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Cool-Power®
ZVS Switching Regulators
PI33xx-x0

8V to 36V_{IN} Cool-Power ZVS Buck Regulator Family

Product Description

The PI33xx-x0 is a family of high efficiency, wide input range DC-DC ZVS-Buck regulators integrating controller, power switches, and support components all within a high density System-in-Package (SiP). The integration of a high performance Zero-Voltage Switching (ZVS) topology, within the PI33xx-x0 series, increases point of load performance providing best in class power efficiency. The PI33xx-x0 requires only an external inductor and minimal capacitors to form a complete DC-DC switching mode Buck Regulator.

Device	Output Voltage		I_{OUT} Max
	Set	Range	
PI3311-x0	1.0V	1.0 to 1.4V	10A
PI3318-x0	1.8V	1.4 to 2.0V	10A
PI3312-x0	2.5V	2.0 to 3.1V	10A
PI3301-x0	3.3V	2.3 to 4.1V	10A
PI3302-x0	5.0V	3.3 to 6.5V	10A
PI3303-x0	12V	6.5 to 13.0V	8A
PI3305-x0	15V	10.0 to 16.0V	8A

The ZVS architecture also enables high frequency operation while minimizing switching losses and maximizing efficiency. The high switching frequency operation reduces the size of the external filtering components, improves power density, and enables very fast dynamic response to line and load transients. The PI33xx-x0 series sustains high switching frequency all the way up to the rated input voltage without sacrificing efficiency and, with its 20ns minimum on-time, supports large step down conversions up to 36V_{IN}.

Features & Benefits

- High Efficiency ZVS-Buck Topology
- Wide input voltage range of 8V to 36V
- Very-Fast transient response
- High accuracy pre-trimmed output voltage
- User adjustable soft-start & tracking
- Power-up into pre-biased load (select versions)
- Parallel capable with single wire current sharing
- Input Over/Undervoltage Lockout (OVLO/UVLO)
- Output Overvoltage Protection (OVP)
- Overtemperature Protection (OTP)
- Fast and slow current limits
- -40°C to 125°C operating range (T_J)
- Optional I²C™ * functionality & programmability:
  - V_{OUT} margining
  - Fault reporting
  - Enable and SYNCI pin polarity
  - Phase delay (interleaving multiple regulators)

Applications

- High efficiency systems
- High voltage battery operation

Package Information

- 10mm x 14mm x 2.6mm LGA SiP

* I²C™ is a trademark of NXP Semiconductors

Contents

Order Information

Cool-Power	Output Range		I_{OUT} Max	Package	Transport Media
	Set	Range			
PI3311-00-LGIZ	1.0V	1.0 to 1.4V	10A	10mm x 14mm 123-pin LGA	TRAY
PI3318-00-LGIZ	1.8V	1.4 to 2.0V	10A	10mm x 14mm 123-pin LGA	TRAY
PI3312-00-LGIZ	2.5V	2.0 to 3.1V	10A	10mm x 14mm 123-pin LGA	TRAY
PI3301-00-LGIZ	3.3V	2.3 to 4.1V	10A	10mm x 14mm 123-pin LGA	TRAY
PI3302-00-LGIZ	5.0V	3.3 to 6.5V	10A	10mm x 14mm 123-pin LGA	TRAY
PI3303-00-LGIZ	12V	6.5 to 13.0V	8A	10mm x 14mm 123-pin LGA	TRAY
PI3305-00-LGIZ	15V	10.0 to 16.0V	8A	10mm x 14mm 123-pin LGA	TRAY

I²C™ Functionality & Programmability

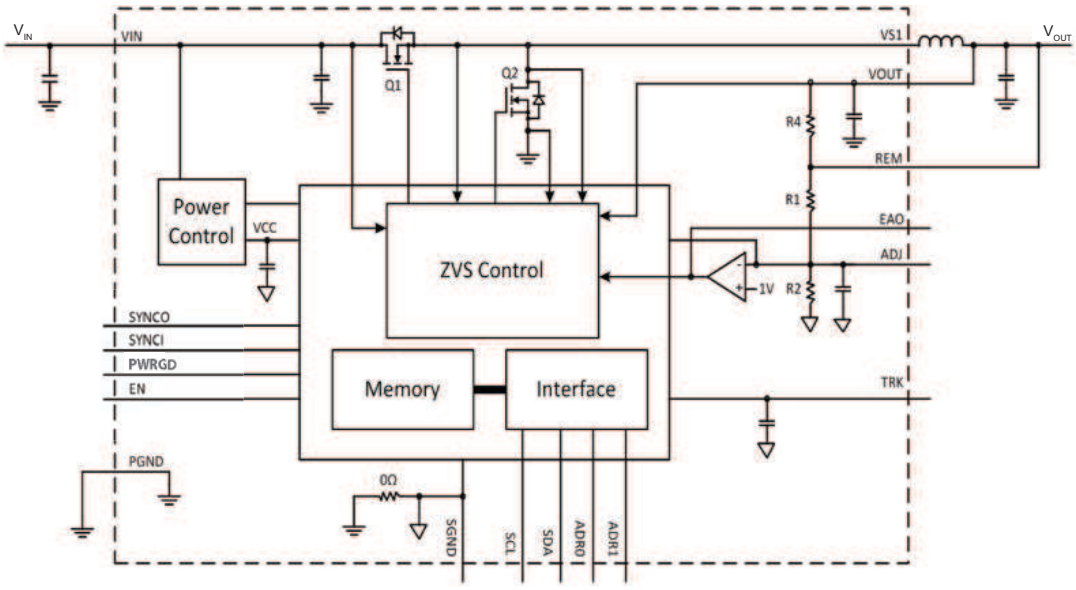
Cool-Power	Output Range		I_{OUT} Max	Package	Transport Media
	Set	Range			
PI3311-20-LGIZ	1.0V	1.0 to 1.4V	10A	10mm x 14mm 123-pin LGA	TRAY
PI3318-20-LGIZ	1.8V	1.4 to 2.0V	10A	10mm x 14mm 123-pin LGA	TRAY
PI3312-20-LGIZ	2.5V	2.0 to 3.1V	10A	10mm x 14mm 123-pin LGA	TRAY
PI3301-20-LGIZ	3.3V	2.3 to 4.1V	10A	10mm x 14mm 123-pin LGA	TRAY
PI3302-20-LGIZ	5.0 V	3.3 to 6.5V	10A	10mm x 14mm 123-pin LGA	TRAY
PI3303-20-LGIZ	12V	6.5 to 13.0V	8A	10mm x 14mm 123-pin LGA	TRAY
PI3305-20-LGIZ	15V	10.0 to 16.0V	8A	10mm x 14mm 123-pin LGA	TRAY

Absolute Maximum Ratings

Name		Rating
V_{IN}		-0.7 to 36V
VS1		-0.7 to $36V_{DC}$
SGND		100mA
PWRGD, SYNCO, SYNCI, EN, EAO, ADJ, TRK, ADR1, ADR2, SCL, SDA, REM		-0.3V to 5.5V / 5mA
V_{OUT}	PI3311-x0-LGIZ	-0.3V to 5.5V
	PI3318-x0-LGIZ	-0.5V to 9V
	PI3312-x0-LGIZ	-0.8V to 13V
	PI3301-x0-LGIZ	-1.0V to 18V
	PI3302-x0-LGIZ	-1.5V to 21V
	PI3303-x0-LGIZ	-3.6V to 25V
	PI3305-x0-LGIZ	-4.5V to 25V
Storage Temperature		-65°C to 150°C
Operating Junction Temperature		-40°C to 125°C
Soldering Temperature for 20 seconds		245°C
ESD Rating		2kV HBM

Notes: At 25°C ambient temperature. Stresses beyond these limits may cause permanent damage to the device. Operation at these conditions or conditions beyond those listed in the Electrical Specifications table is not guaranteed. All voltage nodes are referenced to PGND unless otherwise noted. Test conditions are per the specifications within the individual product electrical characteristics.

Functional Block Diagram

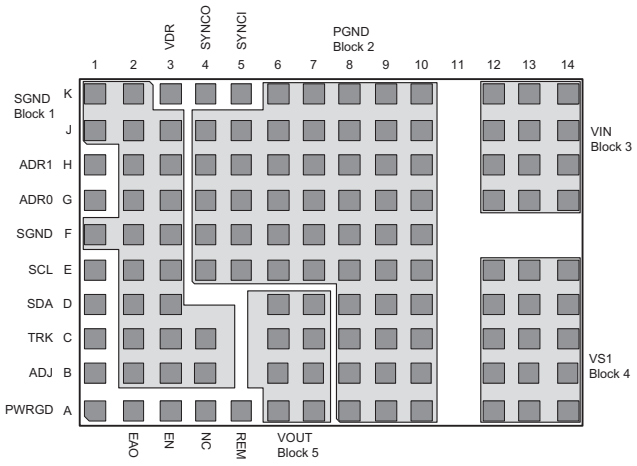


Simplified Block Diagram (I²C™ pins SCL, SDA, ADR0, and ADR1 only active for PI33xx-20 device versions)

Pin Description

Pin Name	Number	Description
SGND	Block 1	**Signal Ground:** Internal logic ground for EA, TRK, SYNCI, SYNCO, ADJ and I^2C (options) communication returns. SGND and PGND are star connected within the regulator package.
PGND	Block 2	**Power Ground:** V_{IN} and V_{OUT} power returns.
VIN	Block 3	**Input Voltage:** and sense for UVLO, OVLO and feed forward ramp.
VOUT	Block 5	**Output Voltage:** and sense for power switches and feed-forward ramp.
VS1	Block 4	**Switching Node**: and ZVS sense for power switches.
PWRGD	A1	**Power Good:** High impedance when regulator is operating and V_{OUT} is in regulation. Otherwise pulls to SGND. Also can be used for parallel timing management intended for lead regulator.
EAO	A2	**Error Amp Output:** External connection for additional compensation and current sharing.
EN	A3	**Enable Input:** Regulator enable control. Asserted high or left floating – regulator enabled; Asserted low, regulator output disabled. Polarity is programmable via I^2C interface.
REM	A5	**Remote Sense:** High side connection. Connect to output regulation point.
ADJ	B1	**Adjust Input:** An external resistor may be connected between ADJ pin and SGND or VOUT to trim the output voltage up or down.
TRK	C1	**Soft-start and Track Input:** An external capacitor may be connected between TRK pin and SGND to decrease the rate of rise during soft-start.
NC	A4	**No Connect:** Leave pins floating.
VDR	K3	VDR can only be used for ADR0 and ADR1 pull up reference voltage. No other external loading is permitted
SYNCO	K4	**Synchronization Output:** Outputs a low signal for ½ of the minimum period for synchronization of other converters.
SYNCI	K5	**Synchronization Input:** Synchronize to the falling edge of external clock frequency. SYNCI is a high impedance digital input node and should always be connected to SGND when not in use.
SDA	D1	**Data Line:** Connect to SGND for PI33xx-00. For use with PI33xx-20 only.
SCL	E1	**Clock Line:** Connect to SGND for PI33xx-00. For use with PI33xx-20 only.
ADR1	H1	**Tri-state Address:** No connect for PI33xx-00. For use with PI33xx-20 only.
ADR0	G1	**Tri-state Address:** No connect for PI33xx-00. For use with PI33xx-20 only.

Package Pin-Out



Block 1: B2-4, C2-4, D2-3, E2-3, F1-3, G2-3, H2-3, J1-3, K1-2

Block 2: A8-10, B8-10, C8-10, D8-10, E4-10, F4-10, G4-10, H4-10, J4-10, K6-10

Block 3: G12-14, H12-14, J12-14, K12-14

Block 4: A12-14, B12-14, C12-14, D12-14, E12-14

Block 5: A6-7, B6-7, C6-7, D6-7

PI3311-x0-LGIZ (1.0V_{OUT}) Electrical Characteristics

Unless otherwise specified: -40°C < T_J < 125°C, V_{IN} = 24V, L1 = 125nH [1]

Parameter	Symbol	Conditions	Min	Typ	Max	Unit
Input Specifications						
Input Voltage	V_{IN_DC}		8	24	36	V
Input Current	I_{IN_DC}	V_{IN} = 24V, T_C = 25°C, I_{OUT} =10A		476		mA
Input Current At Output Short (fault condition duty cycle)	I_{IN_Short}	[2]			20	mA
Input Quiescent Current	I_{Q_VIN}	Disabled		2.0		mA
		Enabled (no load)		2.5		mA
Input Voltage Slew Rate	V_{IN_SR}				1	V/µs
Output Specifications						
Output Voltage Total Regulation	V_{OUT_DC}	[2]	0.987	1.0	1.013	V
Output Voltage Trim Range	V_{OUT_DC}	[3]	1.0		1.4	V
Line Regulation	ΔV_{OUT} (ΔV_{IN})	@25°C, 8V < V_{IN} < 36V		0.10		%
Load Regulation	ΔV_{OUT} (ΔI_{OUT})	@25°C, 0.5A < I_{OUT} < 10A		0.10		%
Output Voltage Ripple	V_{OUT_AC}	I_{OUT} = 5A, C_{OUT} = 8 x 100µF, 20MHz BW [4]		20		mVp-p
Continuous Output Current Range	I_{OUT_DC}	[5] Minimum 1mA load required	0.001		10	A
Current Limit	I_{OUT_CL}			12		A
Protection						
V_{IN} UVLO Start Threshold	V_{UVLO_START}		7.10	7.60	8.00	V
V_{IN} UVLO Stop Threshold	V_{UVLO_STOP}		6.80	7.25	7.60	V
V_{IN} UVLO Hysteresis	V_{UVLO_HYS}			0.33		V
V_{IN} OVLO Start Threshold	V_{OVLO_START}		36.1			V
V_{IN} OVLO Stop Threshold	V_{OVLO_STOP}		37.0	38.4		V
V_{IN} OVLO Hysteresis	V_{OVLO_HYS}			0.77		V
V_{IN} UVLO/OVLO Response Time	t_f			500		ns
Output Overvoltage Protection	V_{OVP}	Above V_{OUT}		20		%
Overtemperature Fault Threshold	T_{OTP}		130	135	140	°C
Overtemperature Restart Hysteresis	T_{OTP_HYS}			30		°C

[1] All parameters reflect regulator and inductor system performance. Measurements were made using a standard PI33xx-x0 evaluation board with 3x4" dimensions and 4 layer, 2oz copper. Refer to inductor pairing table within Application Description section for specific inductor manufacturer and value.
[2] Regulator is assured to meet performance specifications by design, test correlation, characterization, and/or statistical process control.
[3] Output current capability may be limited and other performance may vary from electrical characteristics when switching frequency or V_{OUT} is modified.
[4] Refer to Output Ripple plots.
[5] Refer to Load Current vs. Ambient Temperature curves.
[6] Refer to Switching Frequency vs. Load current curves.

PI3311-x0-LGIZ (1.0V_{OUT}) Electrical Characteristics (Cont.)

Unless otherwise specified: -40°C < T_J < 125°C, V_{IN} = 24V, L1 = 125nH [1]

Parameter	Symbol	Conditions	Min	Typ	Max	Unit
Timing						
Switching Frequency	f_S	[6]		500		kHz
Fault Restart Delay	t_{FR_DLY}			30		ms
Sync In (SYNCI)						
Synchronization Frequency Range	Δf_{SYNCI}	Relative to set switching frequency [3]	50		110	%
SYNCI Threshold	V_{SYNCI}			2.5		V
SYNCI Input Impedance	Z_{SYNCI}			100		kΩ
Sync Out (SYNCO)						
SYNCO High	V_{SYNCO_HI}	Source 1mA	4.5			V
SYNCO Low	V_{SYNCO_LO}	Sink 1mA			0.5	V
SYNCO Rise Time	t_{SYNCO_RT}	20pF load		10		ns
SYNCO Fall Time	t_{SYNCO_FT}	20pF load		10		ns
Soft Start And Tracking						
TRK Active Input Range	V_{TRK}	Internal reference tracking range	0		1.04	V
TRK Max Output Voltage				1.2		V
TRK Disable Threshold	V_{TRK_OV}		20	40	60	mV
Charge Current (Soft – Start)	I_{TRK}		70	50	30	µA
Discharge Current (Fault)	I_{TRK_DIS}	V_{TRK} = 0.5V		6.8		mA
Soft-Start Time	t_{SS}	C_{TRK} = 0µF		2.2		ms
Enable						
High Threshold	V_{EN_HI}		0.9	1	1.1	V
Low Threshold	V_{EN_LO}		0.7	0.8	0.9	V
Threshold Hysteresis	V_{EN_HYS}		100	200	300	mV
Enable Pull-Up Voltage (Floating)	V_{EN_PU}	With positive logic EN polarity		2		V
Enable Pull-Down Voltage (Floating)	V_{EN_PD}	With negative logic EN polarity		0		V
Source Current	I_{EN_SO}	With positive logic EN polarity		50		µA
Sink Current	I_{EN_SK}	With negative logic EN polarity		50		µA

[1] All parameters reflect regulator and inductor system performance. Measurements were made using a standard PI33xx-x0 evaluation board with 3x4" dimensions and 4 layer, 2oz copper. Refer to inductor pairing table within Application Description section for specific inductor manufacturer and value.
[2] Regulator is assured to meet performance specifications by design, test correlation, characterization, and/or statistical process control.
[3] Output current capability may be limited and other performance may vary from electrical characteristics when switching frequency or V_{OUT} is modified.
[4] Refer to Output Ripple plots.
[5] Refer to Load Current vs. Ambient Temperature curves.
[6] Refer to Switching Frequency vs. Load current curves.

PI3311-x0-LGIZ (1.0V_{OUT}) Electrical Characteristics (Cont.)

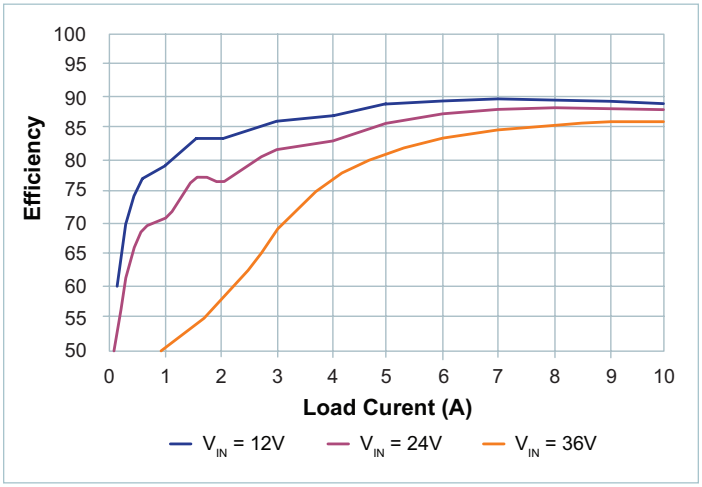


Figure 1 — *Efficiency at 25°C*

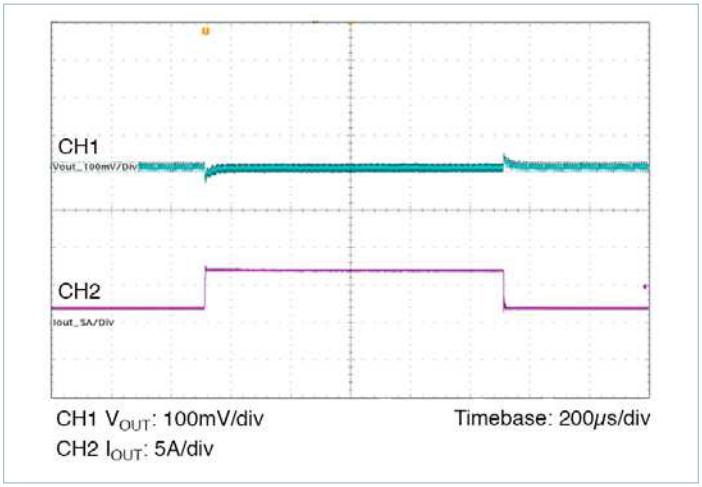


Figure 4 — *Transient Response 2A to 7A, at 5A/µs*

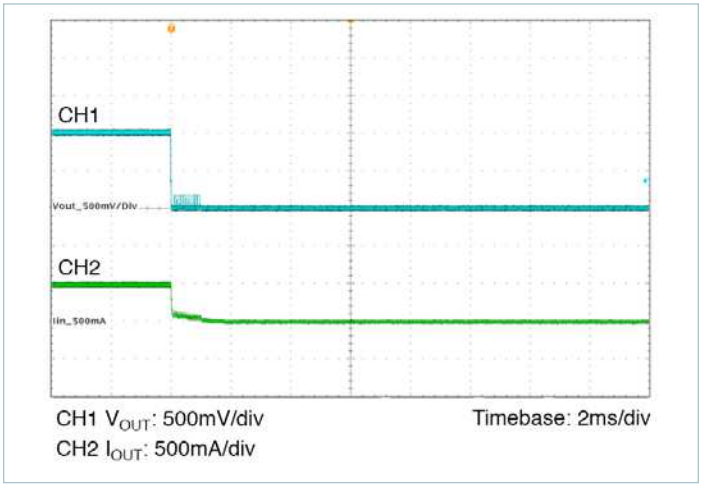


Figure 2 — *Short Circuit Test*

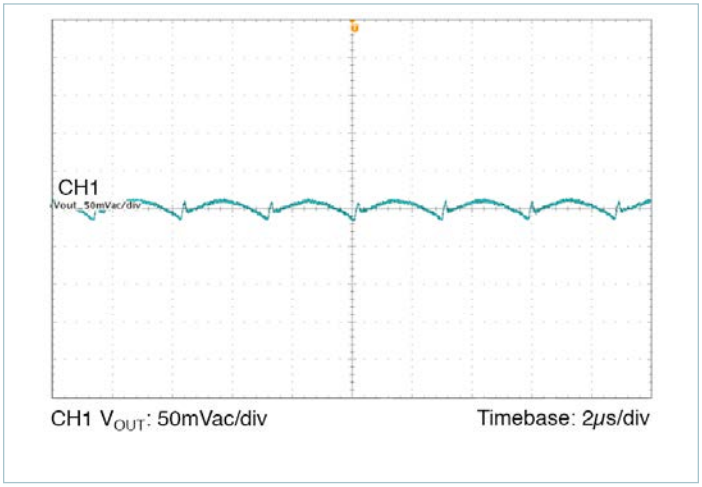


Figure 5 — *Output Ripple 24V_{IN}, 1.0V_{OUT} at 10A*

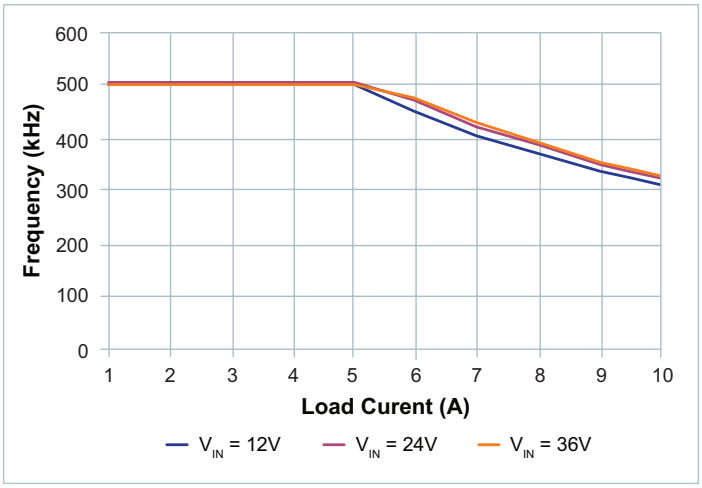


Figure 3 — *Switching Frequency vs. Load Current*

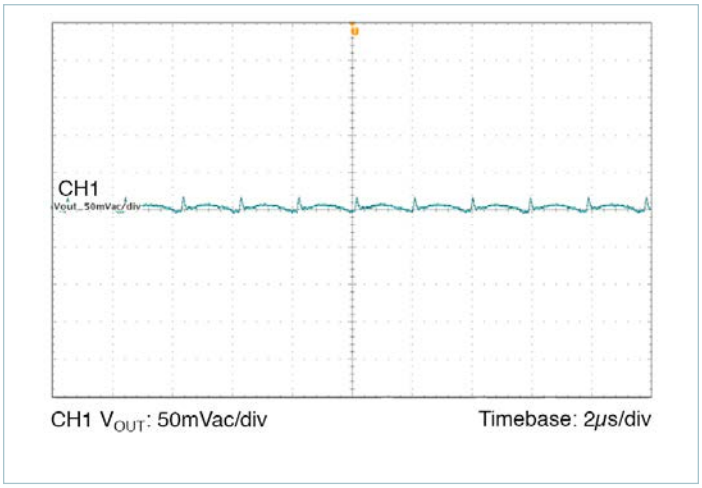


Figure 6 — *Output Ripple 24V_{IN}, 1.0V_{OUT} at 5A*

PI3318-x0-LGIZ (1.8V_{OUT}) Electrical Characteristics

Unless otherwise specified: -40°C < T_J < 125°C, V_{IN} = 24V, L1 = 155nH [1]

Parameter	Symbol	Conditions	Min	Typ	Max	Unit
Input Specifications						
Input Voltage	V_{IN_DC}		8	24	36	V
Input Current	I_{IN_DC}	V_{IN} = 24V, T_C = 25°C, I_{OUT} =10A		835		mA
Input Current At Output Short (fault condition duty cycle)	I_{IN_Short}	[2]			20	mA
Input Quiescent Current	I_{Q_VIN}	Disabled		2.0		mA
		Enabled (no load)		2.5		mA
Input Voltage Slew Rate	V_{IN_SR}				1	V/µs
Output Specifications						
Output Voltage Total Regulation	V_{OUT_DC}	[2]	1.773	1.8	1.827	V
Output Voltage Trim Range	V_{OUT_DC}	[3]	1.4		2.0	V
Line Regulation	ΔV_{OUT} (ΔV_{IN})	@25°C, 8V < V_{IN} < 36V		0.10		%
Load Regulation	ΔV_{OUT} (ΔI_{OUT})	@25°C, 0.5A < I_{OUT} < 10A		0.10		%
Output Voltage Ripple	V_{OUT_AC}	I_{OUT} = 5A, C_{OUT} = 6 x 100µF, 20MHz BW [4]		25		mVp-p
Continuous Output Current Range	I_{OUT_DC}	[5] Minimum 1mA load required	0.001		10	A
Current Limit	I_{OUT_CL}			12		A
Protection						
V_{IN} UVLO Start Threshold	V_{UVLO_START}		7.10	7.60	8.00	V
V_{IN} UVLO Stop Threshold	V_{UVLO_STOP}		6.80	7.25	7.60	V
V_{IN} UVLO Hysteresis	V_{UVLO_HYS}			0.33		V
V_{IN} OVLO Start Threshold	V_{OVLO_START}		36.1			V
V_{IN} OVLO Stop Threshold	V_{OVLO_STOP}		37.0	38.4		V
V_{IN} OVLO Hysteresis	V_{OVLO_HYS}			0.77		V
V_{IN} UVLO/OVLO Response Time	t_f			500		ns
Output Overvoltage Protection	V_{OVP}	Above V_{OUT}		20		%
Overtemperature Fault Threshold	T_{OTP}		130	135	140	°C
Overtemperature Restart Hysteresis	T_{OTP_HYS}			30		°C

[1] All parameters reflect regulator and inductor system performance. Measurements were made using a standard PI33xx-x0 evaluation board with 3x4" dimensions and 4 layer, 2oz copper. Refer to inductor pairing table within Application Description section for specific inductor manufacturer and value.
[2] Regulator is assured to meet performance specifications by design, test correlation, characterization, and/or statistical process control.
[3] Output current capability may be limited and other performance may vary from electrical characteristics when switching frequency or V_{OUT} is modified.
[4] Refer to Output Ripple plots.
[5] Refer to Load Current vs. Ambient Temperature curves.
[6] Refer to Switching Frequency vs. Load current curves.

PI3318-x0-LGIZ (1.8V_{OUT}) Electrical Characteristics (Cont.)

Unless otherwise specified: -40°C < T_J < 125°C, V_{IN} = 24V, L1 = 155nH [1]

Parameter	Symbol	Conditions	Min	Typ	Max	Unit
Timing						
Switching Frequency	f_S	[6]		600		kHz
Fault Restart Delay	t_{FR_DLY}			30		ms
Sync In (SYNCI)						
Synchronization Frequency Range	Δf_{SYNCI}	Relative to set switching frequency [3]	50		110	%
SYNCI Threshold	V_{SYNCI}			2.5		V
SYNCI Input Impedance	Z_{SYNCI}			100		kΩ
Sync Out (SYNCO)						
SYNCO High	V_{SYNCO_HI}	Source 1mA	4.5			V
SYNCO Low	V_{SYNCO_LO}	Sink 1mA			0.5	V
SYNCO Rise Time	t_{SYNCO_RT}	20pF load		10		ns
SYNCO Fall Time	t_{SYNCO_FT}	20pF load		10		ns
Soft Start And Tracking						
TRK Active Input Range	V_{TRK}	Internal reference tracking range	0		1.04	V
TRK Max Output Voltage				1.2		V
TRK Disable Threshold	V_{TRK_OV}		20	40	60	mV
Charge Current (Soft – Start)	I_{TRK}		70	50	30	µA
Discharge Current (Fault)	I_{TRK_DIS}	V_{TRK} = 0.5V		6.8		mA
Soft-Start Time	t_{SS}	C_{TRK} = 0µF		2.2		ms
Enable						
High Threshold	V_{EN_HI}		0.9	1	1.1	V
Low Threshold	V_{EN_LO}		0.7	0.8	0.9	V
Threshold Hysteresis	V_{EN_HYS}		100	200	300	mV
Enable Pull-Up Voltage (Floating)	V_{EN_PU}	With positive logic EN polarity		2		V
Enable Pull-Down Voltage (Floating)	V_{EN_PD}	With negative logic EN polarity		0		V
Source Current	I_{EN_SO}	With positive logic EN polarity		50		µA
Sink Current	I_{EN_SK}	With negative logic EN polarity		50		µA

[1] All parameters reflect regulator and inductor system performance. Measurements were made using a standard PI33xx-x0 evaluation board with 3x4" dimensions and 4 layer, 2oz copper. Refer to inductor pairing table within Application Description section for specific inductor manufacturer and value.
[2] Regulator is assured to meet performance specifications by design, test correlation, characterization, and/or statistical process control.
[3] Output current capability may be limited and other performance may vary from electrical characteristics when switching frequency or V_{OUT} is modified.
[4] Refer to Output Ripple plots.
[5] Refer to Load Current vs. Ambient Temperature curves.
[6] Refer to Switching Frequency vs. Load current curves.

PI3318-x0-LGIZ (1.8V_{OUT}) Electrical Characteristics (Cont.)

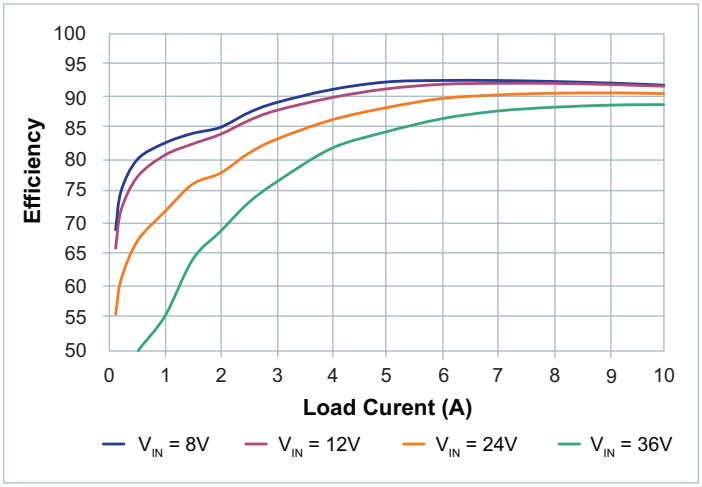


Figure 7 — *Efficiency at 25°C*

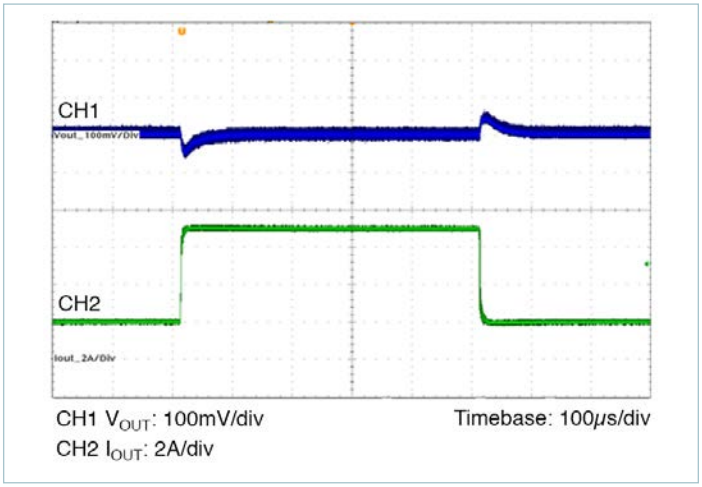


Figure 10 — *Transient Response 2A to 7A, at 5A/µs*

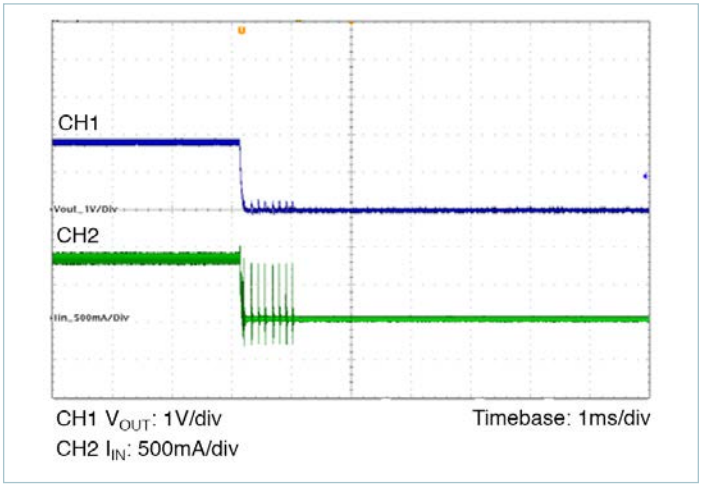


Figure 8 — *Short Circuit Test*

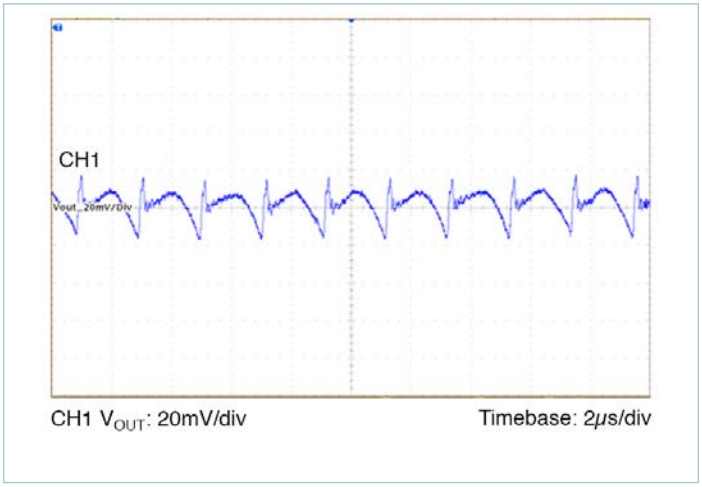


Figure 11 — *Output Ripple 24V_{IN}, 1.8V_{OUT} at 10A*

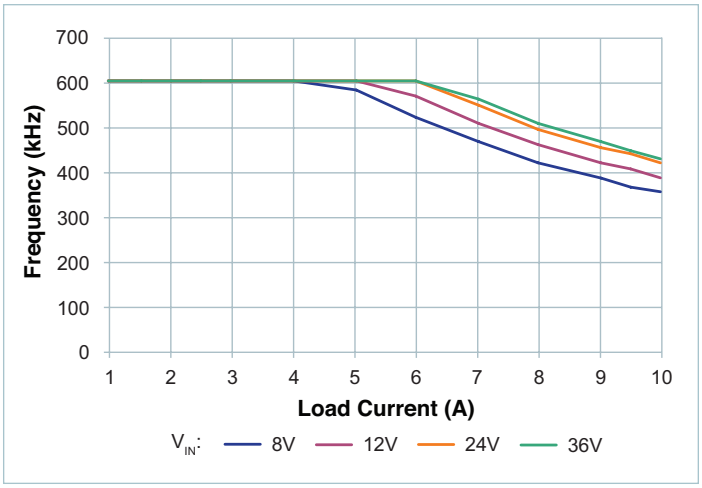


Figure 9 — *Switching Frequency vs. Load Current*

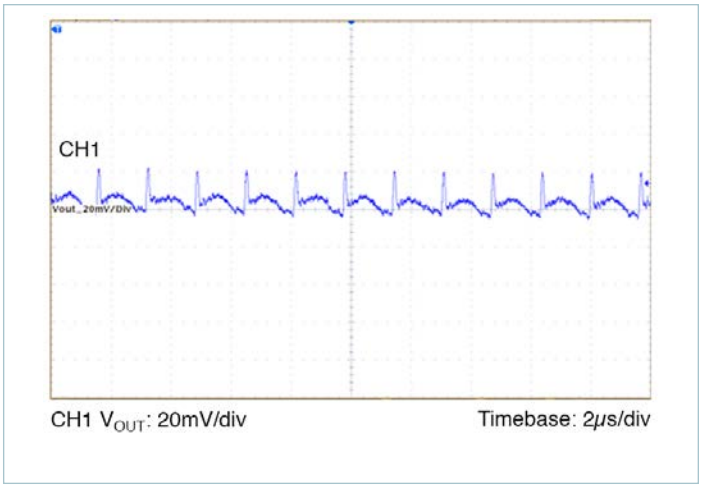


Figure 12 — *Output Ripple 24V_{IN}, 1.8V_{OUT} at 5A*

PI3312-x0-LGIZ (2.5V_{OUT}) Electrical Characteristics

Unless otherwise specified: -40°C < T_J < 125°C, V_{IN} = 24V, L1 = 200nH [1]

Parameter	Symbol	Conditions	Min	Typ	Max	Unit
Input Specifications						
Input Voltage	V_{IN_DC}	[7]	8	24	36	V
Input Current	I_{IN_DC}	V_{IN} = 24V, T_C = 25°C, I_{OUT} = 10A		1.14		A
Input Current At Output Short (fault condition duty cycle)	I_{IN_Short}	[2]			20	mA
Input Quiescent Current	I_{Q_VIN}	Disabled		2.0		mA
		Enabled (no load)		2.5		mA
Input Voltage Slew Rate	V_{IN_SR}				1	V/µs
Output Specifications						
Output Voltage Total Regulation	V_{OUT_DC}	[2]	2.465	2.500	2.535	V
Output Voltage Trim Range	V_{OUT_DC}	[3] [7]	2.0	2.5	3.1	V
Line Regulation	ΔV_{OUT} (ΔV_{IN})	@25°C, 8V < V_{IN} < 36V		0.10		%
Load Regulation	ΔV_{OUT} (ΔI_{OUT})	@25°C, 0.5A < I_{OUT} < 10A		0.10		%
Output Voltage Ripple	V_{OUT_AC}	I_{OUT} = 5A, C_{OUT} = 4 x 100µF, 20MHz BW [4]		28		mVp-p
Continuous Output Current Range	I_{OUT_DC}	[5] [7]			10	A
Current Limit	I_{OUT_CL}			12		A
Protection						
V_{IN} UVLO Start Threshold	V_{UVLO_START}		7.10	7.60	8.00	V
V_{IN} UVLO Stop Threshold	V_{UVLO_STOP}		6.80	7.25	7.60	V
V_{IN} UVLO Hysteresis	V_{UVLO_HYS}			0.33		V
V_{IN} OVLO Start Threshold	V_{OVLO_START}		36.1			V
V_{IN} OVLO Stop Threshold	V_{OVLO_STOP}		37.0	38.4		V
V_{IN} OVLO Hysteresis	V_{OVLO_HYS}			0.77		V
V_{IN} UVLO/OVLO Response Time	t_f			500		ns
Output Overvoltage Protection	V_{OVP}	Above V_{OUT}		20		%
Overtemperature Fault Threshold	T_{OTP}		130	135	140	°C
Overtemperature Restart Hysteresis	T_{OTP_HYS}			30		°C

[1] All parameters reflect regulator and inductor system performance. Measurements were made using a standard PI33xx-x0 evaluation board with 3x4" dimensions and 4 layer, 2oz copper. Refer to inductor pairing table within Application Description section for specific inductor manufacturer and value.
[2] Regulator is assured to meet performance specifications by design, test correlation, characterization, and/or statistical process control.
[3] Output current capability may be limited and other performance may vary from electrical characteristics when switching frequency or V_{OUT} is modified.
[4] Refer to Output Ripple plots.
[5] Refer to Load Current vs. Ambient Temperature curves.
[6] Refer to Switching Frequency vs. Load current curves.
[7] Minimum 5V between V_{IN}-V_{OUT} must be maintained or a minimum load of 1mA required.

PI3312-x0-LGIZ (2.5V_{OUT}) Electrical Characteristics (Cont.)

Unless otherwise specified: -40°C < T_J < 125°C, V_{IN} = 24V, L1 = 200nH [1]

Parameter	Symbol	Conditions	Min	Typ	Max	Unit
Timing						
Switching Frequency	f_S	[6]		500		kHz
Fault Restart Delay	t_{FR_DLY}			30		ms
Sync In (SYNCI)						
Synchronization Frequency Range	Δf_{SYNCI}	Relative to set switching frequency [3]	50		110	%
SYNCI Threshold	V_{SYNCI}			2.5		V
SYNCI Input Impedance	Z_{SYNCI}			100		kΩ
Sync Out (SYNCO)						
SYNCO High	V_{SYNCO_HI}	Source 1mA	4.5			V
SYNCO Low	V_{SYNCO_LO}	Sink 1mA			0.5	V
SYNCO Rise Time	t_{SYNCO_RT}	20pF load		10		ns
SYNCO Fall Time	t_{SYNCO_FT}	20pF load		10		ns
Soft Start And Tracking						
TRK Active Input Range	V_{TRK}	Internal reference tracking range	0		1.04	V
TRK Max Output Voltage				1.2		V
TRK Disable Threshold	V_{TRK_OV}		20	40	60	mV
Charge Current (Soft – Start)	I_{TRK}		70	50	30	µA
Discharge Current (Fault)	I_{TRK_DIS}	V_{TRK} = 0.5V		6.8		mA
Soft-Start Time	t_{SS}	C_{TRK} = 0µF		2.2		ms
Enable						
High Threshold	V_{EN_HI}		0.9	1	1.1	V
Low Threshold	V_{EN_LO}		0.7	0.8	0.9	V
Threshold Hysteresis	V_{EN_HYS}		100	200	300	mV
Enable Pull-Up Voltage (Floating)	V_{EN_PU}	With positive logic EN polarity		2		V
Enable Pull-Down Voltage (Floating)	V_{EN_PD}	With negative logic EN polarity		0		V
Source Current	I_{EN_SO}	With positive logic EN polarity		50		µA
Sink Current	I_{EN_SK}	With negative logic EN polarity		50		µA

[1] All parameters reflect regulator and inductor system performance. Measurements were made using a standard PI33xx-x0 evaluation board with 3x4" dimensions and 4 layer, 2oz copper. Refer to inductor pairing table within Application Description section for specific inductor manufacturer and value.
[2] Regulator is assured to meet performance specifications by design, test correlation, characterization, and/or statistical process control.
[3] Output current capability may be limited and other performance may vary from electrical characteristics when switching frequency or V_{OUT} is modified.
[4] Refer to Output Ripple plots.
[5] Refer to Load Current vs. Ambient Temperature curves.
[6] Refer to Switching Frequency vs. Load current curves.
[7] Minimum 5V between V_{IN}-V_{OUT} must be maintained or a minimum load of 1mA required.

PI3312-x0-LGIZ (2.5V_{OUT}) Electrical Characteristics (Cont.)

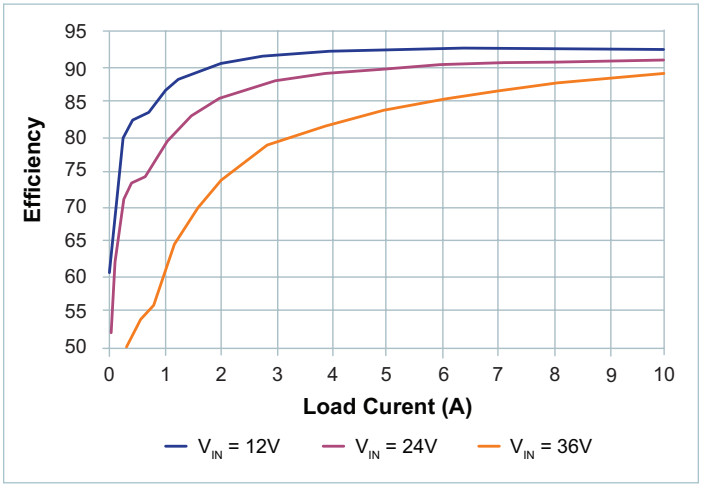


Figure 13 — *Efficiency at 25°C*

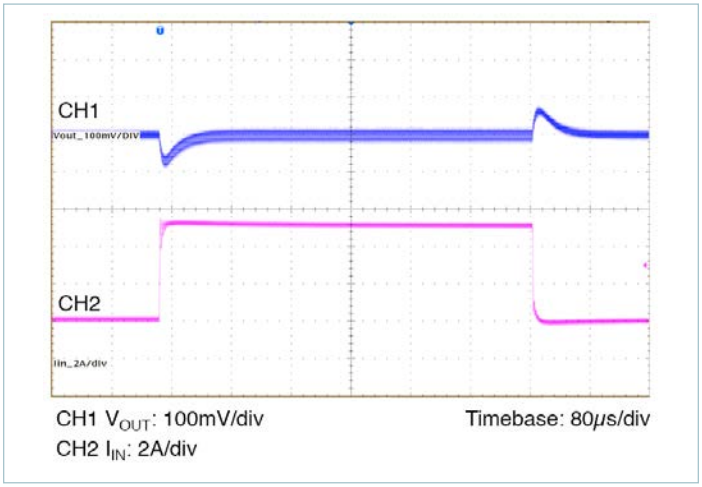


Figure 16 — *Transient Response 5A to 10A, at 5A/µs*

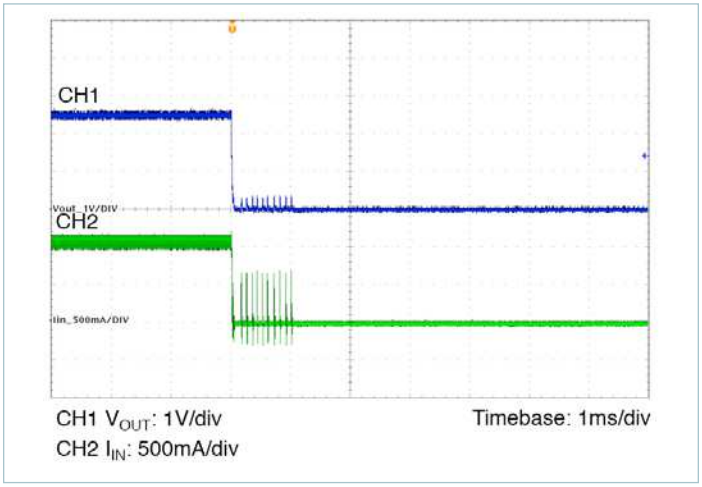


Figure 14 — *Short Circuit Test*

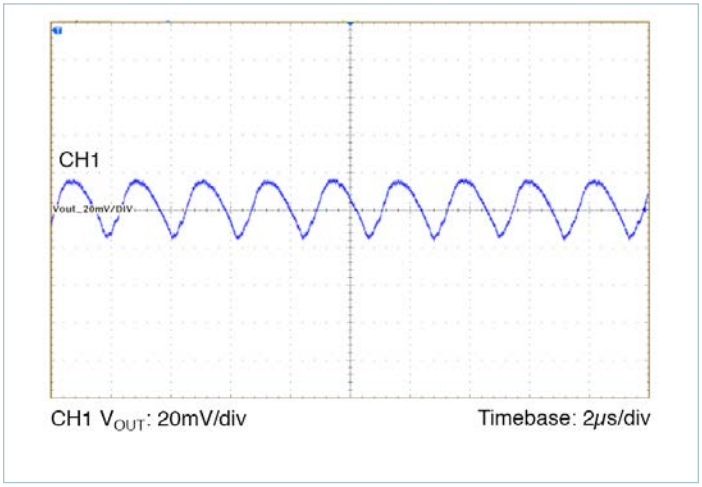


Figure 17 — *Output Ripple 24V_{IN}, 2.5V_{OUT} at 10A*

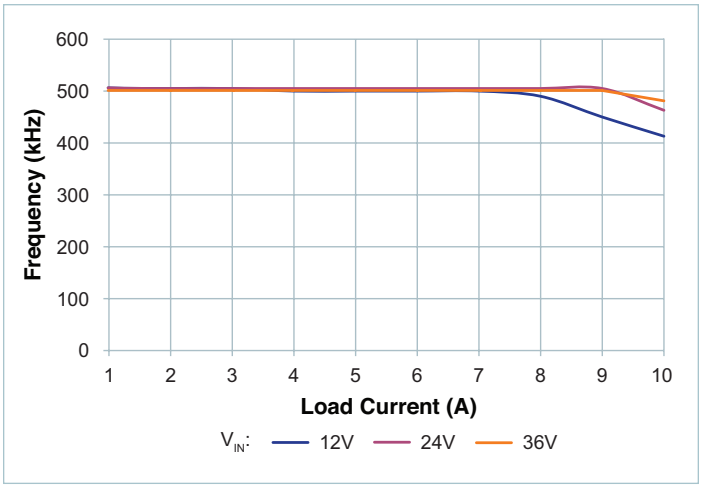


Figure 15 — *Switching Frequency vs. Load Current*

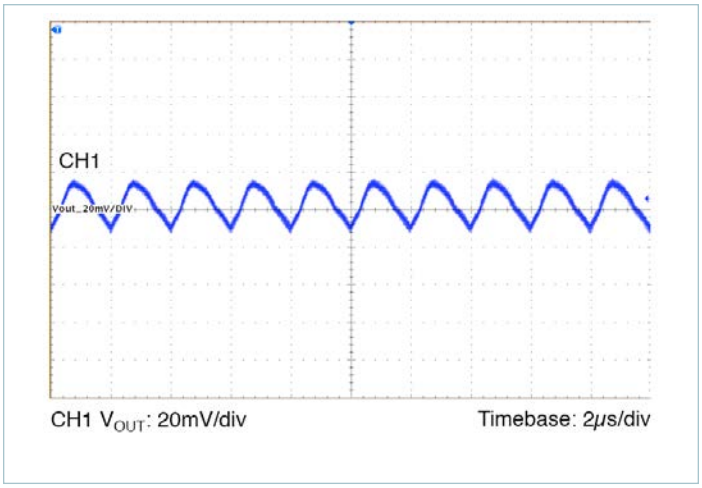


Figure 18 — *Output Ripple 24V_{IN}, 2.5V_{OUT} at 5A*

PI3312-x0-LGIZ (2.5V_{OUT}) Electrical Characteristics (Cont.)

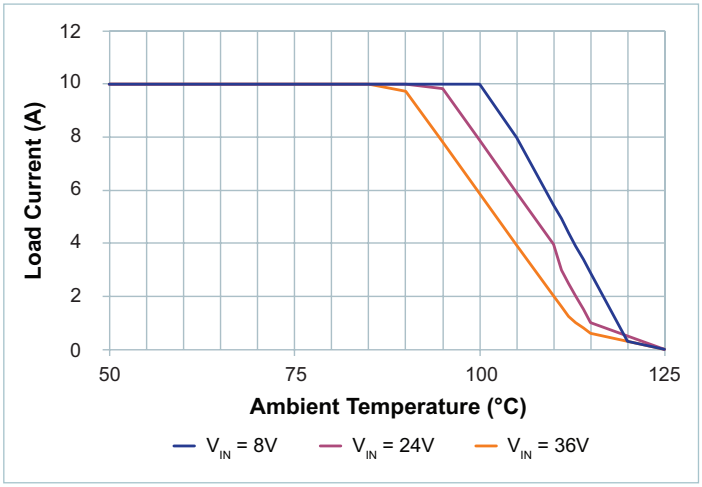


Figure 19 — *Load Current vs. Ambient Temperature, 0LFM*

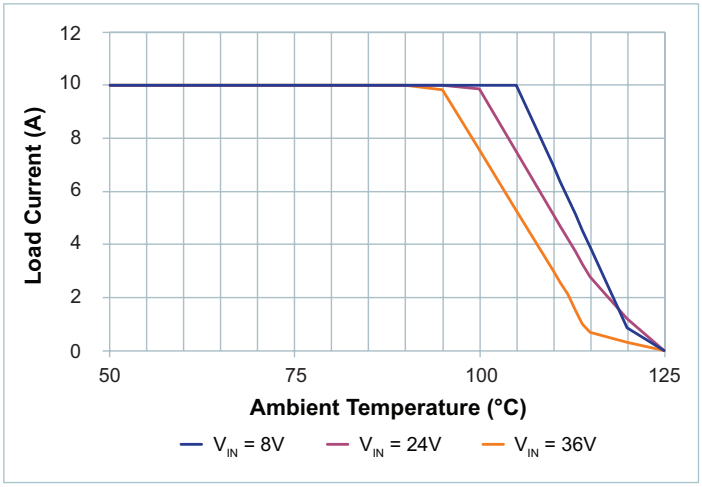


Figure 20 — *Load Current vs. Ambient Temperature, 200LFM*

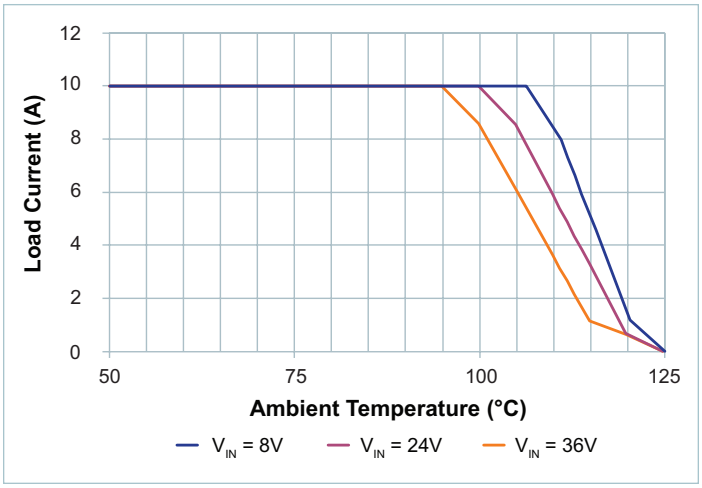


Figure 21 — *Load Current vs. Ambient Temperature, 400LFM*

PI3301-x0-LGIZ (3.3V_{OUT}) Electrical Characteristics

Unless otherwise specified: -40°C < T_J < 125°C, V_{IN} = 24V, L1 = 200nH [1]

Parameter	Symbol	Conditions	Min	Typ	Max	Unit
Input Specifications						
Input Voltage	V_{IN_DC}	[7]	8	24	36	V
Input Current	I_{IN_DC}	V_{IN} = 24V, T_C = 25°C, I_{OUT} =10A		1.49		A
Input Current At Output Short (fault condition duty cycle)	I_{IN_Short}	[2]			20	mA
Input Quiescent Current	I_{Q_VIN}	Disabled		2.0		mA
		Enabled (no load)		2.5		mA
Input Voltage Slew Rate	V_{IN_SR}				1	V/µs
Output Specifications						
Output Voltage Total Regulation	V_{OUT_DC}	[2]	3.25	3.30	3.36	V
Output Voltage Trim Range	V_{OUT_DC}	[3] [7]	2.3	3.3	4.1	V
Line Regulation	ΔV_{OUT} (ΔV_{IN})	@25°C, 8V < V_{IN} < 36V		0.10		%
Load Regulation	ΔV_{OUT} (ΔI_{OUT})	@25°C, 0.5A < I_{OUT} < 10A		0.10		%
Output Voltage Ripple	V_{OUT_AC}	I_{OUT} = 5A, C_{OUT} = 4 x 100µF, 20MHz BW [4]		37.5		mVp-p
Continuous Output Current Range	I_{OUT_DC}	[5]			10	A
Current Limit	I_{OUT_CL}			12		A
Protection						
V_{IN} UVLO Start Threshold	V_{UVLO_START}		7.10	7.60	8.00	V
V_{IN} UVLO Stop Threshold	V_{UVLO_STOP}		6.80	7.25	7.60	V
V_{IN} UVLO Hysteresis	V_{UVLO_HYS}			0.33		V
V_{IN} OVLO Start Threshold	V_{OVLO_START}		36.1			V
V_{IN} OVLO Stop Threshold	V_{OVLO_STOP}		37.0	38.4		V
V_{IN} OVLO Hysteresis	V_{OVLO_HYS}			0.77		V
V_{IN} UVLO/OVLO Response Time	t_f			500		ns
Output Overvoltage Protection	V_{OVP}	Above V_{OUT}		20		%
Overtemperature Fault Threshold	T_{OTP}		130	135	140	°C
Overtemperature Restart Hysteresis	T_{OTP_HYS}			30		°C

[1] All parameters reflect regulator and inductor system performance. Measurements were made using a standard PI33xx-x0 evaluation board with 3x4" dimensions and 4 layer, 2oz copper. Refer to inductor pairing table within Application Description section for specific inductor manufacturer and value.
[2] Regulator is assured to meet performance specifications by design, test correlation, characterization, and/or statistical process control.
[3] Output current capability may be limited and other performance may vary from electrical characteristics when switching frequency or V_{OUT} is modified.
[4] Refer to Output Ripple plots.
[5] Refer to Load Current vs. Ambient Temperature curves.
[6] Refer to Switching Frequency vs. Load current curves.
[7] Minimum 5V between V_{IN}-V_{OUT} must be maintained or a minimum load of 1mA required.

PI3301-x0-LGIZ ($3.3V_{OUT}$) Electrical Characteristics (Cont.)

Unless otherwise specified: -40°C < T_J < 125°C, V_{IN} = 24V, L1 = 200nH [1]

Parameter	Symbol	Conditions	Min	Typ	Max	Unit
Timing						
Switching Frequency	f_S	[6]		650		kHz
Fault Restart Delay	t_{FR_DLY}			30		ms
Sync In (SYNCI)						
Synchronization Frequency Range	Δf_{SYNCI}	Relative to set switching frequency [3]	50		110	%
SYNCI Threshold	V_{SYNCI}			2.5		V
SYNCI Input Impedance	Z_{SYNCI}			100		kΩ
Sync Out (SYNCO)						
SYNCO High	V_{SYNCO_HI}	Source 1mA	4.5			V
SYNCO Low	V_{SYNCO_LO}	Sink 1mA			0.5	V
SYNCO Rise Time	t_{SYNCO_RT}	20pF load		10		ns
SYNCO Fall Time	t_{SYNCO_FT}	20pF load		10		ns
Soft Start And Tracking						
TRK Active Input Range	V_{TRK}	Internal reference tracking range	0		1.04	V
TRK Max Output Voltage				1.2		V
TRK Disable Threshold	V_{TRK_OV}		20	40	60	mV
Charge Current (Soft – Start)	I_{TRK}		70	50	30	µA
Discharge Current (Fault)	I_{TRK_DIS}	V_{TRK} = 0.5V		6.8		mA
Soft-Start Time	t_{SS}	C_{TRK} = 0µF		2.2		ms
Enable						
High Threshold	V_{EN_HI}		0.9	1	1.1	V
Low Threshold	V_{EN_LO}		0.7	0.8	0.9	V
Threshold Hysteresis	V_{EN_HYS}		100	200	300	mV
Enable Pull-Up Voltage (Floating)	V_{EN_PU}	With positive logic EN polarity		2		V
Enable Pull-Down Voltage (Floating)	V_{EN_PD}	With negative logic EN polarity		0		V
Source Current	I_{EN_SO}	With positive logic EN polarity		50		µA
Sink Current	I_{EN_SK}	With negative logic EN polarity		50		µA

[1] All parameters reflect regulator and inductor system performance. Measurements were made using a standard PI33xx-x0 evaluation board with 3x4" dimensions and 4 layer, 2oz copper. Refer to inductor pairing table within Application Description section for specific inductor manufacturer and value.
[2] Regulator is assured to meet performance specifications by design, test correlation, characterization, and/or statistical process control.
[3] Output current capability may be limited and other performance may vary from electrical characteristics when switching frequency or V_{OUT} is modified.
[4] Refer to Output Ripple plots.
[5] Refer to Load Current vs. Ambient Temperature curves.
[6] Refer to Switching Frequency vs. Load current curves.
[7] Minimum 5V between V_{IN}-V_{OUT} must be maintained or a minimum load of 1mA required.

PI3301-x0-LGIZ (3.3V_{OUT}) Electrical Characteristics (Cont.)

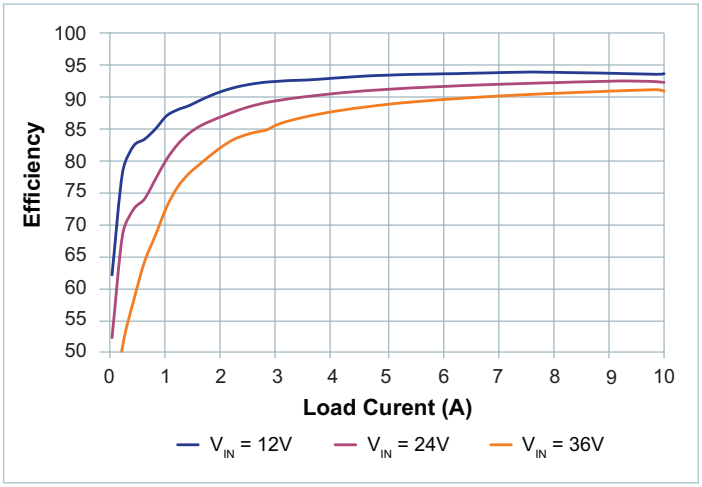


Figure 22 — *Efficiency at 25°C*

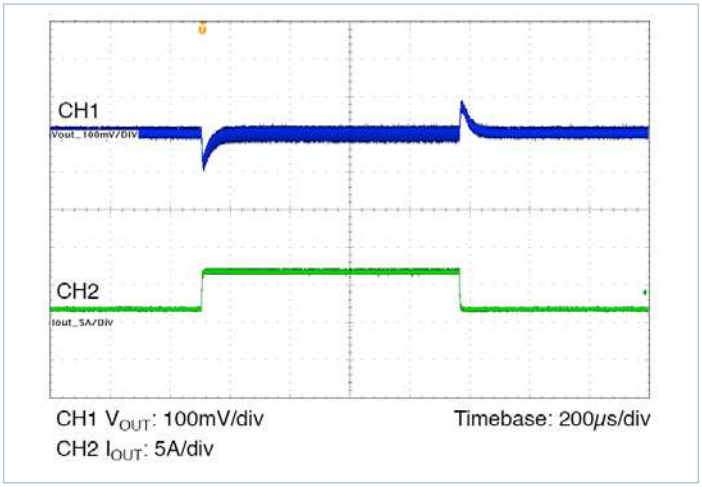


Figure 25 — *Transient Response 2A to 7A, at 5A/µs*

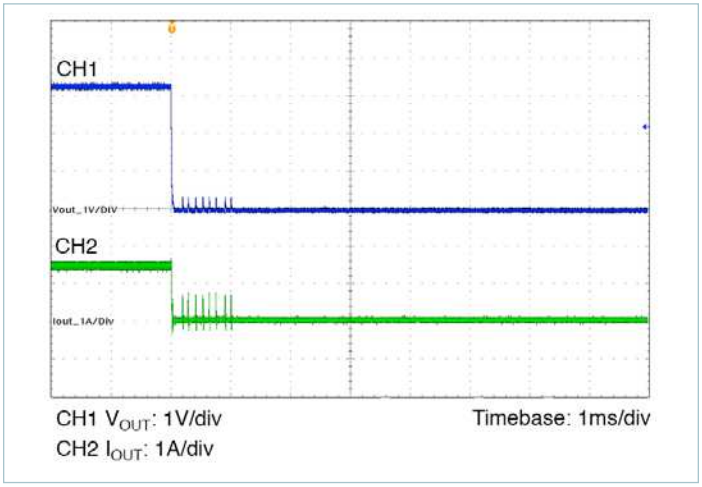


Figure 23 — *Short Circuit Test*

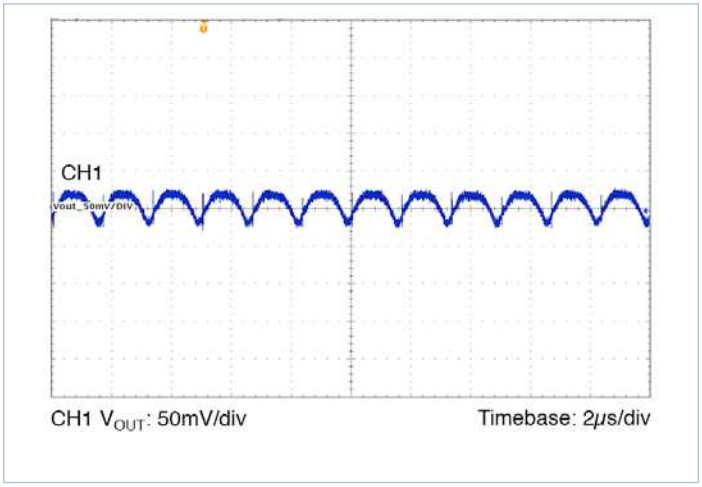


Figure 26 — *Output Ripple 24V_{IN}, 3.3V_{OUT} at 10A*

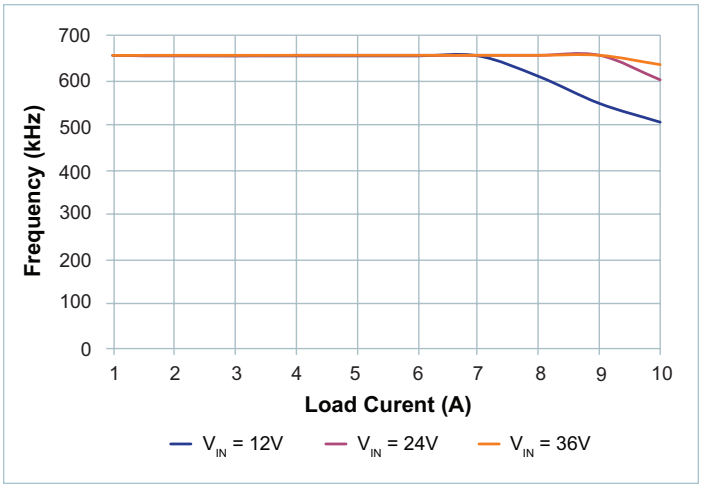


Figure 24 — *Switching Frequency vs. Load Current*

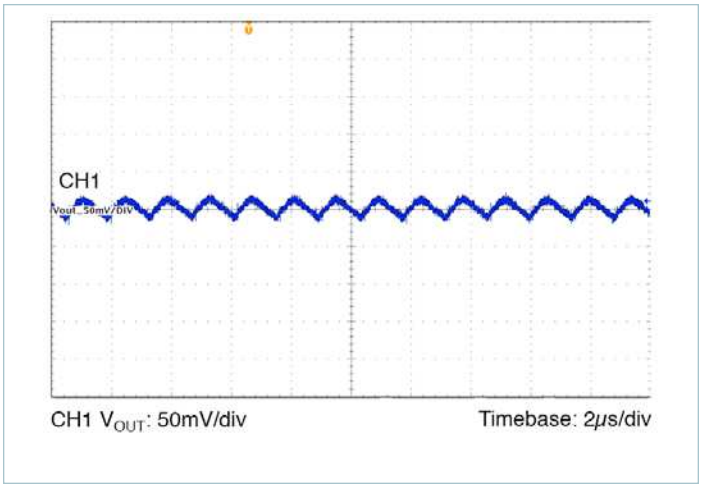


Figure 27 — *Output Ripple 24V_{IN}, 3.3V_{OUT} at 5A*

PI3301-x0-LGIZ (3.3V_{OUT}) Electrical Characteristics (Cont.)

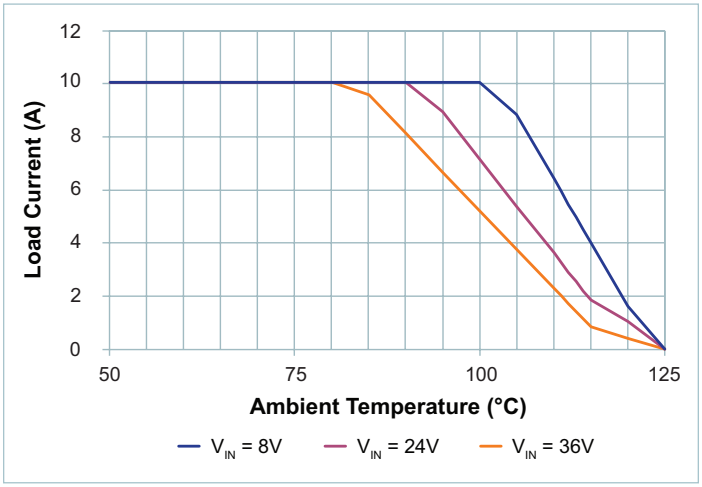


Figure 28 — *Load Current vs. Ambient Temperature, 0LFM*

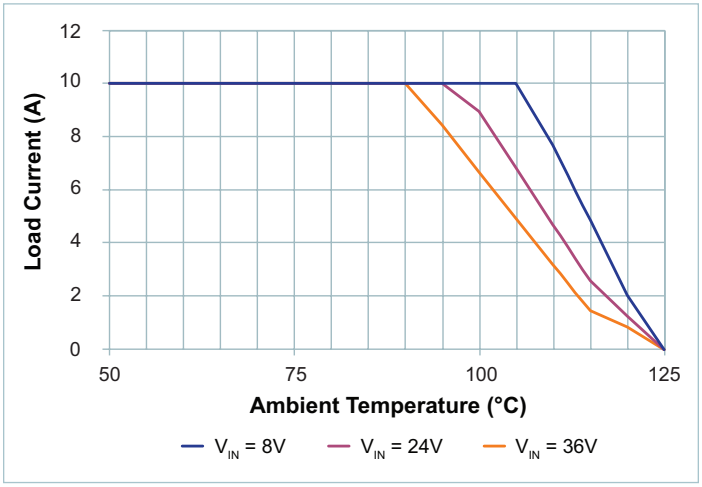


Figure 29 — *Load Current vs. Ambient Temperature, 200LFM*

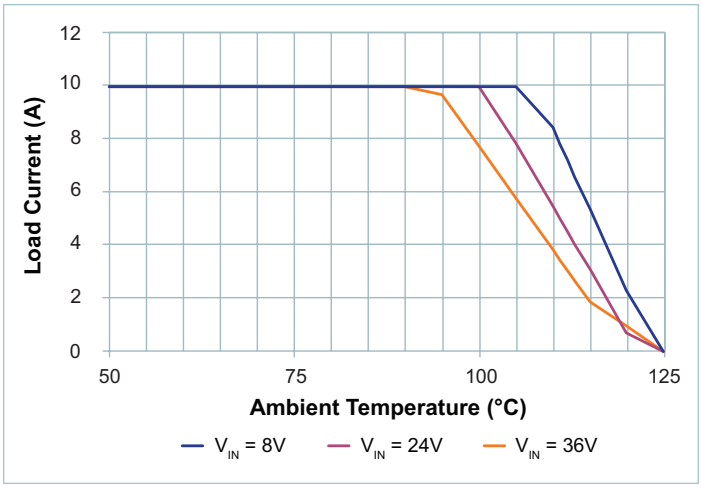


Figure 30 — *Load Current vs. Ambient Temperature, 400LFM*

PI3302-x0-LGIZ (5.0V_{OUT}) Electrical Characteristics

Unless otherwise specified: -40°C < T_J < 125°C, V_{IN} = 24V, L1 = 200nH [1]

Parameter	Symbol	Conditions	Min	Typ	Max	Unit
Input Specifications						
Input Voltage	V_{IN_DC}	[7]	8	24	36	V
Input Current	I_{IN_DC}	V_{IN} = 24V, T_C = 25°C, I_{OUT} =10A		2.23		A
Input Current At Output Short (fault condition duty cycle)	I_{IN_Short}	[2]			20	mA
Input Quiescent Current	I_{Q_VIN}	Disabled		2.0		mA
		Enabled (no load)		2.5		mA
Input Voltage Slew Rate	V_{IN_SR}				1	V/µs
Output Specifications						
Output Voltage Total Regulation	V_{OUT_DC}	[2]	4.93	5.00	5.07	V
Output Voltage Trim Range	V_{OUT_DC}	[3] [7]	3.3		6.5	V
Line Regulation	ΔV_{OUT} (ΔV_{IN})	@25°C, 8V <V_{IN} < 36V		0.10		%
Load Regulation	ΔV_{OUT} (ΔI_{OUT})	@25°C, 0.5A <I_{OUT} < 10A		0.10		%
Output Voltage Ripple	V_{OUT_AC}	I_{OUT} = 5A, C_{OUT} = 4 x 47µF, 20MHz BW [4]		30		mVp-p
Continuous Output Current Range	I_{OUT_DC}	[5] [7]			10	A
Current Limit	I_{OUT_CL}			12		A
Protection						
V_{IN} UVLO Start Threshold	V_{UVLO_START}		7.10	7.60	8.00	V
V_{IN} UVLO Stop Threshold	V_{UVLO_STOP}		6.80	7.25	7.60	V
V_{IN} UVLO Hysteresis	V_{UVLO_HYS}			0.33		V
V_{IN} OVLO Start Threshold	V_{OVLO_START}		36.1			V
V_{IN} OVLO Stop Threshold	V_{OVLO_STOP}		37.0	38.4		V
V_{IN} OVLO Hysteresis	V_{OVLO_HYS}			0.77		V
V_{IN} UVLO/OVLO Response Time	t_f			500		ns
Output Overvoltage Protection	V_{OVP}	Above V_{OUT}		20		%
Overtemperature Fault Threshold	T_{OTP}		130	135	140	°C
Overtemperature Restart Hysteresis	T_{OTP_HYS}			30		°C

[1] All parameters reflect regulator and inductor system performance. Measurements were made using a standard PI33xx-x0 evaluation board with 3x4" dimensions and 4 layer, 2oz copper. Refer to inductor pairing table within Application Description section for specific inductor manufacturer and value.
[2] Regulator is assured to meet performance specifications by design, test correlation, characterization, and/or statistical process control.
[3] Output current capability may be limited and other performance may vary from electrical characteristics when switching frequency or V_{OUT} is modified.
[4] Refer to Output Ripple plots.
[5] Refer to Load Current vs. Ambient Temperature curves.
[6] Refer to Switching Frequency vs. Load current curves.
[7] Minimum 5V between V_{IN}-V_{OUT} must be maintained or a minimum load of 1mA required.

PI3302-x0-LGIZ (5.0V_{OUT}) Electrical Characteristics (Cont.)

Unless otherwise specified: -40°C < T_J < 125°C, V_{IN} = 24V, L1 = 200nH [1]

Parameter	Symbol	Conditions	Min	Typ	Max	Unit
Timing						
Switching Frequency	f_S	[6]		1.0		MHz
Fault Restart Delay	t_{FR_DLY}			30		ms
Sync In (SYNCI)						
Synchronization Frequency Range	Δf_{SYNCI}	Relative to set switching frequency [3]	50		110	%
SYNCI Threshold	V_{SYNCI}			2.5		V
SYNCI Input Impedance	Z_{SYNCI}			100		kΩ
Sync Out (SYNCO)						
SYNCO High	V_{SYNCO_HI}	Source 1mA	4.5			V
SYNCO Low	V_{SYNCO_LO}	Sink 1mA			0.5	V
SYNCO Rise Time	t_{SYNCO_RT}	20pF load		10		ns
SYNCO Fall Time	t_{SYNCO_FT}	20pF load		10		ns
Soft Start And Tracking						
TRK Active Input Range	V_{TRK}		0		1.04	V
TRK Max Output Voltage				1.2		V
TRK Disable Threshold	V_{TRK_OV}		20	40	60	mV
Charge Current (Soft – Start)	I_{TRK}		70	50	30	µA
Discharge Current (Fault)	I_{TRK_DIS}	V_{TRK} = 0.5V		6.8		mA
Soft-Start Time	t_{SS}	C_{TRK} = 0µF		2.2		ms
Enable						
High Threshold	V_{EN_HI}		0.9	1	1.1	V
Low Threshold	V_{EN_LO}		0.7	0.8	0.9	V
Threshold Hysteresis	V_{EN_HYS}		100	200	300	mV
Enable Pull-Up Voltage (Floating)	V_{EN_PU}	With positive logic EN polarity		2		V
Enable Pull-Down Voltage (Floating)	V_{EN_PD}	With negative logic EN polarity		0		V
Source Current	I_{EN_SO}	With positive logic EN polarity		50		µA
Sink Current	I_{EN_SK}	With negative logic EN polarity		50		µA

[1] All parameters reflect regulator and inductor system performance. Measurements were made using a standard PI33xx-x0 evaluation board with 3x4" dimensions and 4 layer, 2oz copper. Refer to inductor pairing table within Application Description section for specific inductor manufacturer and value.
[2] Regulator is assured to meet performance specifications by design, test correlation, characterization, and/or statistical process control.
[3] Output current capability may be limited and other performance may vary from electrical characteristics when switching frequency or V_{OUT} is modified.
[4] Refer to Output Ripple plots.
[5] Refer to Load Current vs. Ambient Temperature curves.
[6] Refer to Switching Frequency vs. Load current curves.
[7] Minimum 5V between V_{IN}-V_{OUT} must be maintained or a minimum load of 1mA required.

PI3302-x0-LGIZ (5.0V_{OUT}) Electrical Characteristics (Cont.)

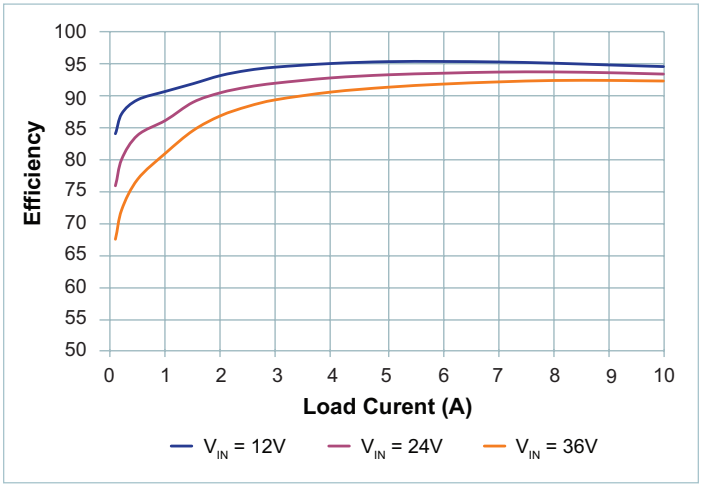


Figure 31 — *Efficiency at 25°C*

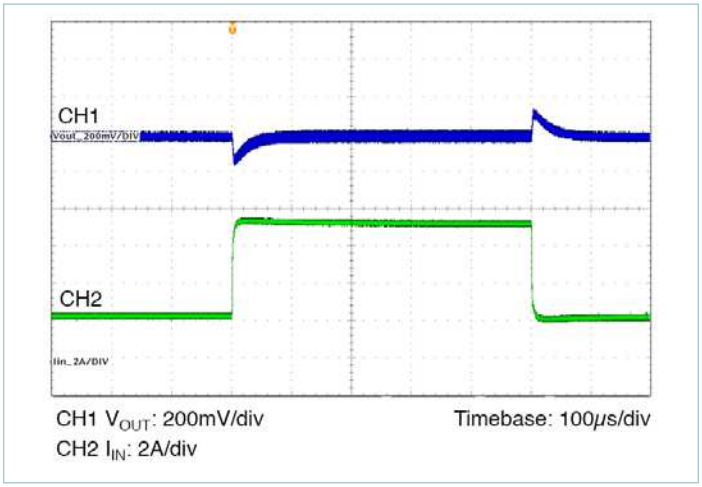


Figure 34 — *Transient Response 2A to 7A, at 5A/µs*

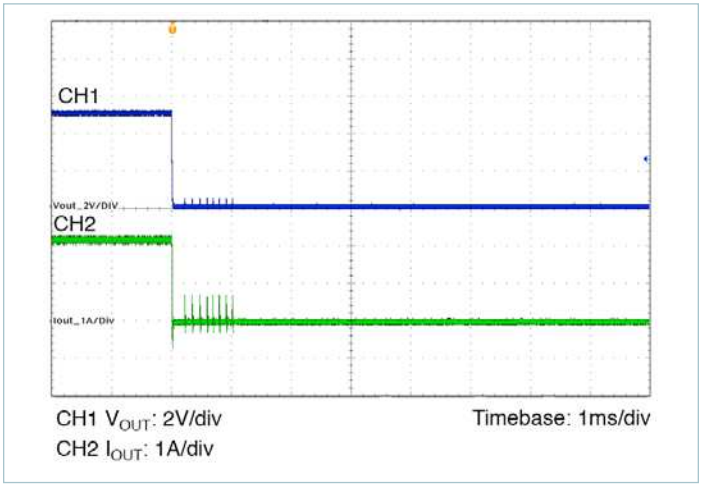


Figure 32 — *Short Circuit Test*

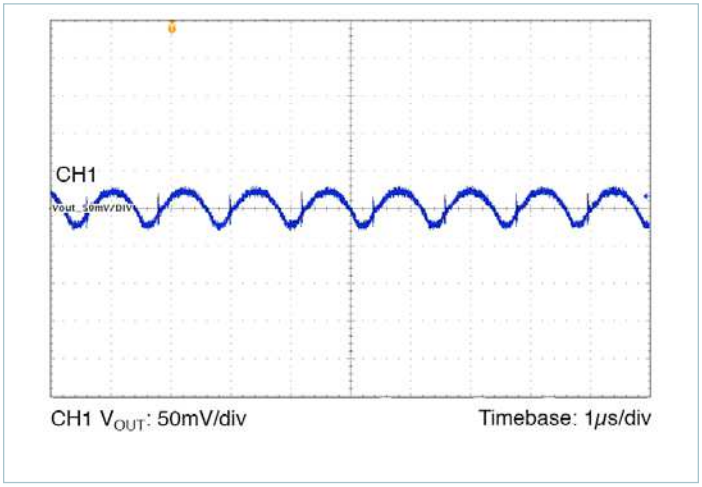


Figure 35 — *Output Ripple 24V_{IN}, 5.0V_{OUT} at 10A*

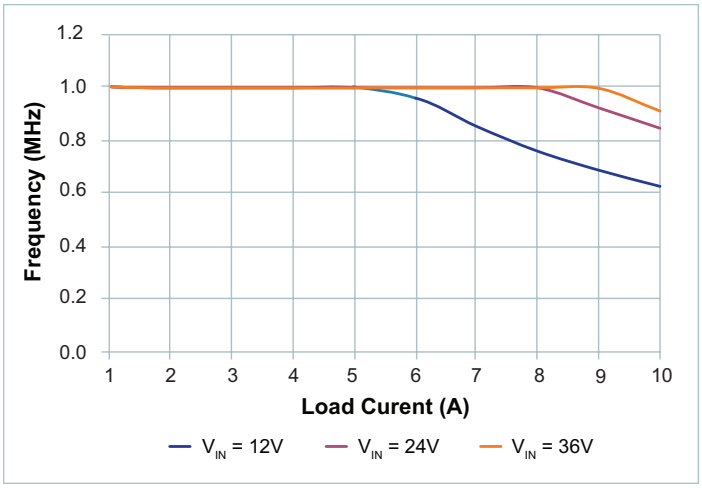


Figure 33 — *Switching Frequency vs. Load Current*

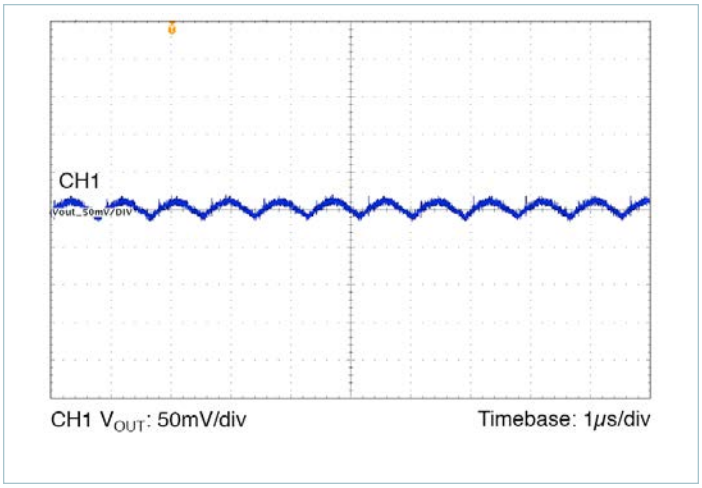


Figure 36 — *Output Ripple 24V_{IN}, 5.0V_{OUT} at 5A*

PI3302-x0-LGIZ (5.0V$_{OUT}$) Electrical Characteristics (Cont.)

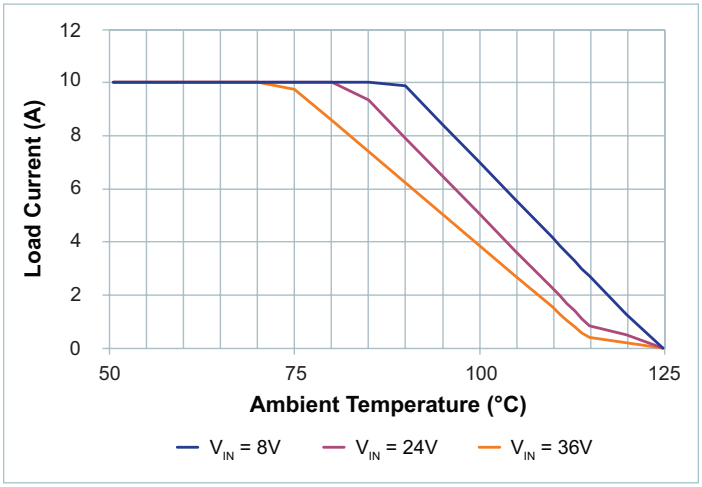


Figure 37 — *Load Current vs. Ambient Temperature, 0LFM*

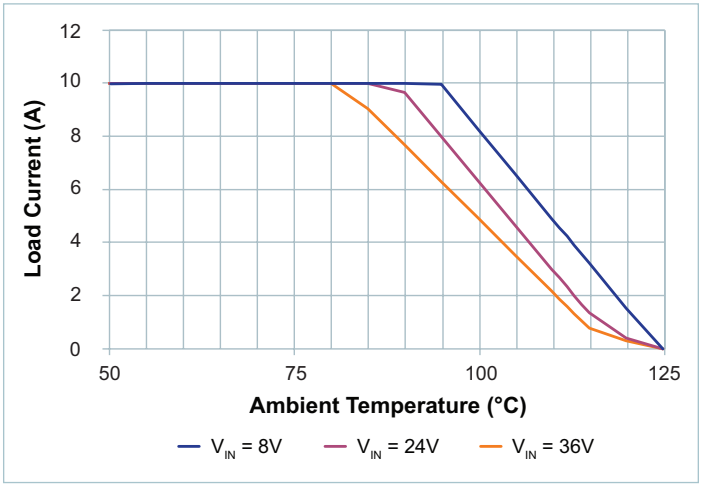


Figure 38 — *Load Current vs. Ambient Temperature, 200LFM*

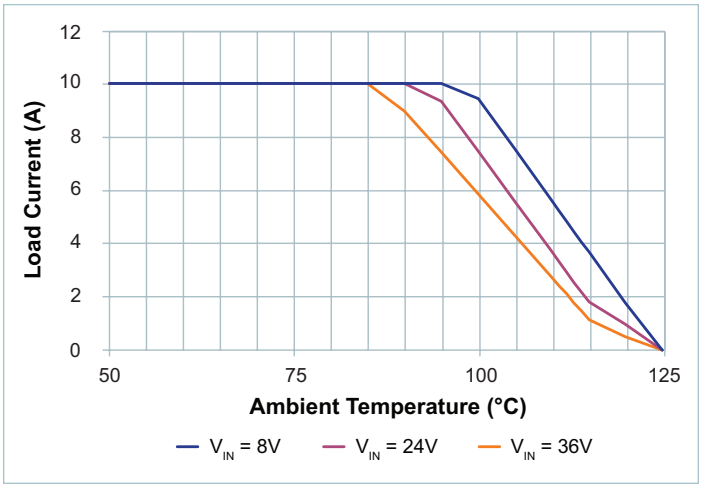


Figure 39 — *Load Current vs. Ambient Temperature, 400LFM*

PI3303-x0-LGIZ (12.0V_{OUT}) Electrical Characteristics

Unless otherwise specified: -40°C < T_J < 125°C, V_{IN} = 24V, L1 = 230nH [1]

Parameter	Symbol	Conditions	Min	Typ	Max	Unit
Input Specifications						
Input Voltage	V_{IN_DC}	[7]	17.4	24	36	V
Input Current	I_{IN_DC}	V_{IN} = 24V, T_C = 25°C, I_{OUT} = 8A		4.15		A
Input Current At Output Short (fault condition duty cycle)	I_{IN_Short}	[2]			20	mA
Input Quiescent Current	I_{Q_VIN}	Disabled		2.0		mA
		Enabled (no load)		2.5		mA
Input Voltage Slew Rate	V_{IN_SR}				1	V/µs
Output Specifications						
Output Voltage Total Regulation	V_{OUT_DC}	[2]	11.82	12.0	12.18	V
Output Voltage Trim Range	V_{OUT_DC}	[3] [7]	6.5	12	13.0	V
Line Regulation	ΔV_{OUT} (ΔV_{IN})	@25°C, 8V < V_{IN} < 36V		0.10		%
Load Regulation	ΔV_{OUT} (ΔI_{OUT})	@25°C, 0.5A < I_{OUT} < 8A		0.10		%
Output Voltage Ripple	V_{OUT_AC}	I_{OUT} = 4A, C_{OUT} = 4 x 22µF, 20MHz BW [4]		60		mVp-p
Continuous Output Current Range	I_{OUT_DC}	[5]			8	A
Current Limit	I_{OUT_CL}			9		A
Protection						
V_{IN} UVLO Start Threshold	V_{UVLO_START}		15.80	16.60	17.40	V
V_{IN} UVLO Stop Threshold	V_{UVLO_STOP}		15.00	15.80	16.60	V
V_{IN} UVLO Hysteresis	V_{UVLO_HYS}			0.77		V
V_{IN} OVLO Start Threshold	V_{OVLO_START}		36.1			V
V_{IN} OVLO Stop Threshold	V_{OVLO_STOP}		37.0	38.4		V
V_{IN} OVLO Hysteresis	V_{OVLO_HYS}			0.77		V
V_{IN} UVLO/OVLO Response Time	t_f			500		ns
Output Overvoltage Protection	V_{OVP}	Above V_{OUT}		20		%
Overtemperature Fault Threshold	T_{OTP}		130	135	140	°C
Overtemperature Restart Hysteresis	T_{OTP_HYS}			30		°C

[1] All parameters reflect regulator and inductor system performance. Measurements were made using a standard PI33xx-x0 evaluation board with 3x4" dimensions and 4 layer, 2oz copper. Refer to inductor pairing table within Application Description section for specific inductor manufacturer and value.
[2] Regulator is assured to meet performance specifications by design, test correlation, characterization, and/or statistical process control.
[3] Output current capability may be limited and other performance may vary from electrical characteristics when switching frequency or V_{OUT} is modified.
[4] Refer to Output Ripple plots.
[5] Refer to Load Current vs. Ambient Temperature curves.
[6] Refer to Switching Frequency vs. Load current curves.
[7] Minimum 5V between V_{IN}-V_{OUT} must be maintained or a minimum load of 1mA required.

PI3303-x0-LGIZ (12.0V_{OUT}) Electrical Characteristics (Cont.)

Unless otherwise specified: -40°C < T_J < 125°C, V_{IN} = 24V, L1 = 230nH [1]

Parameter	Symbol	Conditions	Min	Typ	Max	Unit
Timing						
Switching Frequency	f_S	[6]		1.4		MHz
Fault Restart Delay	t_{FR_DLY}			30		ms
Sync In (SYNCI)						
Synchronization Frequency Range	Δf_{SYNCI}	Relative to set switching frequency [3]	50		110	%
SYNCI Threshold	V_{SYNCI}			2.5		V
SYNCI Input Impedance	Z_{SYNCI}			100		kΩ
Sync Out (SYNCO)						
SYNCO High	V_{SYNCO_HI}	Source 1mA	4.5			V
SYNCO Low	V_{SYNCO_LO}	Sink 1mA			0.5	V
SYNCO Rise Time	t_{SYNCO_RT}	20pF load		10		ns
SYNCO Fall Time	t_{SYNCO_FT}	20pF load		10		ns
Soft Start And Tracking						
TRK Active Input Range	V_{TRK}		0		1.04	V
TRK Max Output Voltage				1.2		V
TRK Disable Threshold	V_{TRK_OV}		20	40	60	mV
Charge Current (Soft – Start)	I_{TRK}		70	50	30	µA
Discharge Current (Fault)	I_{TRK_DIS}	V_{TRK} = 0.5V		6.8		mA
Soft-Start Time	t_{SS}	C_{TRK} = 0µF		2.2		ms
Enable						
High Threshold	V_{EN_HI}		0.9	1	1.1	V
Low Threshold	V_{EN_LO}		0.7	0.8	0.9	V
Threshold Hysteresis	V_{EN_HYS}		100	200	300	mV
Enable Pull-Up Voltage (Floating)	V_{EN_PU}	With positive logic EN polarity		2		V
Enable Pull-Down Voltage (Floating)	V_{EN_PD}	With negative logic EN polarity		0		V
Source Current	I_{EN_SO}	With positive logic EN polarity		50		µA
Sink Current	I_{EN_SK}	With negative logic EN polarity		50		µA

[1] All parameters reflect regulator and inductor system performance. Measurements were made using a standard PI33xx-x0 evaluation board with 3x4" dimensions and 4 layer, 2oz copper. Refer to inductor pairing table within Application Description section for specific inductor manufacturer and value.
[2] Regulator is assured to meet performance specifications by design, test correlation, characterization, and/or statistical process control.
[3] Output current capability may be limited and other performance may vary from electrical characteristics when switching frequency or V_{OUT} is modified.
[4] Refer to Output Ripple plots.
[5] Refer to Load Current vs. Ambient Temperature curves.
[6] Refer to Switching Frequency vs. Load current curves.
[7] Minimum 5V between V_{IN}-V_{OUT} must be maintained or a minimum load of 1mA required.