35A Synchronous Step Down COT Controller

A New Direction in Mixed-Signal

December 2013 Rev. 1.0.1

GENERAL DESCRIPTION

The XRP6141 is a synchronous step-down controller for point-of load supplies up to 35A. A wide 4.5V to 22V input voltage range allows for single supply operation from industry standard 5V, 12V and 19.6V rails.

With a proprietary emulated current mode Constant On-Time (COT) control scheme, the XRP6141 provides extremely fast line and load transient response using ceramic output capacitors. It requires no loop compensation hence simplifying circuit implementation and reducing overall component count. The control loop also provides exceptional line regulation and maintains constant operating frequency. A selectable power saving mode, allows the user to operate in discontinuous mode (DCM) at light current loads thereby significantly increasing the converter efficiency.

A host of protection features, including over-current, over-temperature, short-circuit and UVLO, help achieve safe operation under abnormal operating conditions.

The XRP6141 is available in RoHS compliant, green/halogen free space-saving 16-pin 3x3 QFN package.

APPLICATIONS

- **Networking and Communications**
- **Fast Transient Point-of-Loads**
- **Industrial and Medical Equipment**
- **Embedded High Power FPGA**

FEATURES

- **35A Capable Step Down Controller**
  - Wide Input Voltage Range
    - 5V to 22V Single Supply
    - 4.5V to 5.5V Low Vin
  - Integrated high Current 2A/3A Drivers
  - 0.6V to 18V Adjustable Output Voltage
- **Proprietary Constant On-Time Control**
  - No Loop Compensation Required
  - Ceramic Output Cap. Stable operation
  - Programmable 200ns-2µs
  - Constant 200kHz-800kHz Frequency
  - Selectable CCM or CCM/DCM Operation
- **Programmable hiccup current limit with thermal compensation**
- **Precision Enable and Power-Good Flag**
- **Programmable Soft-start**
- **Integrated Bootstrap diode**
- **16-pin QFN Package**

TYPICAL APPLICATION DIAGRAM

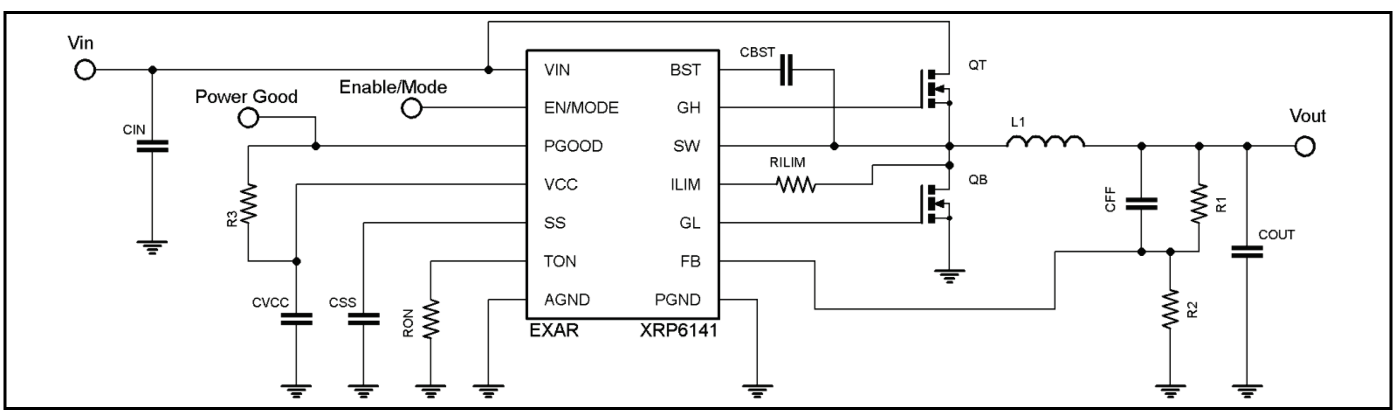


Fig. 1: XRP6141 Application Diagram

Exar Corporation
48720 Kato Road, Fremont CA 94538, USA
www.exar.com
Tel. +1 510 668-7000 – Fax. +1 510 668-7001

ABSOLUTE MAXIMUM RATINGS

These are stress ratings only and functional operation of the device at these ratings or any other above those indicated in the operation sections of the specifications below is not implied. Exposure to absolute maximum rating conditions for extended periods of time may affect reliability.

V_{IN} .... -0.3V to 28V
V_{CC} .... -0.3V to 6.0V
BST .... -0.3V to 34V[2]
BST-SW .... -0.3V to 6V
SW, ILIM .... -5V to 28V[1,2]
GH........ -0.3V to BST+0.3V
GH-SW........ -0.3V to 6V
ALL other pins........ -0.3V to VCC+0.3V
Storage Temperature........ -65°C to 150°C
Junction Temperature .... 150°C
Power Dissipation .... Internally Limited
Lead Temperature (Soldering, 10 sec) .... 300°C
ESD Rating (HBM - Human Body Model)........ 2kV

OPERATING RATINGS

V_{IN} .... -0.3V to 22V
V_{CC} .... -0.3V to 5.5V
SW, ILIM .... -1V to 26V[1]
PGOOD, VCC, TON, SS, EN, GL, FB .... -0.3V to 5.5V
Switching Frequency .... 200kHz-800kHz[3]
Junction Temperature Range........ -40°C to 125°C

Note 1: SW pin's minimum DC range is -1V, transient is -5V for less than 50ns
Note 2: No external voltage applied
Note 3: Recommended

ELECTRICAL SPECIFICATIONS

Specifications are for Operating Junction Temperature of T_J = 25°C only; limits applying over the full Operating Junction Temperature range are denoted by a "•". Minimum and Maximum limits are guaranteed through test, design, or statistical correlation. Typical values represent the most likely parametric norm at T_J = 25°C, and are provided for reference purposes only. Unless otherwise indicated, V_{IN} = 12V, BST=VCC, SW=GND=PGND=0V, CGH=CGL=3.3nF.

Parameter	Min.	Typ.	Max.	Units		Conditions
Power Supply Characteristics						
V_{IN}, Input Voltage Range	5	12	22	V	•	VCC regulating
	4.5	5.0	5.5			VCC tied to VIN
I_{VIN}, VIN supply current		0.7	2	mA	•	Not switching, V_{IN}=12V, VFB=0.7V
I_{VCC}, VCC Quiescent current		0.7	2	mA	•	Not switching, V_{CC}=V_{IN}=5V, VFB=0.7V
I_{VIN}, VIN supply current		11		mA		f=300kHz, RON=108.8k, VFB=0.58V
I_{OFF}, Shutdown current		0.1		μA		Enable=0V, V_{IN}=12V
Enable and Under-Voltage Lock-Out UVLO						
V_{IH_EN}, EN Pin Rising Threshold	1.8	1.9	2.0	V	•	
V_{EN_HYS}, EN Pin Hysteresis		50		mV		
V_{IH_EN}, EN Pin Rising Threshold for DCM/CCM operation	2.9	3.0	3.1	V	•	
V_{EN_HYS}, EN Pin Hysteresis		100		mV		
VCC UVLO start threshold, rising edge	4.00	4.25	4.50	V	•	
VCC UVLO Hysteresis		200		mV		
Reference voltage						
V_{REF}, Reference voltage	0.597	0.600	0.603	V		V_{IN} =5V-22V→ VCC regulating
	0.596		0.604	V		V_{IN} =4.5V-5.5V→ tie VCC to VIN
	0.594	0.600	0.606	V	•	V_{IN} =5V-22V→ VCC regulating, V_{IN} =4.5V-5.5V→ tie VCC to VIN
DC Line regulation		±0.1		%		CCM operation, closed loop, applies to any COUT
DC Load regulation		±0.25		%		CCM operation, closed loop, applies to any

Parameter	Min.	Typ.	Max.	Units		Conditions
						COUT
Programmable Constant On-Time						
On-Time 1	1855	2182	2509	ns	•	RON = 141.2kΩ, V_{IN}=22V
f corresponding to On-Time 1	217	250	294	kHz		V_{IN}=22V, V_{OUT}=12V
Minimum Programmable On-Time		109		ns		RON = 7.059kΩ, V_{IN}=22V
On-Time 2	170	200	230	ns	•	RON = 7.059kΩ, V_{IN}=12V
f corresponding to On-Time 2	1618	1375	1196	kHz		V_{OUT}=3.3V
f corresponding to On-Time 2	490	417	362	kHz		V_{OUT}=1.0V
On-Time 3	391	460	529	ns	•	RON = 16.235kΩ, V_{IN}=12V
Minimum Off-Time		250	350	ns	•	
Diode Emulation Mode						
Zero crossing threshold	-4	-1		mV		DC value measured during test
SoftStart						
SS Charge current	-14	-10	-6	μA	•	
SS Discharge current	1			mA	•	Fault present
VCC Linear Regulator (VCC should be tied to VIN, for 4.5V ≤V_{IN}≤5.5V)						
VCC Output Voltage	4.8	5.0	5.2	V	•	V_{IN}=6V to 22V, Iload=0 to 30mA
	4.51	4.7			•	V_{IN}=5V, Iload=0 to 20mA
Dropout Voltage	200	300	490	mV	•	I_{VCC}=30mA
Power Good Output						
Power Good Threshold	-10	-7.5	-5	%		
Power Good Hysteresis		2	4	%		
Power Good Sink Current	1			mA		
Protection: OCP, OTP, Short-circuit						
Hiccup timeout		110		ms		
ILIM pin source current	45	50	55	μA		
ILIM current temperature coeff.		0.4		%/°C		
OCP comparator offset	-8	0	+8	mV	•	
Current limit blanking		100		ns		GL rising>1V
Thermal shutdown threshold[1]		150		°C		Rising temperature
Thermal Hysteresis[1]		15		°C		
VSCTH Feedback pin short-circuit threshold	50	60	70	%	•	Percent of VREF, short circuit is active After PGOOD is up
Output Gate drivers						
GH Pull-Down Resistance		1.35	2.0	Ω		IGH=200mA
GH Pull-up Resistance		1.8	2.8	Ω		IGH=200mA
GL Pull-Down Resistance		1.35	1.9	Ω		IGL=200mA
GL Pull-up Resistance		1.7	2.7	Ω		IGL=200mA
GH and GL pull-down Resistance		50	---	kΩ		
GH and GL rise time		35	50	ns		10% to 90%
GH and GL fall time		30	40	ns		90% to 10%
GL to GH non-overlap time	20	30	60	ns		Measured GL falling edge =1V to GH rising edge =1V, BST=VCC, SW=0V
GH to GL non-overlap time	15	20	40	ns		Measured GH falling edge =1V to GL rising edge =1V

Note 1: Guaranteed by design

BLOCK DIAGRAM

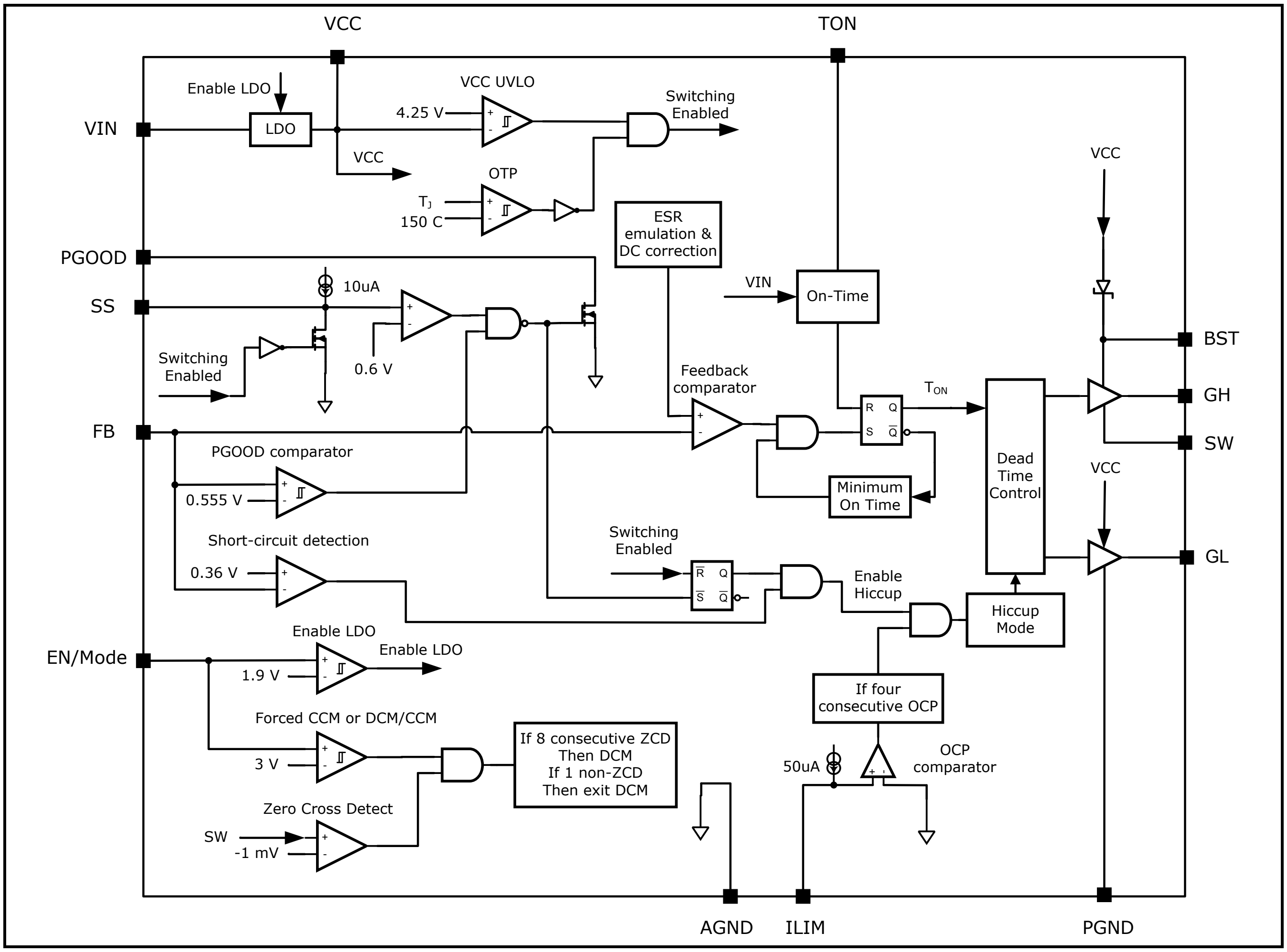


Fig. 2: XRP6141 Block Diagram

PIN ASSIGNMENT

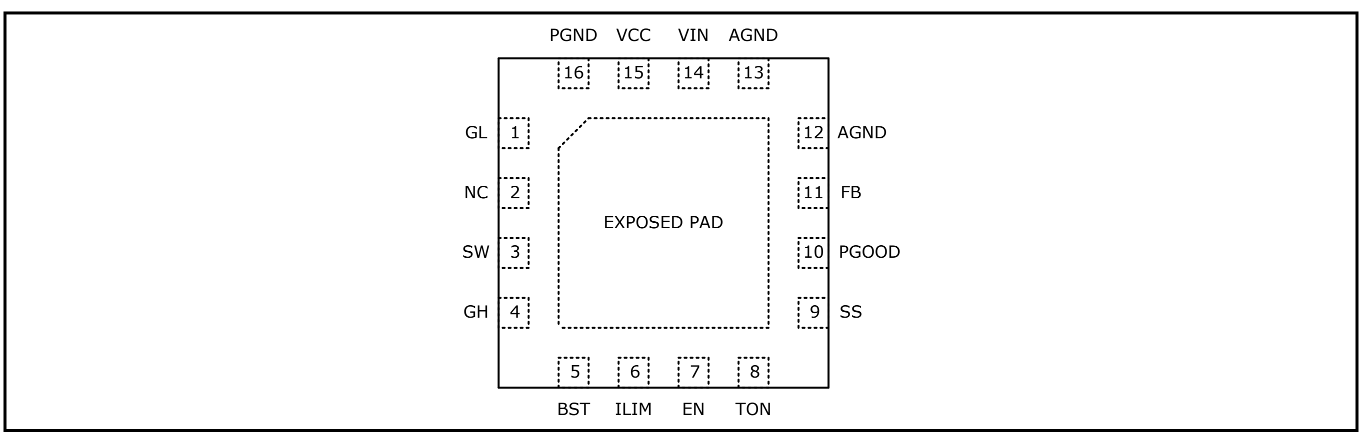


Fig. 3: XRP6141 Pin Assignment

PIN DESCRIPTION

Name	Pin Number	Description
GL	1	Driver output for Low-side N-channel synchronous MOSFET.
NC	2	Internally not connected. Leave this pin floating.
SW	3	Lower supply rail for high-side gate driver GH. Connect this pin to the junction between the two external N-channel MOSFETs.
GH	4	Driver output for high-side N-channel switching MOSFET.
BST	5	High-side driver supply pin. Connect a 0.1uF bootstrap capacitor between BST and SW.
ILIM	6	Over-current protection programming. Connect with a resistor to the Drain of the low-side MOSFET.
EN/MODE	7	Precision enable pin. Pulling this pin above 1.9V will turn the IC on and it will operate in Forced CCM. If the voltage is raised above 3.0V then the IC will operate in DCM or CCM depending on load.
TON	8	Constant on-time programming pin. Connect with a resistor to AGND.
SS	9	Soft-Start pin. Connect an external capacitor between SS and AGND to program the soft-start rate based on the 10uA internal source current.
PGOOD	10	Power-good output. This open-drain output is pulled low when V_{OUT} is outside the regulation.
FB	11	Feedback input to feedback comparator. Connect with a set of resistors to VOUT and GND in order to program V_{OUT}.
AGND	12, 13	Analog ground. Control circuitry of the IC is referenced to this pin.
VIN	14	IC supply input. Provides power to internal LDO.
VCC	15	The output of LDO. For operation using a 5V rail, VCC should be shorted to VIN.
PGND	16	Low side driver ground
Exposed Pad		Thermal pad for heat dissipation. Connect to AGND with a short trace.

ORDERING INFORMATION

Part Number	Temperature Range	Marking	Package	Packing Quantity	Note 1
XRP6141EL-F	$-40°C \le T_J \le +125°C$	6141 YWW XXXX	3x3mm QFN16	Tray	Lead Free and/or Halogen Free
XRP6141ELMTR-F	$-40°C \le T_J \le +125°C$			250/Tape & Reel	
XRP6141ELTR-F	$-40°C \le T_J \le +125°C$			3k/Tape & Reel	
XRP6141EVB	XRP6141 Evaluation Board				

“Y” = Year – “WW” = Work Week – “X” = Lot Number; when applicable.

TYPICAL PERFORMANCE CHARACTERISTICS

All data taken at V_{IN} = 12V, V_{OUT}=1.2V, f=300kHz, T_A = 25°C, unless otherwise specified - Schematic and BOM from Application Information section of this datasheet.

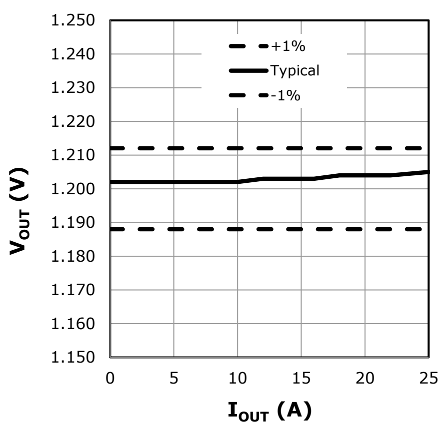


Fig. 4: Load regulation, V_{IN}=12V

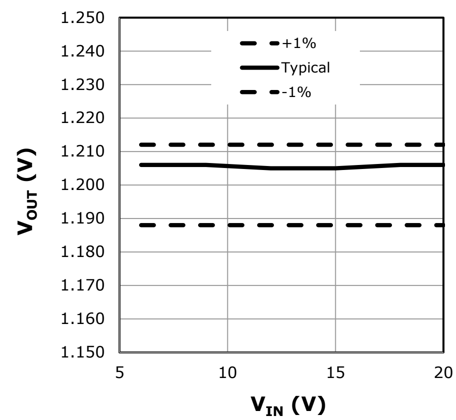


Fig. 5: Line regulation, I_{OUT}=25A

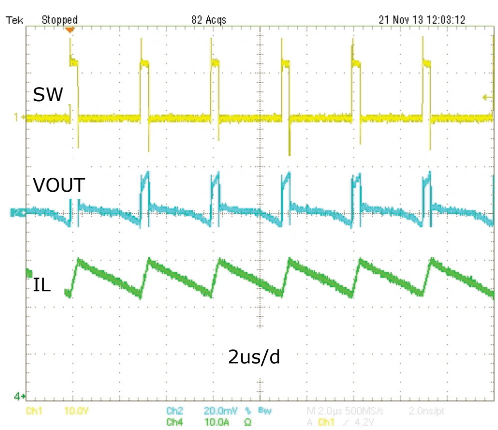


Fig. 6: V_{OUT} ripple is 22mV at 25A, $12V_{IN}$, $1.2V_{OUT}$

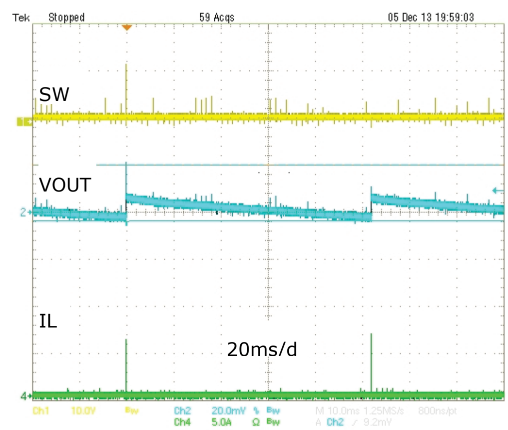


Fig. 7: V_{OUT} ripple is 22mV at 0A, DCM, $12V_{IN}$, $1.2V_{OUT}$

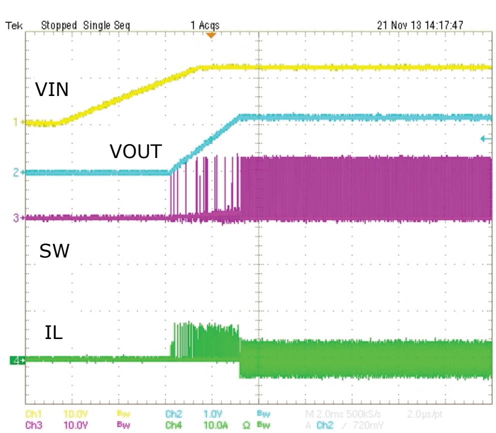


Fig. 8: Powerup, Forced CCM, I_{OUT}=0A

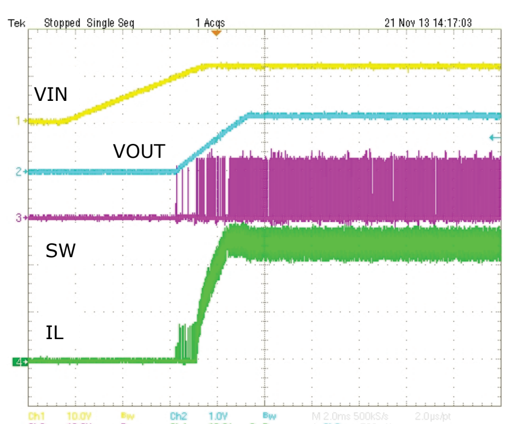


Fig. 9: Powerup, Forced CCM, I_{OUT}=25A

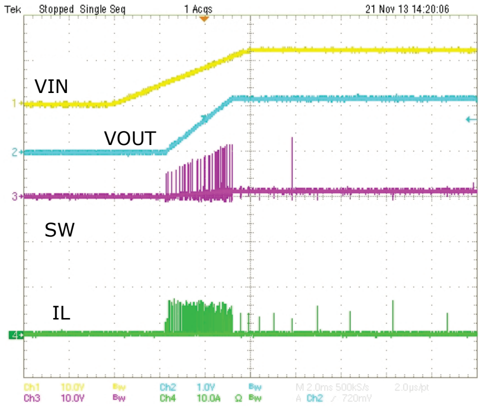


Fig. 10: Powerup, DCM/CCM, I_{OUT}=0A

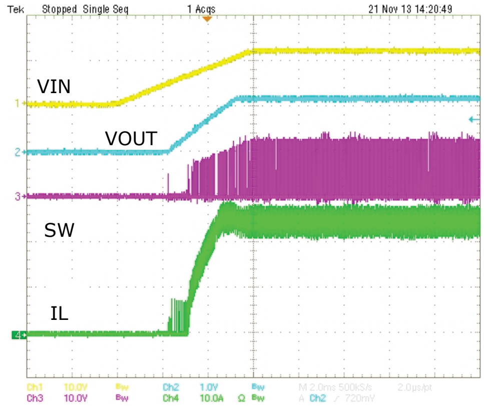


Fig. 11: Powerup, DCM/CCM, I_{OUT}=25A

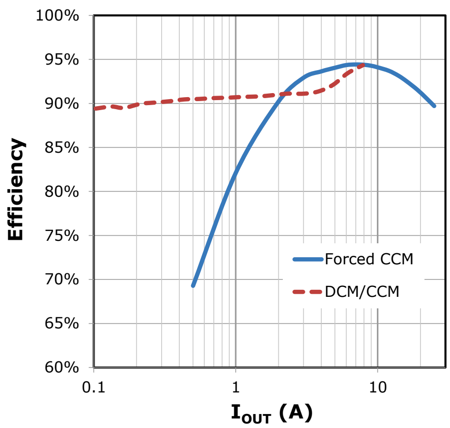


Fig. 12: Efficiency, $5V_{IN}$, $1.8V_{OUT}$, 0.47uH, 300kHz

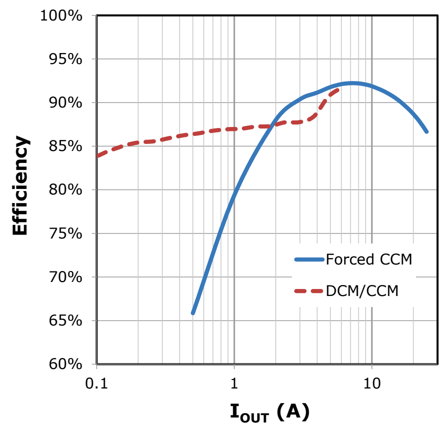


Fig. 13: Efficiency, $5V_{IN}$, $1.2V_{OUT}$, 0.47uH, 300kHz

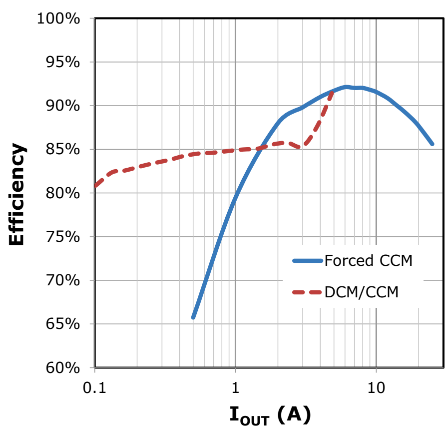


Fig. 14: Efficiency, $5V_{IN}$, $1.0V_{OUT}$, 0.47uH, 300kHz

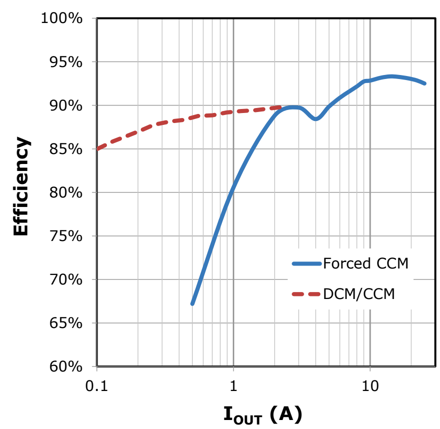


Fig. 15: Efficiency, $12V_{IN}$, $3.3V_{OUT}$, 1uH, 300kHz

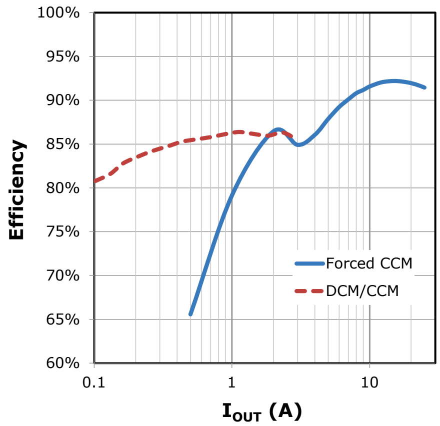


Fig. 16: Efficiency, $12V_{IN}$, $2.5V_{OUT}$, 1uH, 300kHz

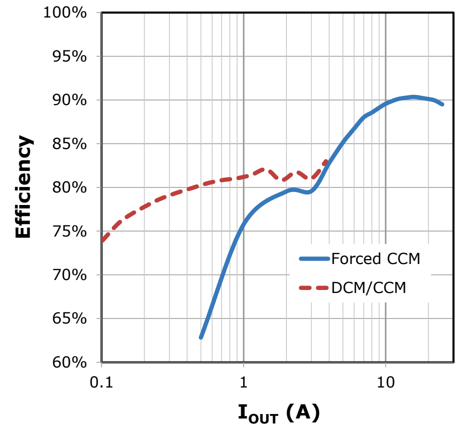


Fig. 17: Efficiency, $12V_{IN}$, $1.8V_{OUT}$, 1uH, 300kHz

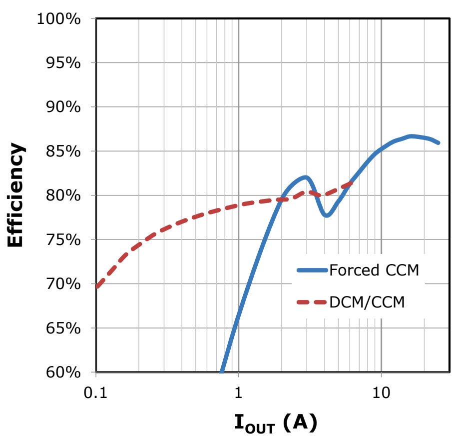


Fig. 18: Efficiency, $12V_{IN}$, $1.2V_{OUT}$, 0.47uH, 300kHz

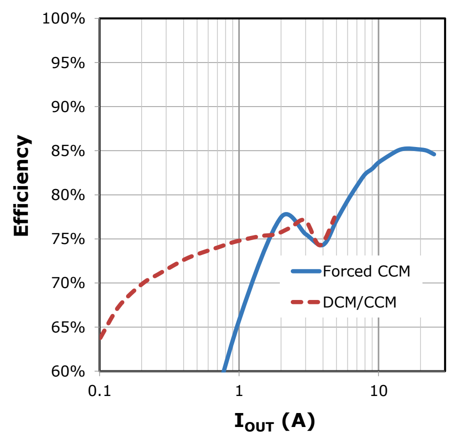


Fig. 19: Efficiency, $12V_{IN}$, $1.0V_{OUT}$, 0.47uH, 300kHz

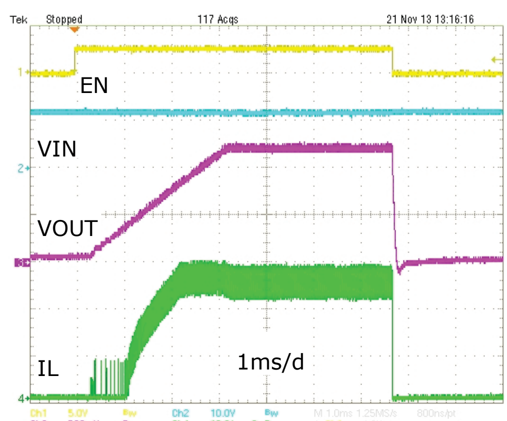


Fig. 20: Enable turn on/turn off, $12V_{IN}$, $1.2V_{OUT}$, 25A

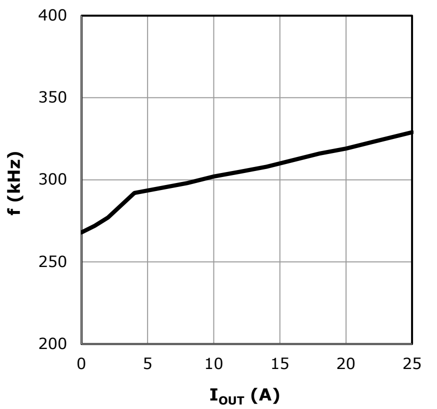


Fig. 22: frequency versu I_{OUT}, Forced CCM

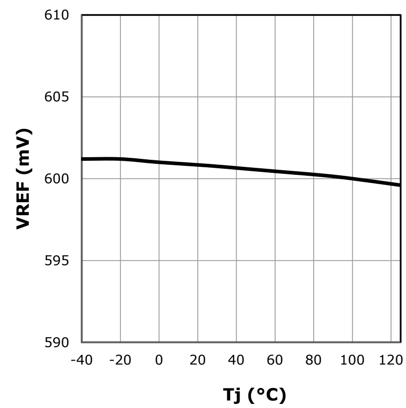


Fig. 23: VREF versus temperature

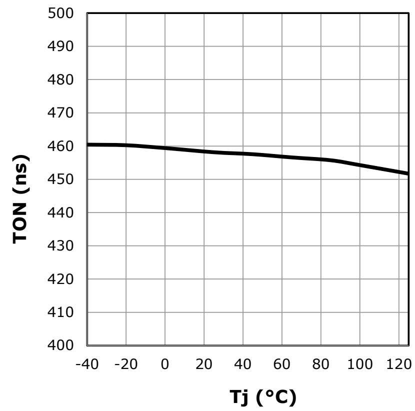


Fig. 24: On-Time versus temperature

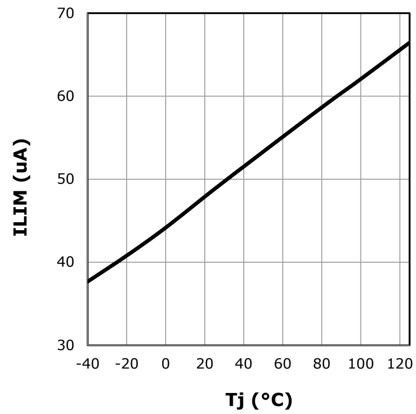


Fig. 25: ILIM versus temperature

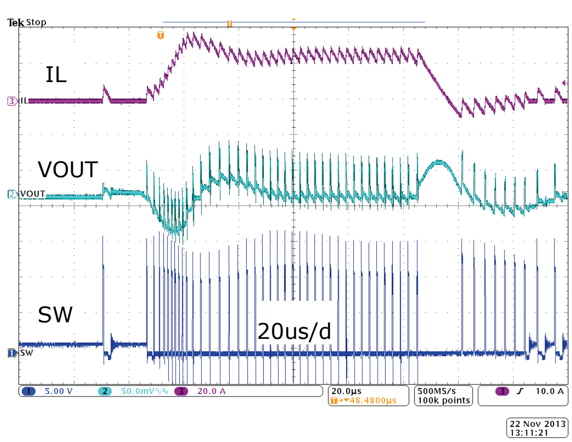


Fig. 26: Load step, DCM/CCM, 0A-25A-0A

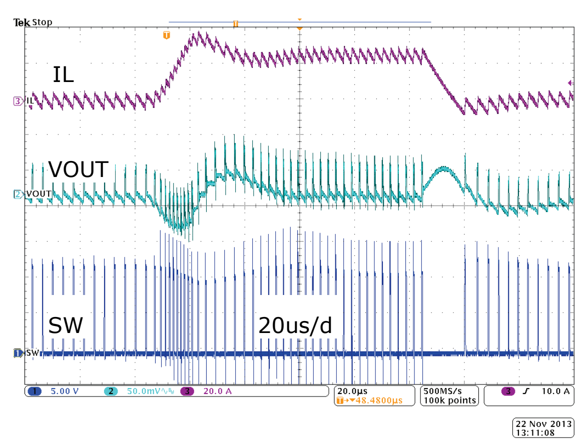


Fig. 27: Load step, Forced CCM, 0A-25A-0A

Detailed Operation

XRP6141 is a synchronous step-down proprietary emulated current-mode Constant On-Time (COT) controller. The on-time, which is programmed via RON, is inversely proportional to VIN and maintains a nearly constant frequency. The emulated current-mode control allows the use of ceramic output capacitors.

Each switching cycle begins with GH signal turning the high-side (switching) FET for a preprogrammed time. At the end of the on-time the high-side FET is turned off and the low-side (synchronous) FET is turned on for a preset minimum time (250ns nominal). This parameter is termed Minimum Off-Time. After the minimum off-time the voltage at the feedback pin FB is compared to an internal voltage ramp at the feedback comparator. When VFB drops below the ramp voltage, the high-side FET is turned on and the cycle repeats. This voltage ramp constitutes an emulated current ramp and makes possible the use of ceramic capacitors, in addition to other capacitor types, for output filtering.

Enable/Mode

EN/MODE pin accepts a tri-level signal that is used to control turn on/off. It also selects between two modes of operation: 'Forced CCM' and 'DCM/CCM'. If EN is pulled below 1.9V the IC shuts down. A voltage between 1.9V and 3V selects the Forced CCM mode, which will run the converter in continuous conduction at all times. A voltage higher than 3V selects the DCM/CCM mode, which will run the converter in discontinuous conduction at light loads. DCM/CCM, which is based on diode emulation, is described below.

Diode Emulation Mode (DCM/CCM)

Diode Emulation Mode is designed to increase the converter efficiency at light loads. Light-load efficiency is increased by preventing negative inductor current. This is achieved by monitoring the inductor current valley (bottom) via SW and turning off the synchronous FET as inductor current I_L approaches zero. I_L is monitored indirectly by monitoring V_{SW} during the synchronous FET conduction (i.e., $V_{SW}=I_L$ x Rds). If V_{SW} does not drop to -1mV the converter operates in continuous conduction as shown in figure 28. If V_{SW} equals -1mV then a zero-crossing is detected (figure 29). Eight consecutive zero-crossings activate the diode emulation mode. Then, on every subsequent switching cycle, GL is turned off when V_{SW} reaches -1mV (figure 30). If IOUT decreases further, discontinuous conduction ensues (figure 30). The constant on-time delivers a fixed energy at the start of each switching cycle. The synchronous FET is turned off when V_{SW} drops to -1mV. Remaining inductor energy is discharged through the FET's body diode. Now, because IOUT is low, it takes longer for VOUT to drop below regulation and trigger a new switching cycle. Hence switching frequency f decreases. This increase the efficiency at light loads.

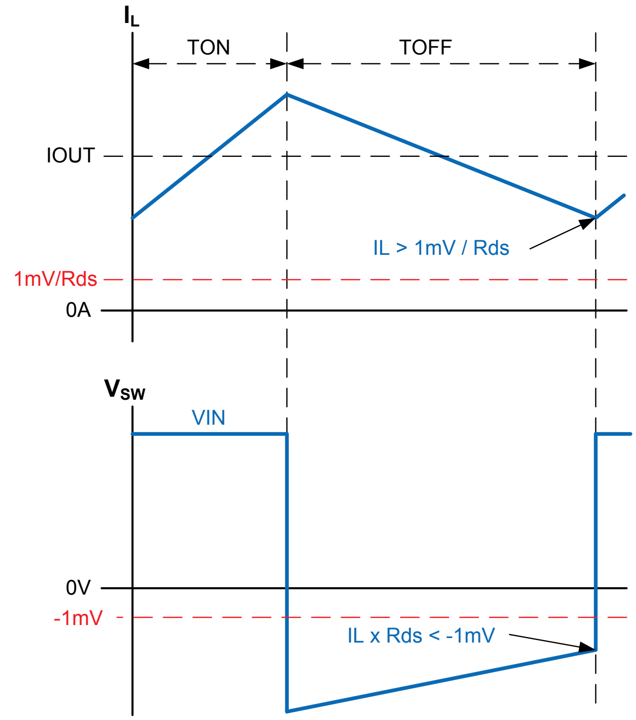


Figure 28. Continuous conduction during diode emulation

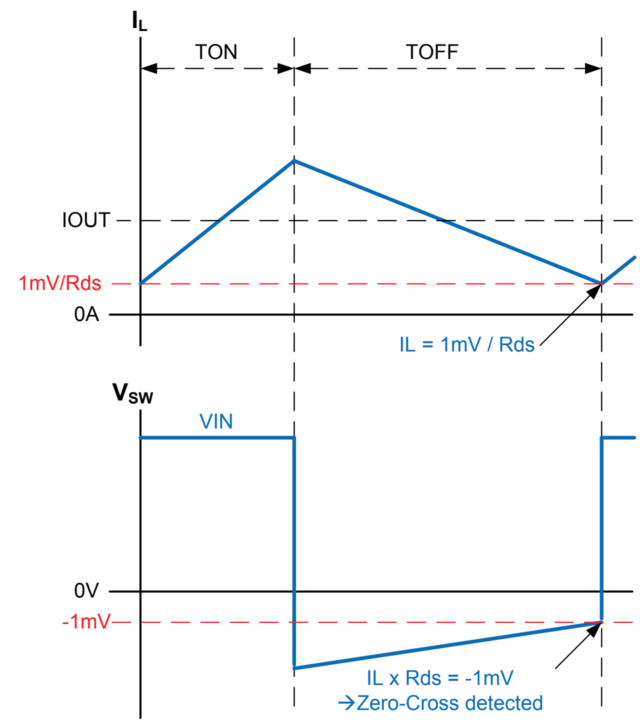


Figure 29. Zero-Crossing detection

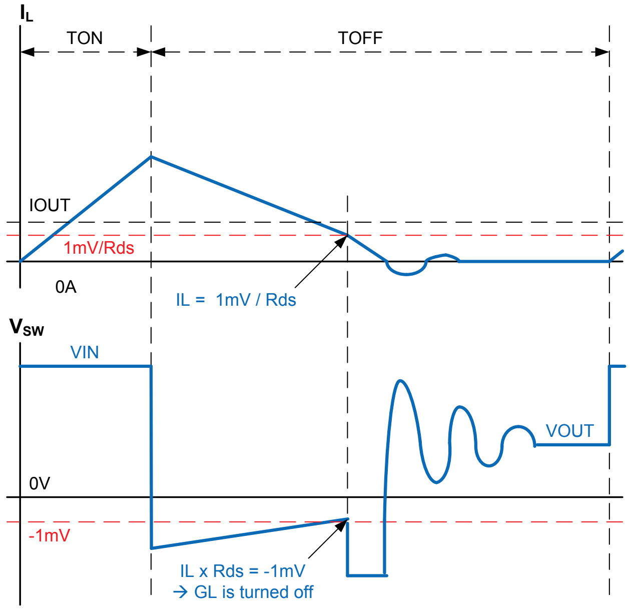


Figure 30. Discontinuous conduction during diode emulation

Programming the On-Time

The on-time TON is programmed via resistor RON according to following equation:

$$TON = \frac{(3.4E-10) \times RON}{VIN}$$

The required TON for a given application is calculated from:

$$TON = \frac{VOUT}{VIN \times f}$$

Note that switching frequency f will increase somewhat, as a function of increasing load current and increasing losses (see figure 22).

Over-Current Protection (OCP)

If load current exceeds the programmed overcurrent IOCP for four consecutive switching cycles, then IC enters hiccup mode of operation. In hiccup the MOSFET gates are turned off for 110ms (hiccup timeout). Following the hiccup timeout a soft-start is attempted. If OCP persists, hiccup timeout will repeat. The IC will remain in hiccup mode until load current is reduced below the programmed IOCP. In order to program overcurrent protection use the following equation:

$$RLIM = \frac{(IOCP \times RDS) + 8mV}{ILIM}$$

Where:

RLIM is resistor value for programming IOCP

IOCP is the overcurrent value to be programmed

RDS is the MOSFET rated on resistance

8mV is the OCP comparator offset

ILIM is the internal current that generates the necessary OCP comparator threshold (use 45uA)

Note that ILIM has a positive temperature coefficient of 0.4%/°C. This is meant to roughly match and compensate for positive temperature coefficient of the synchronous FET. In order for this feature to be effective the temperature rise of the IC should approximately match the temperature rise of the FET.

Short-Circuit Protection (SCP)

If the output voltage drops below 60% of its programmed value, the IC will enter hiccup mode. Hiccup will persist until short-circuit is removed. SCP circuit becomes active after PGOOD asserts high.

Over-Temperature Protection (OTP)

OTP triggers at a nominal die temperature of 150°C. The gate of switching FET and synchronous FET are turned off. When die temperature cools down to 135°C, softstart is initiated and operation resumes.

Programming the Output Voltage

Use an external voltage divider as shown in figure 1 to program the output voltage VOUT.

$$R1 = R2 \times \left(\frac{VOUT}{0.6} - 1\right)$$

R2 recommended range is 2kΩ to 10kΩ.

Programming the Softstart

Place a capacitor CSS between the SS and GND pins to program the softstart. In order to program a softstart time of TSS, calculate the required capacitance CSS from the following equation:

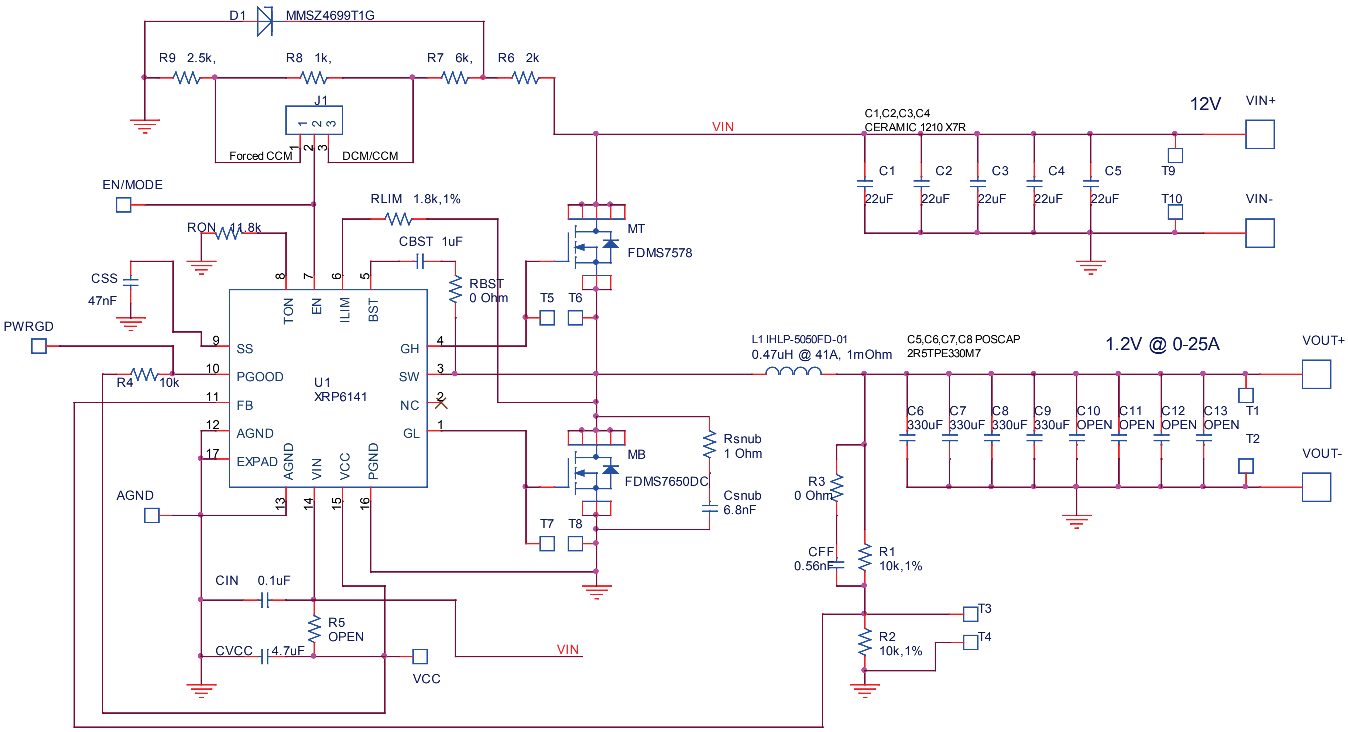
$$CSS = TSS \times \frac{10uA}{0.6V}$$

Feed-Forward Capacitor CFF

A feed-forward capacitor CFF is recommended. CFF provides a low-impedance/high-frequency path for the output voltage ripple to be transmitted to FB. It also helps get an optimum load transient response. Calculate CFF from:

$$CFF = \frac{1}{2 \times \pi \times fs \times 0.1 \times R1}$$

Applications Circuit

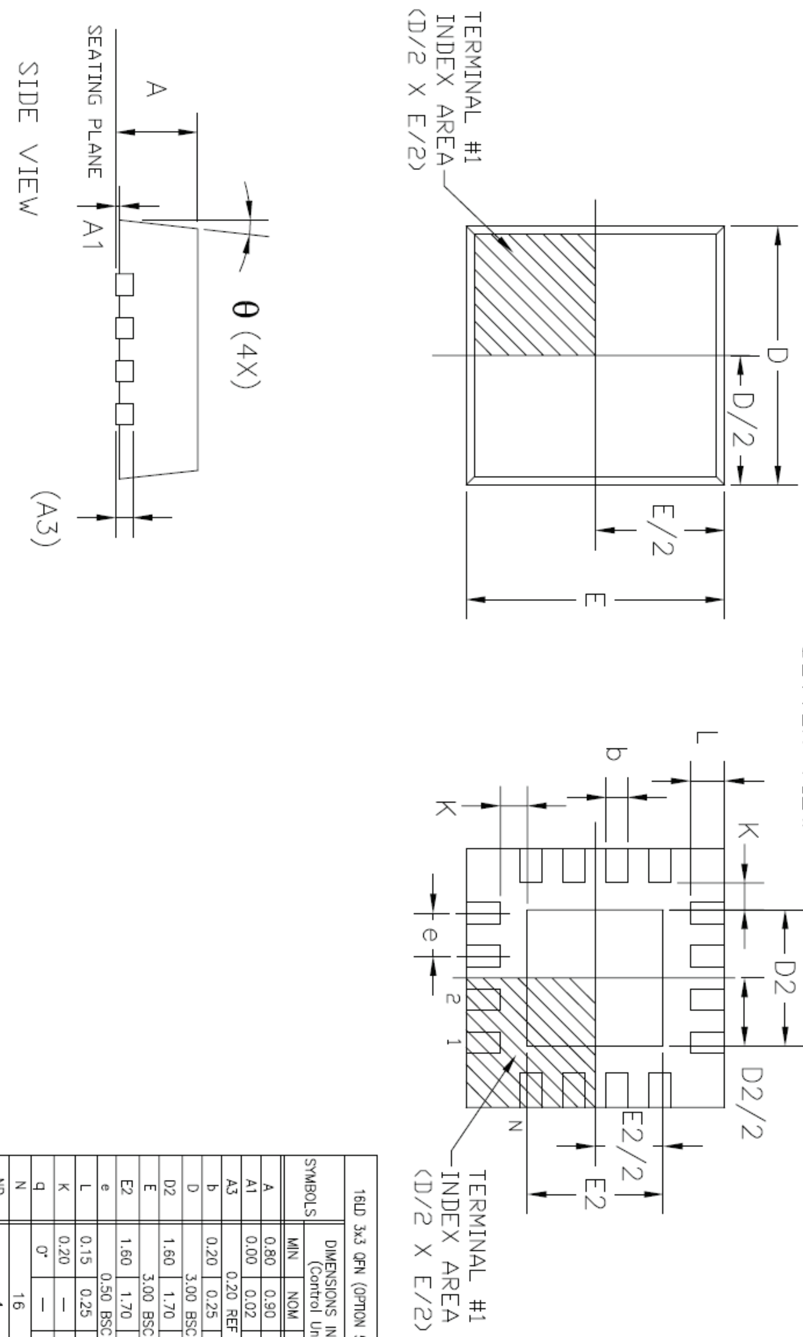


Note: If jumper J1 is set to CCM position, the converter will operate in 'Forced CCM' at VIN=12V(+/-10%). In order to operate in Forced CCM over a wider VIN range, remove Jumper and apply an auxilary voltage in the 1.9V-3V range to the EN/MODE test point.

If jumper J1 is set to DCM/CCM position the converter will operate at DCM or CCM, depending on load, at VIN=12V(+/-10%). In order to operate in DCM/CCM over a wider VIN range, remove Jumper and apply an auxilary voltage in the 3.1V-5V range to the EN/MODE test point.

PACKAGE SPECIFICATION

16 PIN 3X3 QFN



16LD 3x3 QFN (OPTION 5) JEDEC MO-220 Variation VEED

SYMBOLS	DIMENSIONS IN MM (Control Unit)			DIMENSIONS IN INCH (Reference Unit)		
	MIN	NOM	MAX	MIN	NOM	MAX
A	0.80	0.90	1.00	0.032	0.036	0.039
A1	0.00	0.02	0.05	0.000	0.001	0.002
A3	0.20 REF			0.008 REF		
b	0.20	0.25	0.30	0.008	0.010	0.012
D	3.00 BSC			0.118 BSC		
D2	1.60	1.70	1.80	0.063	0.067	0.071
E	3.00 BSC			0.118 BSC		
E2	1.60	1.70	1.80	0.063	0.067	0.071
e	0.50 BSC			0.020 BSC		
L	0.15	0.25	0.35	0.005	0.009	0.013
K	0.20	—	—	0.008	—	—
q	0°	—	14°	0°	—	14°
N	16			16		
ND	4			4		
NE	4			4		

REVISION HISTORY

REV.	DESCRIPTION	DATE	APP'D
A	DRAWING ORIGINATION.	12/16/13	AD

A New Direction in Mixed-Signal	EXAR CORPORATION
	16 PIN 3x3 QFN PACKAGE OUTLINE (OPTION 5)
Packaging Approval:	Drawing No: POD-00000042
By: AD Date: 12/16/13	Revision: A Sheet: 1 OF 1

ECN: 1351-04 12/16/2013

REVISION HISTORY

Revision	Date	Description
1.0.0	12/16/2013	Initial release
1.0.1	12/20/2013	Specification improvement

FOR FURTHER ASSISTANCE

Email: customersupport@exar.com
powertechsupport@exar.com

Exar Technical Documentation: http://www.exar.com/TechDoc/default.aspx?

EXAR CORPORATION

HEADQUARTERS AND SALES OFFICES

48720 Kato Road
Fremont, CA 94538 – USA
Tel.: +1 (510) 668-7000
Fax: +1 (510) 668-7030
www.exar.com

NOTICE