSEN1+) - V(VOSEN1-) ≤ 1.52V	0.4	1	2	mA
		V(VOSEN+) - V(VOSEN-) = 0.25V, V(VOSEN1+) - V(VOSEN1-) = 0.25V	0.225	0.5	0.8	
Source Current	RSASRC	0.25V ≤ V(VOSEN+) - V(VOSEN-) ≤ 1.52V, 0.25V ≤ V(VOSEN1+) - V(VOSEN1-) ≤ 1.52V	3	9	20	mA
Slew Rate	RSASLEW	0.25V ≤ V(VOSEN+) - V(VOSEN-) ≤ 1.52V, 0.25V ≤ V(VOSEN1+) - V(VOSEN1-) ≤ 1.52V	2	4	8	V/μs
VOSEN+ Bias Current	VOSNS-BIAS	0.25 V < V(VOSEN+) < 1.52V, 0.25 V < V(VOSEN1+) < 1.52V	-	27	50	μA
VOSEN- Bias Current	VOSNS+BIAS	-0.3V ≤ VOSEN- ≤ 0.3V, All VID Codes, -0.3V ≤ VOSEN1- ≤ 0.3V, All VID Codes	-	27	70	μA
High Voltage	VOHIGH	V(VCC) – V(VO), V(VCC) – V(VO1)	1.5	2	2.5	V
Low Voltage	VOLOW	V(VCC) = 7V	-	60	100	mV
<b>VRHOT# Comparator</b>						
Output Voltage	VRHTOUT	I(VRHOT#) = 30mA	-	150	400	mV
VRHOT# Leakage Current	VRHTLEAK	V(VRHOT#) = 5.5V	-	0	10	μA
<b>Platform Test Mode</b>						
Comparator Threshold	PTMTHR	Raise ADDR voltage after VIN power-up	2.2	2.6	3.1	V
Link States Reset Timer	PTMTIME		20	-	24	μs
<b>VR Settled</b>						
Comparator Offset	VRSTLOFF	Compare FB to VDAC reference	-	20	-	mV
Delay to ALERT#	VRSTLDELAY	Delay after DAC settled to within 2 VID steps of final value	-	5	-	μs
<b>Current Inputs</b>						
IINx to IINx Impedance	IINRES		-	3000	-	Ω
IINx to IINx Leakage Current	IINLEAK		-1	0	1	μA
<b>TRACK Inputs</b>						
Input Leakage			-1	0	1	μA

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNIT
TRACK to FB Offset		Error amp in unity gain	15	36	65	mV
Release Error Voltage		TRACK = VDAC+100mV, VDAC-FB	-1	0	1	mV
<b>VO Discharge Comparators</b>						
Tri-state Enable Threshold		VO when PWM outputs enter tri-state	200	250	300	mV
<b>SCLK Synchronization Input</b>						
Rising Threshold			0.8	1.2	1.3	V
Falling Threshold		Note 1	0.625	0.85	1.025	V
Input Leakage			-5	0	5	μA
Propagation Delay Rising			-	-	60	ns
Input Capacitance		Note 1	-	-	10	pF
<b>General</b>						
VCC Supply Current	VCCBIAS		3	7	12	mA

**Notes:**

1. Guaranteed by design but not tested in production
2. Error Amplifier input offset is trimmed to within ±1% for optimal system set point accuracy.
3. Final test VBOOT options of 0, 0.9, 1.35 and 1.5V are feasible.  
 Contact International Rectifier Enterprise Power Business Unit for details.
4. Use of internal oscillator is not recommended, use SCLK input to set PWM frequency.

## THEORY OF OPERATION

### SYSTEM DESCRIPTION

The IR3531 Multiphase Buck power system provides voltage regulation solutions for two individual supply outputs. The main output, Rail0, controls up to four phases and produce up to 200A when paired with appropriate power stages. The secondary output, Rail1, is a single phase output capable of up to 50A, again with appropriate power stage. The IR3531 control IC is specialized to allow external clock synchronization and tracking capability for each rail. Features include a serial control and telemetry bus that can control output voltage settings and slew rates while allowing monitoring of the system thermals and load currents. The IR3531 control IC contains all necessary housekeeping, protection and control functions and communicates a three-level PWM signal to each power stage.

### FREQUENCY AND PHASE TIMING CONTROL

The IR3531 operates with external frequency synchronization which can be used to control input ripple from multiple paralleled power supply systems. Systems can be forced to operate out of phase thereby reducing instantaneous peak input currents and also controlling system noise signatures. The internal oscillator is used to calibrate the PWM ramp slopes and other functions at power up therefore it is desirable for the externally applied synchronization frequency to be very near the ROSC programmed internal frequency times the number of active phases. Calibration can take up to 1ms. This results in the PWM gain to be near the desired 50mV/% duty cycle. Furthermore, it is desired the SCLK input be stable prior to enabling the IR3531 voltage regulator.

The SCLK input frequency provided needs to equal the desired base switching frequency multiplied by the active number of phases. Phase shedding is available however SCLK needs to be adjusted accordingly to match the number of active phases.

Phase timing and interleave spacing is automatically optimized inside the controller and can accommodate changing phases on the fly (phase shedding). The PHSSHD pin can be used to dynamically drop from 1-3 phases while minimizing output voltage transients. Also, phases can be disabled by grounding the PWM outputs of the IR3531. Notice the driver ICs should be removed since a PWM low signal indicates a 0% duty cycle state which turns on the low-side MOSFETs and can potentially develop large negative inductor currents. The control IC detects which PWM pins are grounded during power up to determine the populated number of phases and automatically optimizes phase timing for minimal system ripple.

### TRACK FUNCTIONALITY

Both Rail outputs of the IR3531 can be independently controlled through their respective TRACK inputs. TRACK pins override the internal VDAC reference inputs to the Error Amplifiers allowing users to control power up and power down VR output voltage characteristics. The IR3531 is fully soft-stop and pre-bias compatible. The control loop is full synchronous during soft stop events thereby preventing COUT capacitor discharge-induced inductive kicks. The control system allows non-synchronous buck operation once  $V_O \leq 250\text{mV}$  — this allows outputs to return to their pre-biased operating points if available.

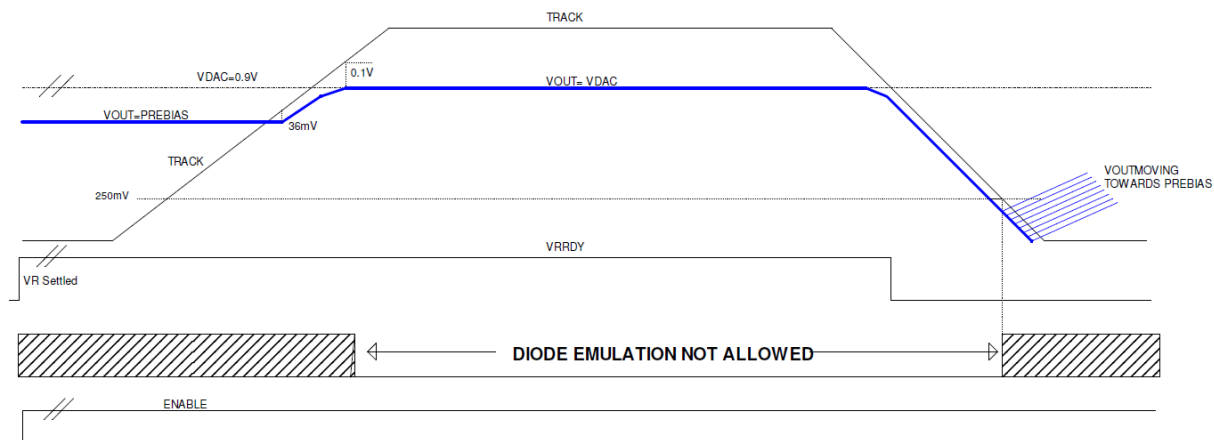


Figure 6: TRACK Operation with Pre-Bias

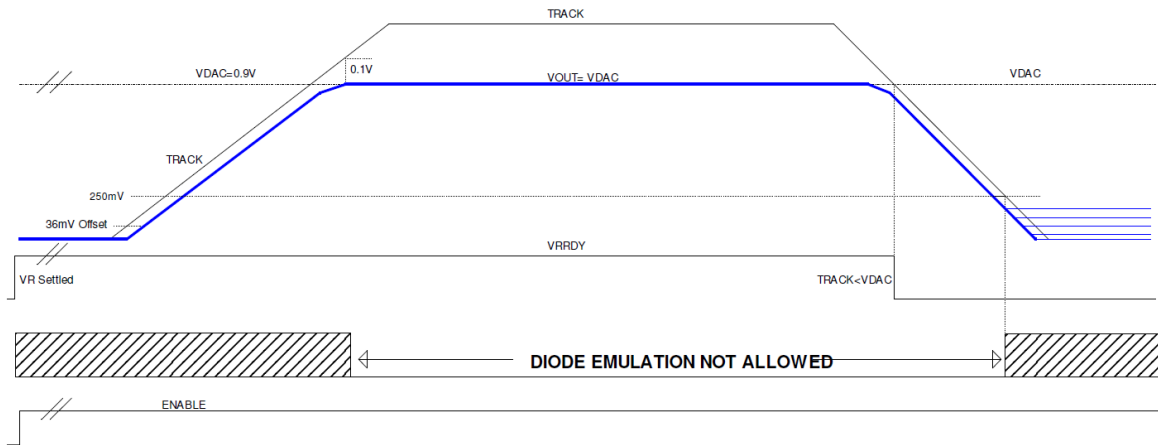


Figure 7: TRACK Operation without Pre-Bias

The TRACK inputs have a typical 36mV offset from the closed loop feedback operating point to ensure the error amplifier is in an off state when TRACK=0V. Furthermore, TRACK must exceed the respective VDAC by at least 100mV to ensure VDAC has complete control of the Error Amplifier as shown in Figures 6 and 7.

As a cautionary note the track input provides direct control of the output PWM duty cycle. The presence of excessive noise or glitches on TRACK when this input is active can cause sudden increases in the PWM duty cycle (up to 100%), potentially causing damage to the power converter.

### PWM CONTROL METHOD

The steady state control architecture utilized in the IR3531 is feed-forward voltage mode control with trailing edge modulation. A high-gain wide-bandwidth voltage type error amplifier is used to achieve accurate voltage regulation and ultra-fast transient response. Feed-forward control is established by varying the PWM ramp slope proportionally to the input voltage resulting in the error amplifier operating point being independent of the input voltage. The input voltage can change due to variations in the silver box output voltage or due to the wire and PCB-trace voltage drop related to changes in load current. All PWM ramp slopes are calibrated at initial power-up. The PWM pulse is terminated once the PWM ramp exceeds the Error Amplifier output voltage.

Under dynamic load transitions, the IR3531 utilizes our patented Body Braking™ algorithm allows all low-side MOSFETs to be turned off during a load relaxation event allowing the MOSFET body diodes to conduct and dissipate some of the stored inductor energy and also speed up the inductor current slew rate by introducing a larger voltage

across the inductor. Body Braking™ reduces the peak overshoot of the converter.

An error amplifier output voltage greater than the common mode input range of the PWM comparator results in 100% duty cycle regardless of the voltage of the PWM ramp. The resulting PWM control loop is capable of transitioning from 0% duty cycle to 100% duty cycle with overlapping phases within a few tens of nanoseconds in response to a load step decrease. Figure 8 on the next page depicts PWM operating waveforms under various conditions.

### BODY BRAKING™

In a conventional synchronous buck converter, the minimum time required to reduce the current in the inductor in response to a load-step decrease is:

$$T_{SLEW} = \frac{L * (I_{MAX} - I_{MIN})}{V_O}$$

The slew rate of the inductor current can be significantly increased by turning off the synchronous rectifier in response to a load-step decrease. The switch node voltage is then forced to decrease until conduction of the synchronous rectifier's body diode occurs. This increases the voltage across the inductor from Vout to Vout + V<sub>BODYDIODE</sub>. The minimum time required to reduce the current in the inductor in response to a load transient decrease is now:

$$T_{SLEW} = \frac{L * (I_{MAX} - I_{MIN})}{V_O + V_{BODYDIODE}}$$



Since the voltage drop in the body diode is often comparable to the output voltage, the inductor current

slew rate can be increased significantly. This patented

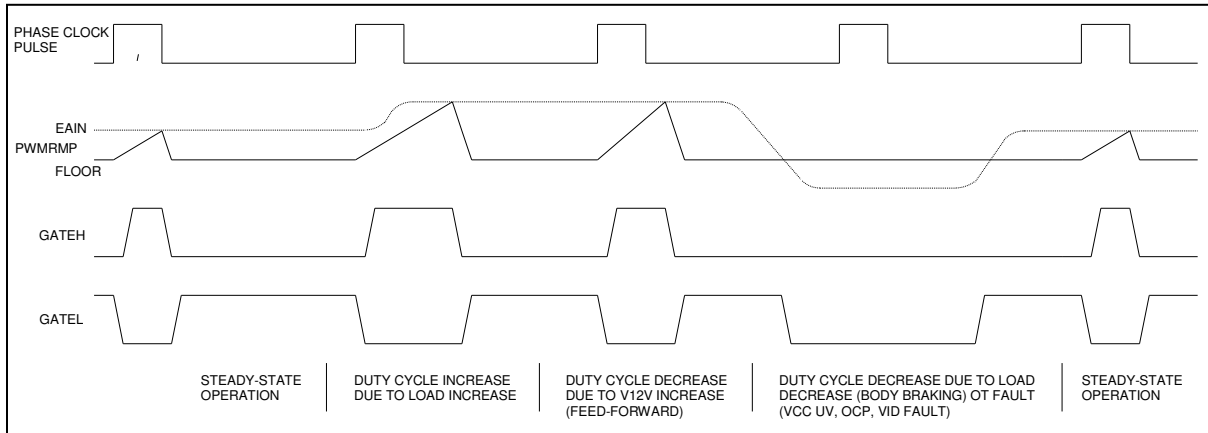


Figure 8: PWM Operating Waveforms

technique is referred to as “body braking” and is accomplished through the “body braking comparator.” If the error amplifier’s output voltage drops below VDAC, this comparator turns off the low-side gate driver, enabling the bottom FET body diode to take over. There is 100mV upslope and 200mV down slope hysteresis for the body braking comparator.

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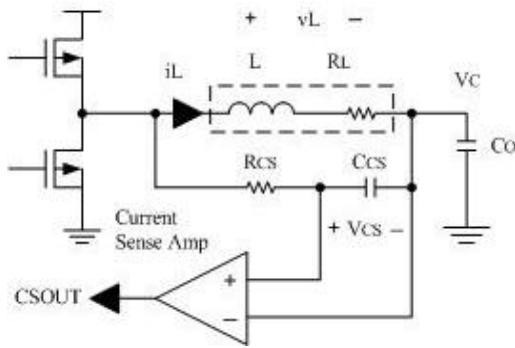
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**LOSSLESS AVERAGE INDUCTOR CURRENT SENSING**

Inductor current can be sensed by connecting a series resistor and a capacitor network in parallel with the inductor and measuring the voltage across the capacitor, as shown in Figure 8. The equation of the sensing network is:

$$v_C(s) = v_L(s) \frac{1}{1 + sR_{CS}C_{CS}} = i_L(s) \frac{R_L + sL}{1 + sR_{CS}C_{CS}}$$

Usually the resistor Rcs and capacitor Ccs are chosen, such that, the time constant of Rcs and Ccs equals the time constant of the inductor, which is the inductance L over the inductor DCR RL. If the two time constants match, the voltage across Ccs is proportional to the current through L, and the sense circuit can be treated as if only a sense resistor with the value of RL was used. The mismatch of the time constants does not affect the measurement of inductor DC current, but affects the AC component of the inductor current.



**Figure 9: Inductor Current Sensing and Current Sense Amplifier**

The advantage of sensing the inductor current versus high-side or low-side sensing is that actual output current being delivered to the load is obtained rather than peak or sampled information about the switch currents. The output voltage can be positioned to meet a load line based on real-time information. Except for a sense resistor in series with the inductor, this is the only sense method that can support a single cycle transient response. Other methods provide no information during either load increase (low-side sensing) or load decrease (high-side sensing).

An additional problem associated with peak or valley current mode control for voltage positioning is that they suffer from peak-to-average errors. These errors will appear in many ways but one example is the effect of frequency variation. If the frequency of a particular unit is 10% low, the peak-to-peak inductor current will be 10% larger and the output impedance of the converter will drop by about 10%. Variations in inductance, current sense amplifier bandwidth, PWM prop delay, any added slope compensation, input voltage, and output voltage are all additional sources of peak-to-average errors.

### CURRENT SENSE AMPLIFIER

A high speed differential current sense amplifier is located in our driver ICs, as shown in Figure 9. Its gain is nominally 32.5 over the entire temperature operating range therefore the 3850 ppm/°C inductor DCR temperature coefficient should be compensated in the voltage loop feedback path. This can be accurately compensated by using a linearized Negative TC resistor network where the NTC can be located near the output inductors. The resulting temperature compensated current information is used by the control IC for voltage positioning and current reporting, and over current limit protection.

The input offset of this amplifier is calibrated to within +/- 450µV (6 sigma limits) with a 200uV typical LSB calibration bit. This calibration routine is continuous and occurs at every 56 PWM cycles.

The current sense amplifier can accept positive differential input up to 50mV and negative up to -10mV before clipping. The output of the current sense amplifier is summed with the VDAC voltage and is returned to the control IC through the IIN pin. The IIN pins in the control IC are internally tied together through 3 KOhm resistors to produce a voltage representative of the average phase inductor current.

### AVERAGE CURRENT SHARE LOOP

A current sharing loop is also incorporated in the IR3531 to ensure balance between the multiphase buck power stages. Poor current sharing can hamper transient response and degrade overall system efficiency. The current information of each phase is compared against the average phase current through a Share Adjust Amplifier which then manipulates the respective PWM ramp start voltage to add or subtract PWM output duty cycle. The current share amplifier is internally compensated such that the crossover frequency of the current share loop is much slower than that of the voltage loop and the two loops do not interact.

### INSTANTANEOUS CURRENT BALANCE

A form of coarse current sharing is also incorporated into the IR3531 to protect against Synchronized High Load Repetition Rate transients which can saturate inductors and cause OVP conditions. The phase firing order of the multiphase system is continually being re-assessed and adjusted if required on a cycle-by-cycle basis to prevent instantaneous phase currents from deviating from each other. This also improves transient response by ensuring all phase currents track each other within a few switching cycles. Individual switch nodes will appear to be variable frequency however input and output ripple are unaffected by the varying phase firing order.

**SVID CONTROL**

The SVID bus allows the processor to communicate with the IR3531. The processor can program the voltage regulator output voltage and monitor telemetry data the IR3531 offers such as temperature and both rail currents. VCLK, VDIO and ALERT# communication lines are designed for external 50-75 ohm pull up resistors to 1.0-1.2V bias voltage and should not be floated. Note that ALERT# may assert twice for VID transitions of 2 VID steps or less. Addressing is programmed as a percentage of VDAC as shown by selecting the appropriate ADDR pin resistor divider combination and supports up to 14 addresses and 2 all call addresses (refer to Table 1). Table 2 provides a list of supported SVID commands. Table 3 provides a list of supported required SVID registers. The SVID communicates VID codes listed in Table 4a and 4b to program the VDAC set point.

The IR3531 can accept changes in the VID code and will vary the VDAC voltage accordingly. The slew rate of the voltage at the VDAC pin can be set by the appropriate command. The slew rate is internally programmed and no external pins or components are necessary. Digital VID transitions result in a smooth analog transition of the VDAC voltage and converter output voltage minimizing inrush currents, false over current conditions and overshoot of the output voltage.

The VID data from the SVID bus is stored in registers and is sent to the Digital-to-Analog Converter (DAC), whose output is sent to the VDAC buffer amplifier. The output of the buffer amplifier is the VDAC pin. To achieve optimal system setpoint voltage accuracy, first all contributing offsets of the IR3531 are independently trimmed and lastly the internal VDAC reference is trimmed to take into account all sum of all the offset components. Note that the resulting final VDAC voltage will have a slightly wider tolerance as it is compensating for the sum of all other offset components. This results in an overall 0.5% system set-point accuracy for VID range between 1V to 1.52V.

**TABLE 1: ADDR/PSN A/D VOLTAGE PROGRAMMING (AS % OF VDAC)**

% of VDAC	Binary Code	Address Name	Sync	Turbo
1.5%	00000	A0/A1	Ext. Sync	Enable
4.7%	00001	A0/A1	Ext. Sync	Disable
7.8%	00010	A0/A1	Int. Clock	Enable
11%	00011	A0/A1	Int. Clock	Disable
14%	00100	A2/A3	Ext. Sync	Enable
17.2%	00101	A2/A3	Ext. Sync	Disable
20.3%	00110	A2/A3	Int. Clock	Enable
23.4%	00111	A2/A3	Int. Clock	Disable
26.5%	01000	A4/A5	Ext. Sync	Enable
29.7%	01001	A4/A5	Ext. Sync	Disable
32.8%	01010	A4/A5	Int. Clock	Enable
36%	01011	A4/A5	Int. Clock	Disable
39%	01100	A6/A7	Ext. Sync	Enable
42.2%	01101	A6/A7	Ext. Sync	Disable
45.3%	01110	A6/A7	Int. Clock	Enable
48.4%	01111	A6/A7	Int. Clock	Disable
51.5%	10000	A8/A9	Ext. Sync	Enable
54.7%	10001	A8/A9	Ext. Sync	Disable
57.8%	10010	A8/A9	Int. Clock	Enable
61%	10011	A8/A9	Int. Clock	Disable
64%	10100	A10/A11	Ext. Sync	Enable
67.2%	10101	A10/A11	Ext. Sync	Disable
70.3%	10110	A10/A11	Int. Clock	Enable
73.4%	10111	A10/A11	Int. Clock	Disable
76.6%	11000	A12/A13	Ext. Sync	Enable
79.7%	11001	A12/A13	Ext. Sync	Disable
82.8%	11010	A12/A13	Int. Clock	Enable
86%	11011	A12/A13	Int. Clock	Disable

**Note:** A14/A15 are reserved all-call address.

**SVID COMMAND STRUCTURE**

SVID protocol has two main command groups: the Get and Set commands. The Get commands retrieve data from the voltage regulator controller, while the Set commands make changes to voltage regulator operating points and power states.

When the processor (master) issues a Get command, it transmits the intended controller address and the address of the register it wants to read. The addressed controller acknowledges the command and returns the requested data. Similarly, when the processor issues a Set command, it transmits the intended controller address and the data it wants to insert. The only exception is the SetRegADR command which is used to declare the register address that SetRegDAT will alter. The controller acknowledges these commands. Parity checking is not enforced on SetRegADR/SetRegDAT.

TABLE 2: SUPPORTED COMMAND

Command	Description
<b>SetVIDfast</b>	Slews VOUT to a new Programmed setpoint at 20mV/usec
<b>SetVIDslow</b>	Slews VOUT to a new Programmed setpoint at 5mV/usec
<b>SetPS</b>	Sets power state
<b>SetRegADR</b>	Declares the address of the register to be written to
<b>SetRegDAT</b>	Writes data to the SetRegADR declared register
<b>GetReg</b>	Read data of a specified register
<b>TestMode</b>	Test mode is used for final test trimming of the IR3531 and is not available to users.

Note: SetVID decay is not supported

TABLE 3: SUPPORTED REGISTER

Register	Description
<b>VendorID</b>	Identifies the VR vendor
<b>ProductID</b>	Identifies the product model
<b>ProductRev</b>	Identifies the product revision
<b>SVID Protocol ID</b>	Identifies the version of SVID protocol
<b>VR Capability</b>	Communicates functions the IR3531 supports
<b>Status1 Reg</b>	Stores VR status data
<b>Status2 Reg</b>	Stores SVID bus errors
<b>Temp Zone</b>	Temperature zone from Rail0 sensor
<b>Output Current</b>	Stores output current for Rail0/Rail1
<b>Status2_last_read</b>	Stores previous data of status 2
<b>ICC Max</b>	Programs the maximum supported output current
<b>Temp Max</b>	Programs maximum operating temperature
<b>SR-fast</b>	Stores the fast slew rate value
<b>SR-slow</b>	Stores the slow slew rate value
<b>Vboot</b>	Overrides the default Vboot value
<b>Vout Max</b>	Programs the maximum supported operational Vout
<b>VID Setting</b>	Register contains the current VID setting
<b>Power State</b>	Register contains the current power state
<b>VID Offset<sup>1</sup></b>	Allows margining around the VID setpoint
<b>Multi VR Config</b>	Configures other VR-s on the same SVID bus
<b>SetRegADR</b>	Scratch pad register for temporary storage of the SetRegADR pointer register

Note 1: VID Offset commands that attempt to push the VID above 1.52V or below 0V are not acknowledged.

TABLE 4: VID VALUES

VID7:VID0 (Hex)	VID7:VID0 (Bin)	Voltage	VID7:VID0 (Hex)	VID7:VID0 (Bin)	Voltage	VID7:VID0 (Hex)	VID7:VID0 (Bin)	Voltage
00	00000000	0	26	00100110	0.435	4C	01001100	0.625
01	00000001	0.250	27	00100111	0.440	4D	01001101	0.630
02	00000010	0.255	28	00101000	0.445	4E	01001110	0.635
03	00000011	0.260	29	00101001	0.450	4F	01001111	0.640
04	00000100	0.265	2A	00101010	0.455	50	01010000	0.645
05	00000101	0.270	2B	00101011	0.460	51	01010001	0.650
06	00000110	0.275	2C	00101100	0.465	52	01010010	0.655
07	00000111	0.280	2D	00101101	0.470	53	01010011	0.660
08	00001000	0.285	2E	00101110	0.475	54	01010100	0.665
09	00001001	0.290	2F	00101111	0.480	55	01010101	0.670
0A	00001010	0.295	30	00110000	0.485	56	01010110	0.675
0B	00001011	0.300	31	00110001	0.490	57	01010111	0.680
0C	00001100	0.305	32	00110010	0.495	58	01011000	0.685
0D	00001101	0.310	33	00110011	0.500	59	01011001	0.690
0E	00001110	0.315	34	00110100	0.505	5A	01011010	0.695
0F	00001111	0.320	35	00110101	0.510	5B	01011011	0.700
10	00010000	0.325	36	00110110	0.515	5C	01011100	0.705
11	00010001	0.330	37	00110111	0.520	5D	01011101	0.710
12	00010010	0.335	38	00111000	0.525	5E	01011110	0.715
13	00010011	0.340	39	00111001	0.530	5F	01011111	0.720
14	00010100	0.345	3A	00111010	0.535	60	01100000	0.725
15	00010101	0.350	3B	00111011	0.540	61	01100001	0.730
16	00010110	0.355	3C	00111100	0.545	62	01100010	0.735
17	00010111	0.360	3D	00111101	0.550	63	01100011	0.740
18	00011000	0.365	3E	00111110	0.555	64	01100100	0.745
19	00011001	0.370	3F	00111111	0.560	65	01100101	0.750
1A	00011010	0.375	40	01000000	0.565	66	01100110	0.755
1B	00011011	0.380	41	01000001	0.570	67	01100111	0.760
1C	00011100	0.385	42	01000010	0.575	68	01101000	0.765
1D	00011101	0.390	43	01000011	0.580	69	01101001	0.770
1E	00011110	0.395	44	01000100	0.585	6A	01101010	0.775
1F	00011111	0.400	45	01000101	0.590	6B	01101011	0.780
20	00100000	0.405	46	01000110	0.595	6C	01101100	0.785



VID7:VID0 (Hex)	VID7:VID0 (Bin)	Voltage	VID7:VID0 (Hex)	VID7:VID0 (Bin)	Voltage	VID7:VID0 (Hex)	VID7:VID0 (Bin)	Voltage
21	00100001	0.410	47	01000111	0.600	6D	01101101	0.790
22	00100010	0.415	48	01001000	0.605	6E	01101110	0.795
23	00100011	0.420	49	01001001	0.610	6F	01101111	0.800
24	00100100	0.425	4A	01001010	0.615	70	01110000	0.805
25	00100101	0.430	4B	01001011	0.620	71	01110001	0.810
72	01110010	0.815	99	10011001	1.010	C0	11000000	1.205
73	01110011	0.820	9A	10011010	1.015	C1	11000001	1.210
74	01110100	0.825	9B	10011011	1.020	C2	11000010	1.215
75	01110101	0.830	9C	10011100	1.025	C3	11000011	1.220
76	01110110	0.835	9D	10011101	1.030	C4	11000100	1.225
77	01110111	0.840	9E	10011110	1.035	C5	11000101	1.230
78	01111000	0.845	9F	10011111	1.040	C6	11000110	1.235
79	01111001	0.850	A0	10100000	1.045	C7	11000111	1.240
7A	01111010	0.855	A1	10100001	1.050	C8	11001000	1.245
7B	01111011	0.860	A2	10100010	1.055	C9	11001001	1.250
7C	01111100	0.865	A3	10100011	1.060	CA	11001010	1.255
7D	01111101	0.870	A4	10100100	1.065	CB	11001011	1.260
7E	01111110	0.875	A5	10100101	1.070	CC	11001100	1.265
7F	01111111	0.880	A6	10100110	1.075	CD	11001101	1.270
80	10000000	0.885	A7	10100111	1.080	CE	11001110	1.275
81	10000001	0.890	A8	10101000	1.085	CF	11001111	1.280
82	10000010	0.895	A9	10101001	1.090	D0	11010000	1.285
83	10000011	0.900	AA	10101010	1.095	D1	11010001	1.290
84	10000100	0.905	AB	10101011	1.100	D2	11010010	1.295
85	10000101	0.910	AC	10101100	1.105	D3	11010011	1.300
86	10000110	0.915	AD	10101101	1.110	D4	11010100	1.305
87	10000111	0.920	AE	10101110	1.115	D5	11010101	1.310
88	10001000	0.925	AF	10101111	1.120	D6	11010110	1.315
89	10001001	0.930	B0	10110000	1.125	D7	11010111	1.320
8A	10001010	0.935	B1	10110001	1.130	D8	11011000	1.325
8B	10001011	0.940	B2	10110010	1.135	D9	11011001	1.330
8C	10001100	0.945	B3	10110011	1.140	DA	11011010	1.335
8D	10001101	0.950	B4	10110100	1.145	DB	11011011	1.340
8E	10001110	0.955	B5	10110101	1.150	DC	11011100	1.345

VID7:VID0 (Hex)	VID7:VID0 (Bin)	Voltage	VID7:VID0 (Hex)	VID7:VID0 (Bin)	Voltage	VID7:VID0 (Hex)	VID7:VID0 (Bin)	Voltage
<b>8F</b>	10001111	0.960	<b>B6</b>	10110110	1.155	<b>DD</b>	11011101	1.350
<b>90</b>	10010000	0.965	<b>B7</b>	10110111	1.160	<b>DE</b>	11011110	1.355
<b>91</b>	10010001	0.970	<b>B8</b>	10111000	1.165	<b>DF</b>	11011111	1.360
<b>92</b>	10010010	0.975	<b>B9</b>	10111001	1.170	<b>E0</b>	11100000	1.365
<b>93</b>	10010011	0.980	<b>BA</b>	10111010	1.175	<b>E1</b>	11100001	1.370
<b>94</b>	10010100	0.985	<b>BB</b>	10111011	1.180	<b>E2</b>	11100010	1.375
<b>95</b>	10010101	0.990	<b>BC</b>	10111100	1.185	<b>E3</b>	11100011	1.380
<b>96</b>	10010110	0.995	<b>BD</b>	10111101	1.190	<b>E4</b>	11100100	1.385
<b>97</b>	10010111	1.000	<b>BE</b>	10111110	1.195	<b>E5</b>	11100101	1.390
<b>98</b>	10011000	1.005	<b>BF</b>	10111111	1.200	<b>E6</b>	11100110	1.395
<b>E7</b>	11100111	1.400	<b>F0</b>	11110000	1.445	<b>F9</b>	11111001	1.490
<b>E8</b>	11101000	1.405	<b>F1</b>	11110001	1.450	<b>FA</b>	11111010	1.495
<b>E9</b>	11101001	1.410	<b>F2</b>	11110010	1.455	<b>FB</b>	11111011	1.500
<b>EA</b>	11101010	1.415	<b>F3</b>	11110011	1.460	<b>FC</b>	11111100	1.505
<b>EB</b>	11101011	1.420	<b>F4</b>	11110100	1.465	<b>FD</b>	11111101	1.510
<b>EC</b>	11101100	1.425	<b>F5</b>	11110101	1.470	<b>FE</b>	11111110	1.515
<b>ED</b>	11101101	1.430	<b>F6</b>	11110110	1.475	<b>FF</b>	11111111	1.520
<b>EE</b>	11101110	1.435	<b>F7</b>	11110111	1.480			
<b>EF</b>	11101111	1.440	<b>F8</b>	11111000	1.485			

**ADAPTIVE VOLTAGE POSITIONING**

Adaptive Voltage Positioning (AVP) is a control algorithm where the output voltage is reduced as the load current increases. This may also be referred to as VR output impedance, Voltage Droop or Load Line. AVP is implemented to reduce the amount of bulk capacitance for a given load transient and regulation window and reduces power dissipation at heavy load. The IR3531 implementation of voltage positioning for Rail0 and Rail1 is shown in Figure 10. The output voltage is set by the VDAC or TRACK reference voltage at the positive input of the error amplifier.

The VDRP pin is connected to the FB pin through the resistor RDRP. As load current increases, the VDRP voltage increases proportionally. Since the error amplifier will force the loop to maintain FB to be equal to the VDAC reference voltage, the additional RDRP current has to flow through the RFB resistor which introduces an offset voltage that is proportional to the load current. The RFB current is equal to  $(VDRP - VDAC) / RDRP$ . The positioning voltage can be programmed by the resistors RDRP and RFB so that the droop impedance produces the desired converter output impedance. The offset and slope of the converter output impedance are referenced to and therefore independent of the VDAC voltage.

**INDUCTOR DCR TEMPERATURE COMPENSATION**

The load current information for all the phases is fed back to the control IC through the Driver IC IOOUT pins where this information is averaged and buffered to the Thermal Compensation Amplifier. The gain of the Thermal Compensation Amplifier is modified by temperature by introducing a negative temperature coefficient (NTC) thermistor (R THERM1) and linearizing resistor network (RTCMP1 and 2) connected between the VN and VDRP pins. The thermistor should be placed close to the power stage to accurately sense the thermal performance of the inductor DCR.

**CURRENT MONITOR (IMON)**

The control IC generates a current monitor signal IMON using the VDRP voltage and the VDAC reference, also shown in Figure 10. The voltage at this pin reports the average load current information referenced to LGND. The slope of the IMON signal with respect to the load current can be adjusted with the resistors RTCMP2 and RTCMP3. The IMON signal is clamped at 1.09V in order to facilitate direct interfacing with the master.

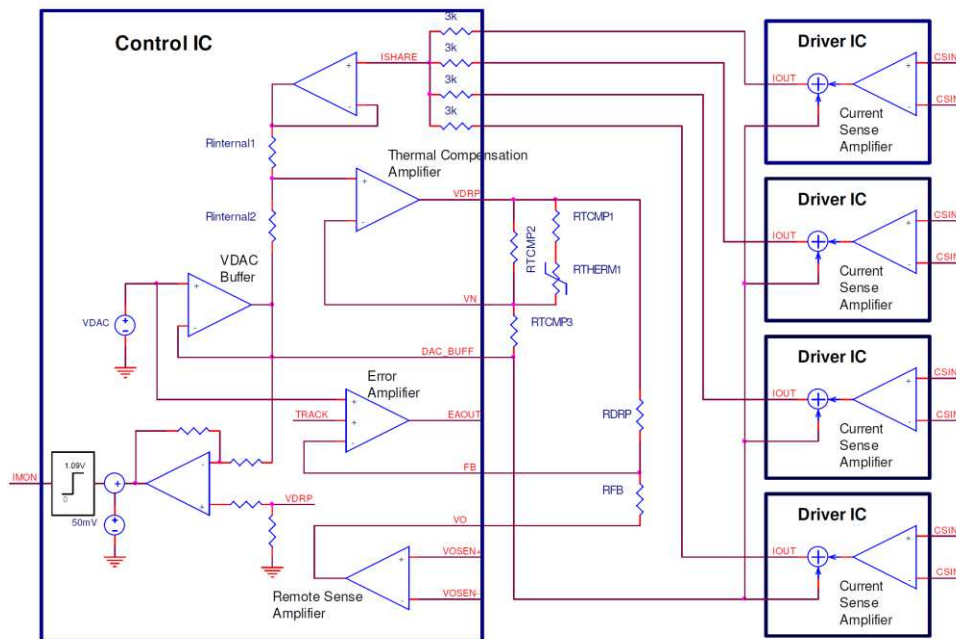


Figure 10: Adaptive voltage positioning with thermal compensation