Demonstration System EPC9151 Quick Start Guide

18–60 V Input, 12 V, 25 A Output (Buck)

12–15 V Input, 48 V, 5.5 A Output (Boost)

300 W 1/16 th Brick Evaluation Module

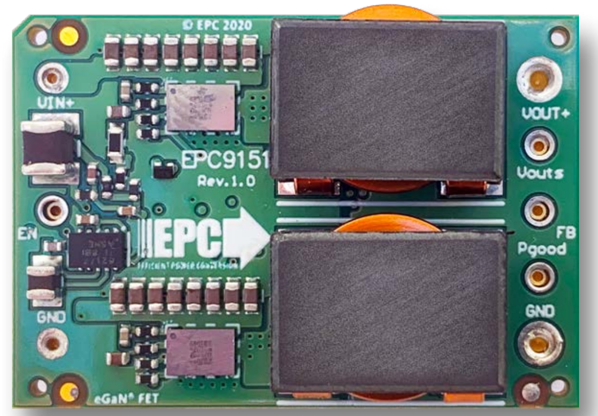
Revision 1.0

EFFICIENT POWER CONVERSION

DESCRIPTION

The EPC9151 $^{1}/_{16}$th brick evaluation power module is designed for 48 V to/from 12 V DC-DC applications. It features the EPC2152 ePower™ stage – enhancement mode eGaN® field effect transistors (FETs) with integrated gate drivers, as well as the Microchip dsPIC33CK32MP102 16-bit digital controller. Other features include:

- High efficiency: 95% @ 12 V/25 A output (buck)
  95% @ 48 V/5.5 A output (boost)
- Dimension: 33 mm x 22.9 mm x 9 mm (1.30 in. x 0.90 in. x 0.35 in.)
- Industry standard footprint and pinout
- Power good output
- Constant switching frequency: 500 kHz
- Remote output voltage sense (buck)
- Re-programmable – Average current mode control (default)
- Fault protection:
  - o Input undervoltage
  - o Input overvoltage
  - o Regulation error
  - o Inductor overcurrent



EPC9151 top view

EPC9151 bottom view

REGULATORY INFORMATION

This power module is for evaluation purposes only. It is not a full-featured power module and cannot be used in final products. No EMI test was conducted. It is not FCC approved.

FIRMWARE UPDATES

The module is programmed as a Buck converter by default. To change to Boost converter, please re-program the module with the boost firmware. Using the incorrect firmware could result in damage.

Every effort has been made to ensure all control features function as specified. It may be necessary to provide updates to the firmware. Please check the EPC and Microchip websites for the latest firmware updates.

Table 1: Maximum Ratings

Symbol	Parameter	Conditions	Min	Max	Units
V_{IN}	Input voltage	Buck		65	V
		Boost		17	
I_{OUT}	Output current	Buck		25	A
		Boost		5.5	
T_C	Operating temperature	Measured at FET case as indicated in thermal measurement figure, airflow 1700 LFM		100	°C

Table 2: Electrical Characteristics

Symbol	Parameter	Conditions	Min	Typ	Max	Units
V_{IN}	Input voltage	Buck	18	48	60	
		Boost, during operation	11.3	12	15	
		Boost, start up	12.3	12.5	15	
$V_{IN,on}$	Input UVLO turn on voltage	Buck		18		
		Boost		12.3		V
$V_{IN,off}$	Input UVLO turn off voltage	Buck		17.5		
		Boost		11.3		
V_{OUT}	Output voltage	Buck	5	12	15	
		Boost	20	48	50	
C_{OUT}	External capacitance load	Buck	200		550	uF
		Boost	47			
$t_{OUT,rise}$	Output voltage rise time			100		ms
ΔV_{OUT}	Output voltage ripple	Buck, I_{OUT} = 25 A, C_{OUT} = 200 µF		100		mV
		Boost, I_{OUT} = 5.5 A, C_{OUT} = 47 µF		600		
I_{OUT}	Output current	Buck	0		25	
		Boost	0		5.5	A
$I_{OUT,limit}$	Output current limit threshold	Buck	26		27	
		Boost	6		6.8	
f_s	Switching frequency			500		kHz
On/off control input logic						
V_{on}/V_{off}	Function not available	Not implemented	0		3.3	V
Power good output logic						
P_{good}	Logic high (in regulation)		2.6	3.1	3.3	V
P_{good}	Logic low (not regulated)		0	0.25	0.7	

TYPICAL EFFICIENCY AND POWER LOSS

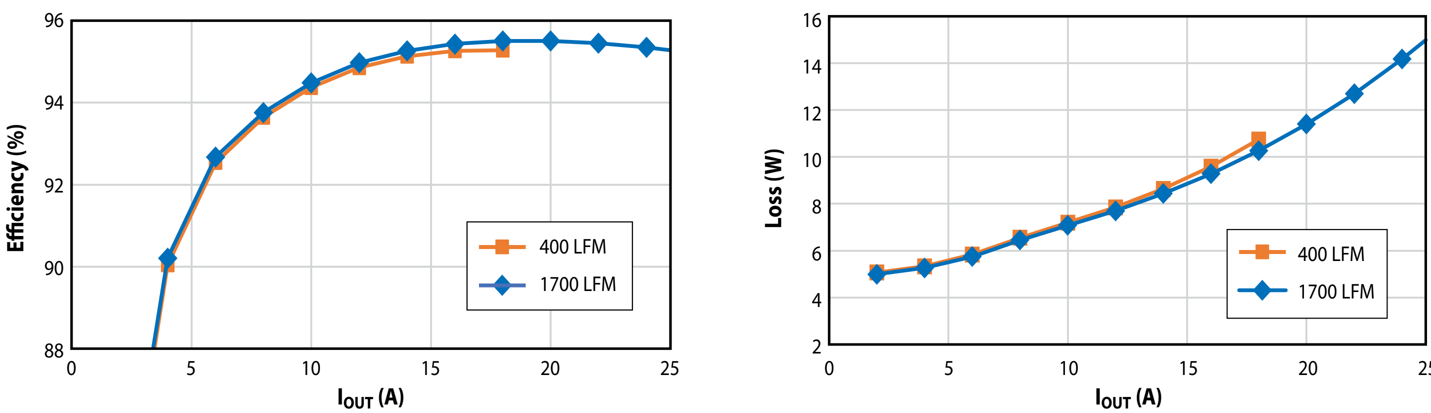


Figure 1. 48 V input, 12 V output (Buck)

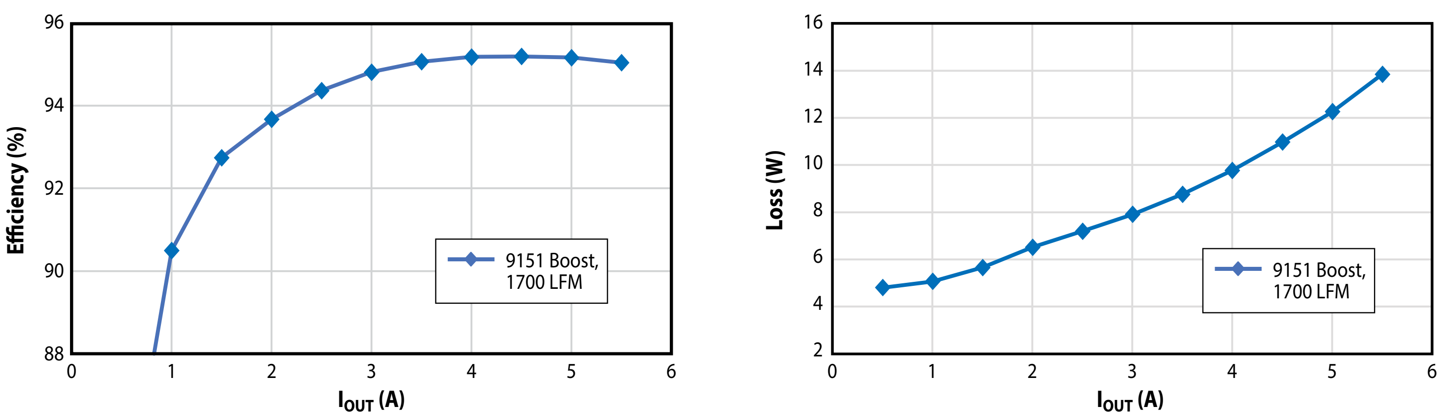


Figure 2. 12 V input, 48 V output (Boost)

ELECTRICAL PERFORMANCE

Typical output voltage ripple

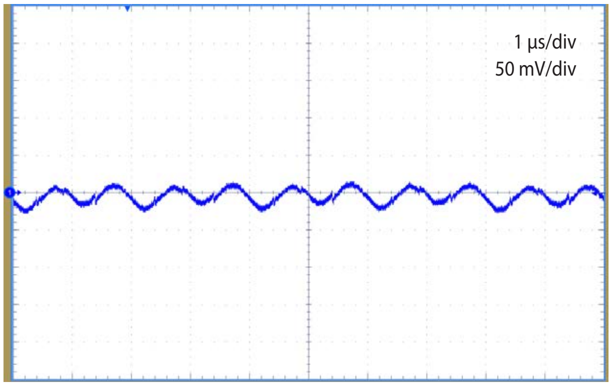


Figure 3: V_{IN} = 48 V, V_{OUT} = 12 V, I_{OUT} = 25 A (Buck)

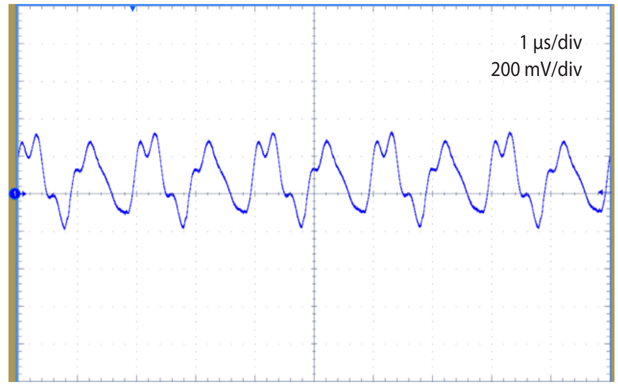


Figure 4: V_{IN} = 12 V, V_{OUT} = 48 V, I_{OUT} = 5.5 A (Boost)

Typical transient response

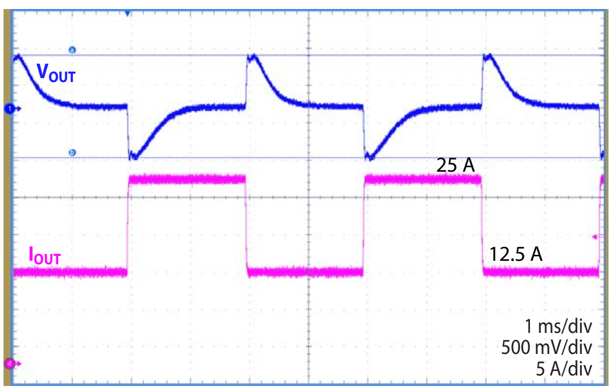


Figure 5: V_{IN} = 48 V, V_{OUT} = 12 V, output 50% (12.5 A) to 100% (25 A), 250 Hz transitions (Buck)

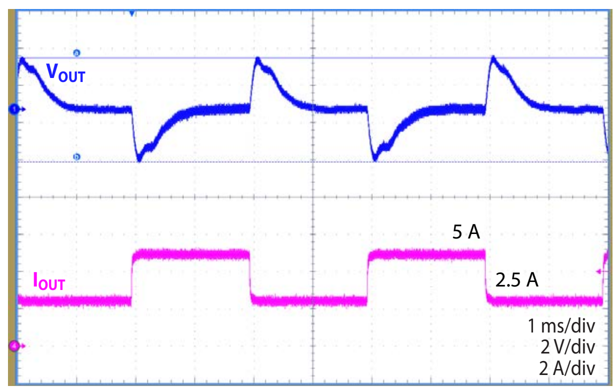


Figure 6: V_{IN} = 12 V, V_{OUT} = 48 V, output 45% (2.5 A) to 90% (5 A), 250 Hz transitions (Boost)

Startup waveform

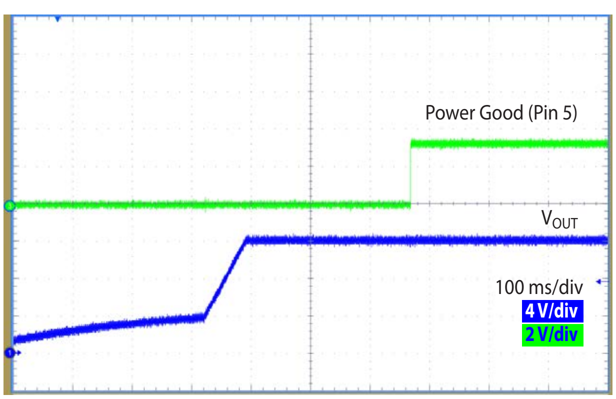


Figure 7: V_{IN} = 48 V (Buck)

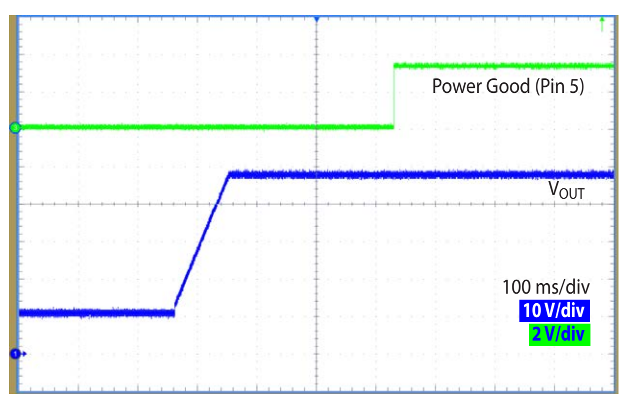


Figure 8: V_{IN} = 12 V (Boost)

ELECTRICAL PERFORMANCE *(continued)*

Typical load regulation

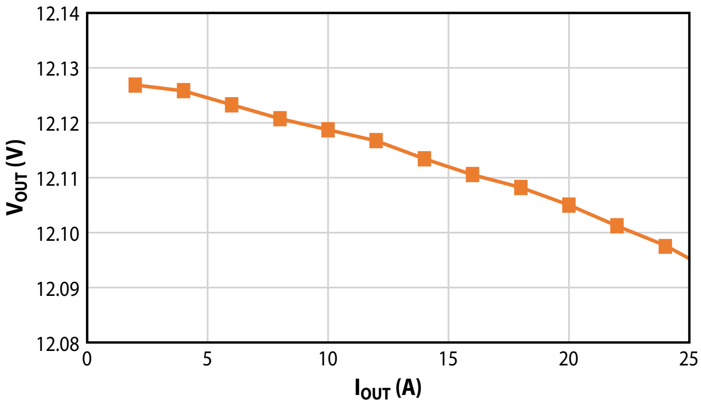


Figure 9: V_{IN} = 48 V, V_{OUT} = 12 V (Buck)

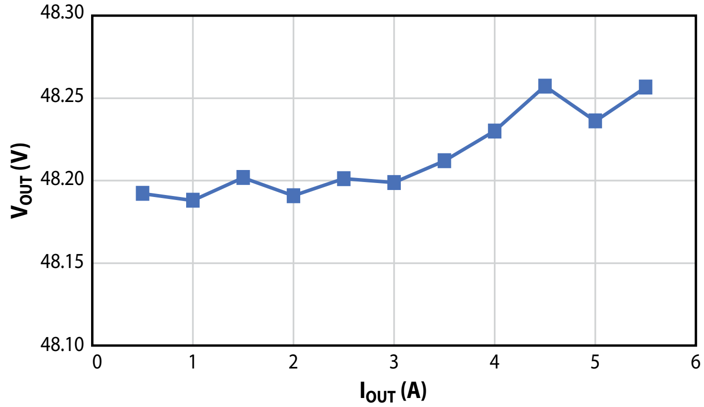


Figure 10: V_{IN} = 12 V, V_{OUT} = 48 V (Boost)

Temperature vs. output current

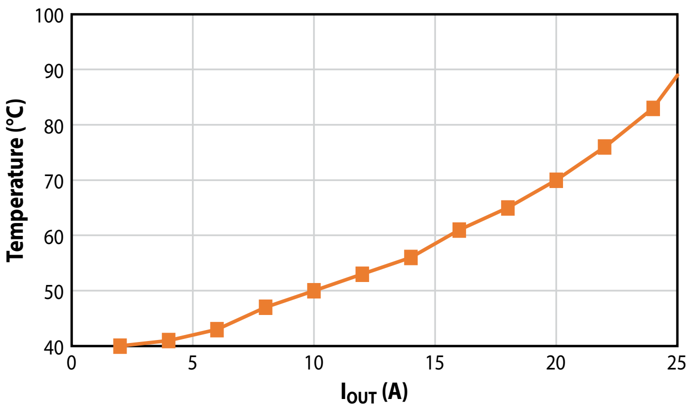


Figure 11: V_{IN} = 48 V, V_{OUT} = 12 V, 1700 LFM, Buck

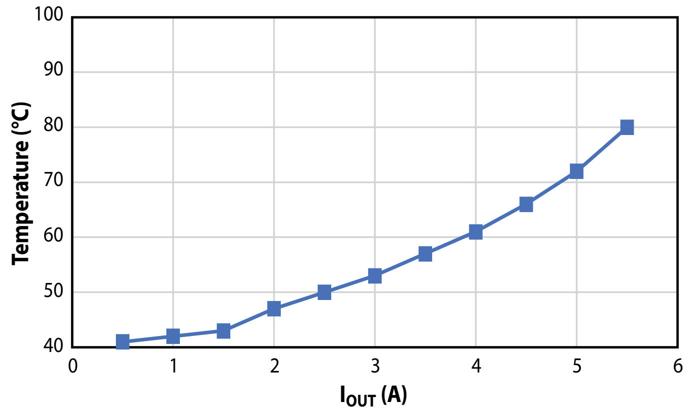


Figure 12: V_{IN} = 12 V, V_{OUT} = 48 V, 1700 LFM, Boost

OPERATING CONSIDERATIONS

Buck/Boost Modes

The module is programmed with Buck mode by default. To operate as a Boost converter, please download the firmware for Boost mode and re-program the module. In Boost mode, input voltage (12 V) is supplied to the Vout+ pin, and the output is at the Vin+ pin.

Output capacitance

Minimum external output capacitance of 200 µF is required for stability. The maximum capacitance tested is 550 µF. The EPC9531 test fixture includes this extra capacitance.

Input capacitance

To minimize the impact from the input voltage feeding line, low-ESR capacitors should be located at the input to the module. It is recommended that a 33 µF–100 µF input capacitor be placed near the module. This will also be the external output capacitance in boost mode.

Over-current protection

If the load current exceeds a pre-determined maximum setpoint, this condition will be regarded as a fault condition and the module will shut down. The module will then attempt to restart after 2 seconds. This shut down and restart cycle will continue until the over-current condition clears.

Remote On/Off

This feature is not implemented for this module. Please leave EN pin floating.

Remote sense

For Buck mode only: remote sense can compensate for output voltage distribution drops by sensing the actual output voltage at the point of load. The maximum voltage allowed between the output and sense pins is 5% of the output voltage (0.6 V for 12 V output). If the remote sense feature is not used, the pin can be either left floating or connected to Vout+.

Power good

This module features a power good signal with 3.3 V logic. This signal will be logic high when the output voltage is regulated to +/- 10% of the set point; and logic low for all other conditions. The maximum sink/source current on this pin is 6 mA. If the power good feature is not used, the pin should be left floating.

Output voltage trim (adjustment)

For Buck mode only: the output voltage of this module can be trimmed (adjusted) by connecting an external resistor between the Trim pin and Vout- (GND) pin. The new output voltage can be calculated as follows:

$$V_{OUT} = V_{FB} R_{FB1} \left(\frac{1}{R_{FB2}} + \frac{1}{R_1} \right) + V_{FB}$$

For this design, V_{FB} is 2.5 V, R_{FB1} is 18 kΩ, R_{FB2} is 4.75 kΩ, therefore

$$V_{OUT} = 12 + \frac{45}{R_1\ [k\Omega]}$$

The maximum trim voltage is 1 V using this method. It is recommended to re-program the controller to further change the output voltage set point.

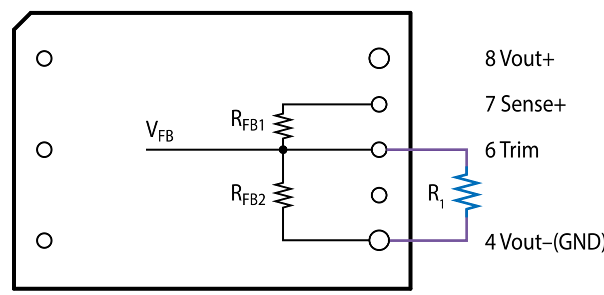


Figure 13. External resistor connection for output voltage trim adjust.

CONTROLLER

The EPC9151 $^1/_{16}$th brick evaluation power module features a Microchip dsPIC33CK32MP102 Digital Signal Controller (DSC). This 100 MHz single core device is equipped with dedicated peripheral modules for Switched-Mode Power Supply (SMPS) applications, such as a feature-rich 4-channel (8x output), 250 ps resolution pulse-width modulation (PWM) logic, three 3.5 Msps Analog-To-Digital Converters (ADC), three 15 ns propagation delay analog comparators with integrated Digital-To-Analog Converters (DAC) supporting ramp signal generation, three operational amplifiers as well as Digital Signal Processing (DSP) core with tightly coupled data paths for high-performance real-time control applications. The device used is the smallest derivative of the dsPIC33CK single core and dsPIC33CH dual core DSC families. The device used in this design comes in a 28 pin 6x6 mm UQFN package, specified for ambient temperatures from -40 to +125° C. Other packages including a 28 pin UQFN package with only 4x4 mm are available.

The dsPIC33CK device is used to drive and control the converter in a fully digital fashion where the feedback loops are implemented and executed in software. Migrating control loop execution from analog circuits to embedded software enhances the flexibility in terms of applied control laws as well as making modifications to the feedback loop and control signals during runtime, optimizing control schemes and adapting control accuracy and performance to most recent operating conditions. As a result, digital control allows users to tailor the behavior of the converter to application specific requirements without the need for modifying hardware.

There are two firmware versions available for the EPC9151 $^1/_{16}$th brick evaluation power module in buck mode: average current mode control (ACMC) and adaptive voltage mode control (AVMC). For the boost mode, only ACMC is available.

- **Conventional, Robust Average Current Mode Control (ACMC) (*figure 14*):** With this firmware the power converter is controlled by one outer voltage loop providing a shared reference to two independent inner average current loops controlling the phase current of each converter phase. This conventional approach ensures proper current balancing between both phases of this interleaved converter, operating 180° out of phase to minimize the input current ripple and filtering. The inner current loops are adjusted to average cross-over frequencies of 10 kHz. To balance the current reference perturbation of the inner current loops, the outer voltage loop has been adjusted to an average cross-over frequency of 2 kHz, which determines the overall response time of the converter.

For Buck mode only:

- **Adaptive Type IV Voltage Mode Control (AVMC) with featuring Adaptive Gain Control (AGC) and Phase Current Balancing PWM Steering (*figure 15*):** The second, alternative firmware is tailored to intermediate bus converter module applications in power distribution networks (PDN). The major focus of this firmware lies on reducing PDN segment decoupling capacitance by maximizing the control bandwidth and the output impedance tuning capabilities, enhancing system robustness while minimizing cost.

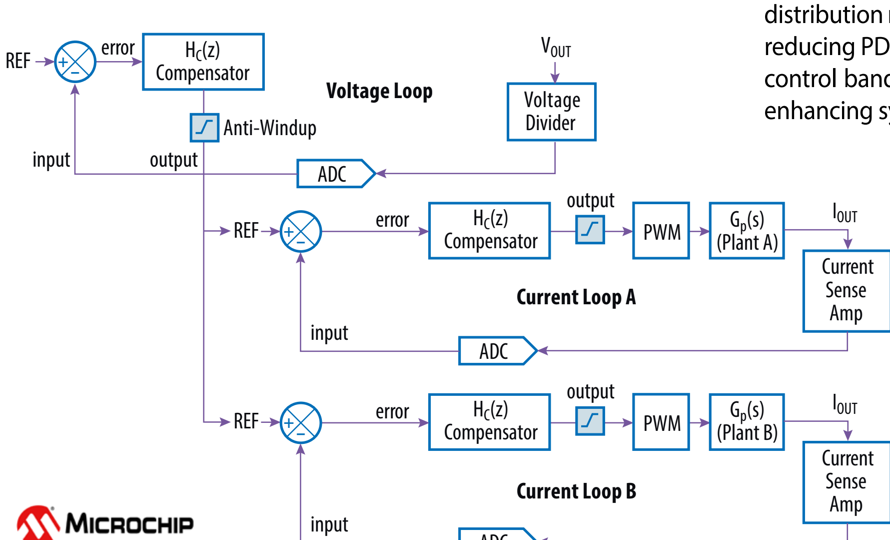


Figure 14. Interleaved buck converter average current mode control

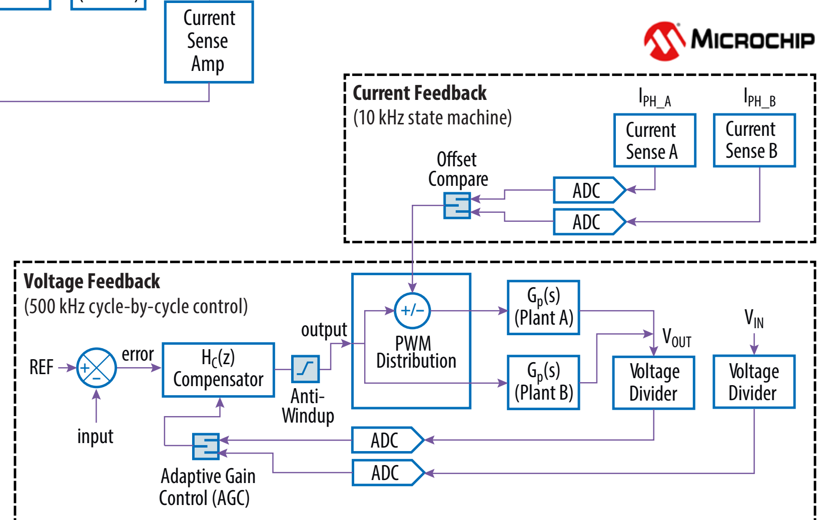


Figure 15. Interleaved buck converter advanced voltage mode control

PROGRAMMING

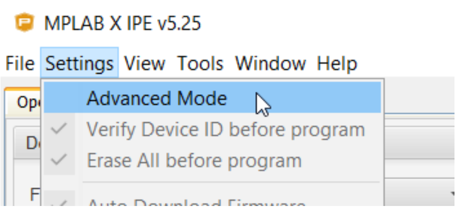
The Microchip dsPIC33CK controller can be re-programmed using the in-circuit serial programming port (ICSP) available on the RJ-11 programming interface. It supports all of Microchip's in-circuit programmers/debuggers, such as MPLAB® ICD4, MPLAB® REAL ICE or MPLAB® PICkit4 and previous derivatives.

Development tools: https://www.microchip.com/development-tools

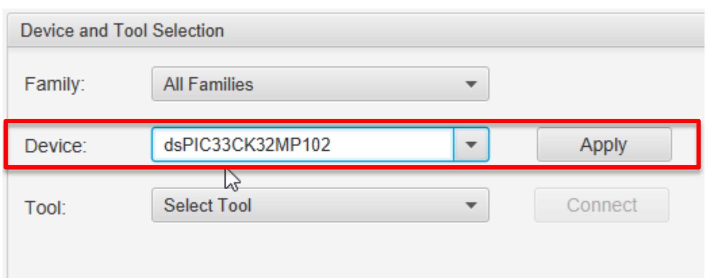
Programming with HEX file

Download the latest MPLAB IPE from Microchip website and follow the steps below:
https://www.microchip.com/mplab/mplab-integrated-programming-environment

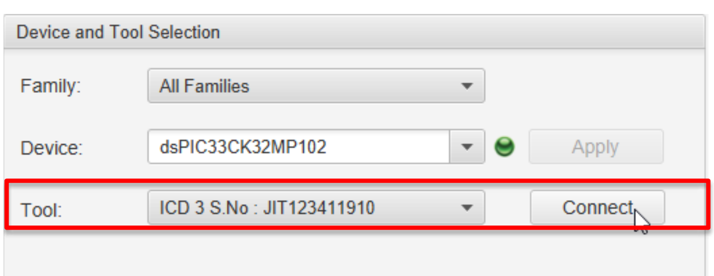
1 Enable Advanced Mode:



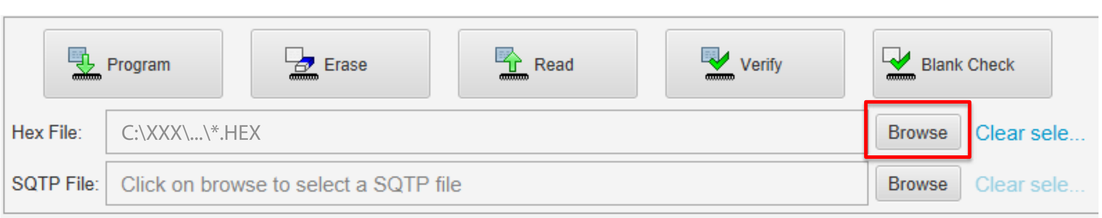
2 Select Device: dsPIC33CK32MP102 and then apply:



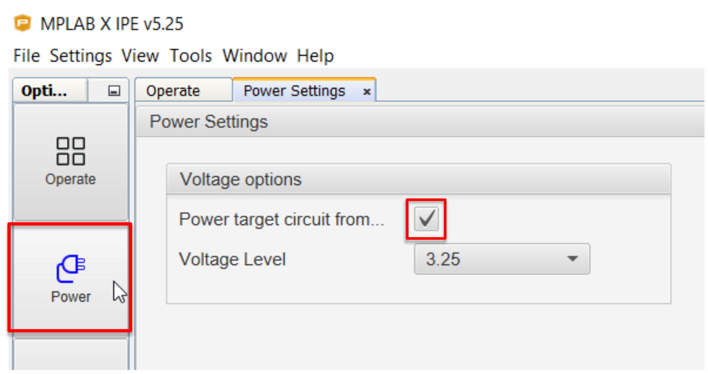
3 Select programming tool and then connect:



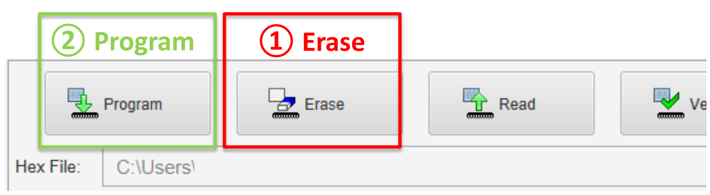
4 Click 'Browse' to select the provided .hex file:



Optional: Enable 'Power target circuit from programming tool' from left panel 'power' tab so that no additional power supply is necessary during programming:



5 Erase device, and then program device:



MECHNICAL SPECIFICATIONS

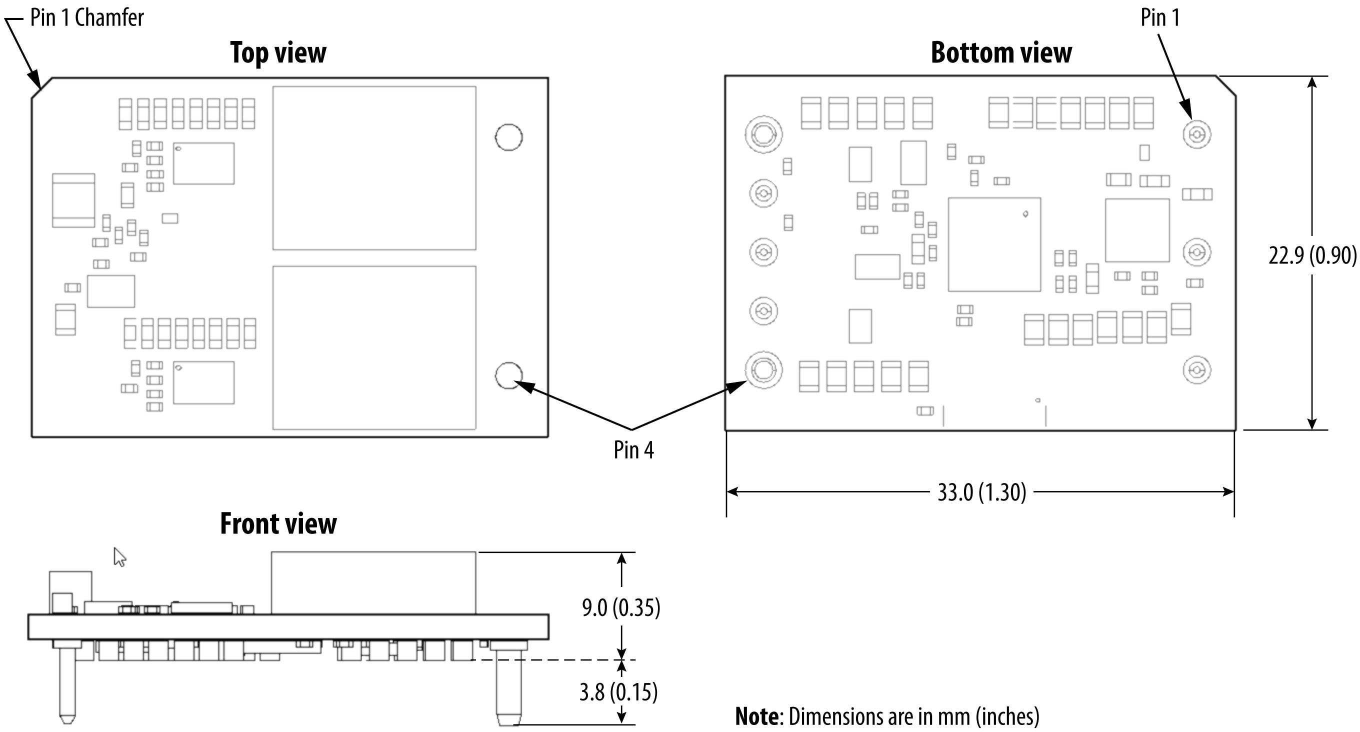


Figure 16. EPC9151 mechanical dimensions

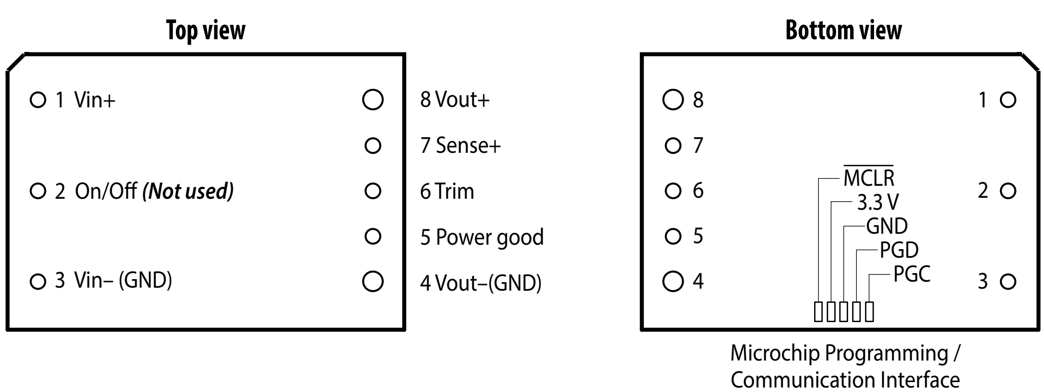


Figure 17. Pin assignment

THERMAL MANAGEMENT

Thermal management is very important to ensure proper and reliable operation. Sufficient cooling is required for this module to operate in the full specified output current range. Forced air of 1700 LFM is used for specification testing.

Heatsink or heat spreader can also be used.

The hot spots are the GaN ICs (U1 and U2) as shown in figure 18.

Thermal derating

Without sufficient cooling, the output current capability is reduced. The module temperature should be monitored to ensure the maximum temperature does not exceed the rating. Especially when the input voltage is higher than 48 V, the maximum output current is reduced.

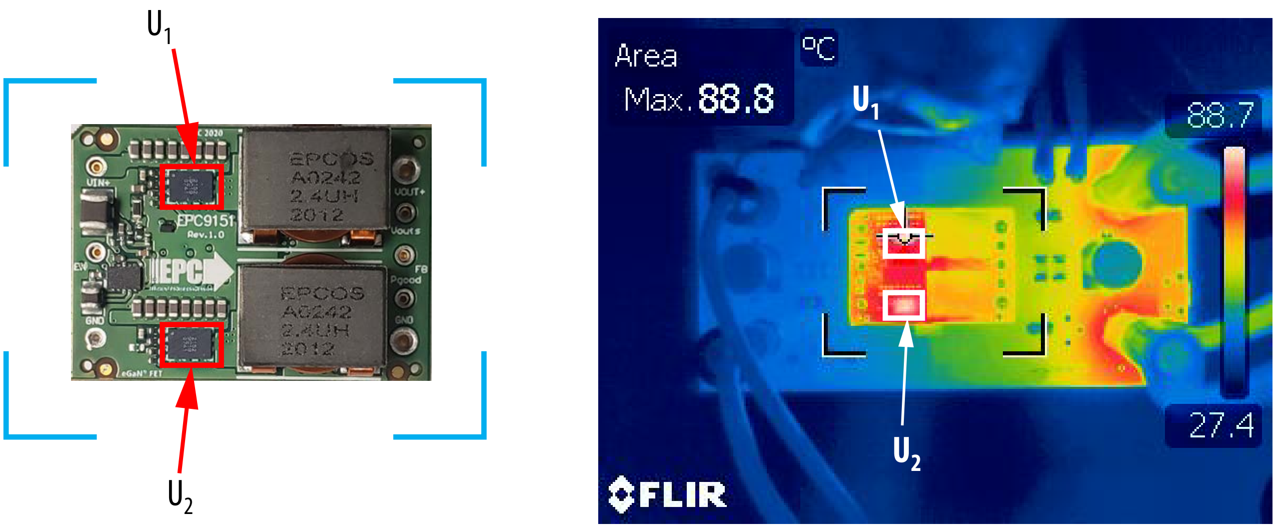


Figure 18. V_{IN} = 48 V, V_{OUT} = 12 V, 1700 LFM forced air cooling

Table 3: Bill of Materials

Item	Qty	Reference	Part Description	Manufacturer	Part #
1	14	C1, C2, C3, C9, C11, C15, C16, C19, C21, C26, C31, C35, C48, C51	1 µF, 100 V	TDK	C2012X7S2A105M125AB
2	10	C5, C6, C7, C8, C10, C27, C28, C29, C30, C37	22 µF, 25 V	Murata	GRT21BR61E226ME13L
3	16	C12, C13, C20, C23, C24, C25, C32, C36, C40, C41, C42, C43, C44, C45, C46, C47	220 nF, 100 V	Taiyo Yuden	HMK107C7224
4	7	C14, C22, C38, C49, C50, C62, C65	0.1 µF, 25 V	Yageo	CC0402KRX7R8BB104
5	2	C17, C18	2.2 µF, 25 V	Murata	GRM155R61E225KE11D
6	2	C33, C34	1 nF, 25 V	Murata	GRM1555C1E102JA01D
7	1	C39	10 nF, 25 V	Kemet	C0402C103K4RECAUTO
8	2	C60, C63	51pF, 50 V	Murata	GRM1555C1H510JA01D
9	2	C61, C64	2.2 µF, 25 V	Murata	GRM155R61E225ME15D
10	2	C67, C69	10 nF, 50 V	Murata	GRM155R71H103KA88D
11	1	C68	220pF, 50 V	Kemet	C0402C221K5RACTU
12	1	C90	0.22 µF, 100 V	Taiyo Yuden	HMK107C7224KAHTE
13	1	C91	1 µF, 16 V	TDK	C1005X6S1C105K050BC
14	1	C92	10 nF, 100 V	TDK	C1005X7S2A103K050BB
15	1	C93	10 µF, 16 V	Murata	GRM188R61C106KAALD
16	1	C94	3300pF, 100 V	TDK	CGA2B3X7S2A332M050BB
17	1	C95	0.1 µF, 50 V	Murata	GRM155R71H104KE14J
18	2	C96, C98	1 µF, 25 V	Murata	GRT155R61E105ME01D
19	1	C97	22 µF, 6.3 V	Samsung	CL05A226MQ5N6J8
20	2	D1, D2	80 V, 125 mA	Diodes	1N4448HLP-7
21	6	J1, J2, TP1, TP2, TP9, TP10	.040 dia pin	Mill-Max	3102-1-00-21-00-00-08-0
22	1	J3	1 mm Header	Molex	5013310507
23	2	J4, J5	.062 dia pin	Mill-Max	3144-1-00-15-00-00-08-0
24	2	L1, L2	2.4 µH	TDK	B82559A0242A013
25	1	L90	220 µH 190 mA	Taiyo Yuden	CBC3225T221KR
26	1	L91	10 µH	Taiyo Yuden	CBC2016T100M
27	1	R1	6.8 k	Yageo	RC0402JR-076K8L
28	4	R2, R3, R4, R5	10 Ω	Panasonic	ERJ-2RKF10R0X
29	1	R20	20 Ω	Yageo	RC0402FR-0720RL
30	1	R21	110 k	Panasonic	RC0603FR-07110KL
31	1	R22	4.87 k	Panasonic	ERA-2AEB4871X
32	1	R23	18 k	Panasonic	ERA-2AEB183X
33	1	R24	4.75 k	Panasonic	ERA-2AEB4751X
34	1	R26	Ferrite Bead 180 Ω 1 LN	Murata	BLM18PG181SN1D
35	4	R32, R33, R34, R35	22 k	Yageo	RC0402JR-0722KL
36	2	R61, R62	1 mΩ	Susumu	KRL2012E-M-R001-J-T5
37	1	R63	10 k	Yageo	RC0402JR-0710KL
38	2	R64, R65	20 Ω	Yageo	RC0402FR-0720RL
39	1	R90	300 k	Stackpole	RMCF0603FT300K
40	1	R91	3.65 k	Panasonic	ERA-2AEB3651X
41	1	R92	31.6 k	Panasonic	ERA-2AEB3162X
42	1	R94	51 k	Stackpole	RMCF0603FT51K0
43	1	R95	0 Ω	Yageo	RC0402JR-070RL
44	1	R98	16.5 k	Yageo	RC0402FR-0716K5L
45	1	R99	86.6 k	Yageo	RC0603FR-0786K6L
46	2	U1, U2	80 V, 10 mΩ	EPC	EPC2152
47	1	U20	dsPIC	Microchip	DSPIC33CK32MP102-E/2N
48	2	U61, U62	current sense amplifier	Microchip	MCP6C02T-050E/CHY
49	1	U90	Buck Regulator 100 V, 300 mA	Texas Instruments	LM5018SD/NOPB
50	1	U91	IC REG BUCK 3.3 V	TI	TPS62177DQCR

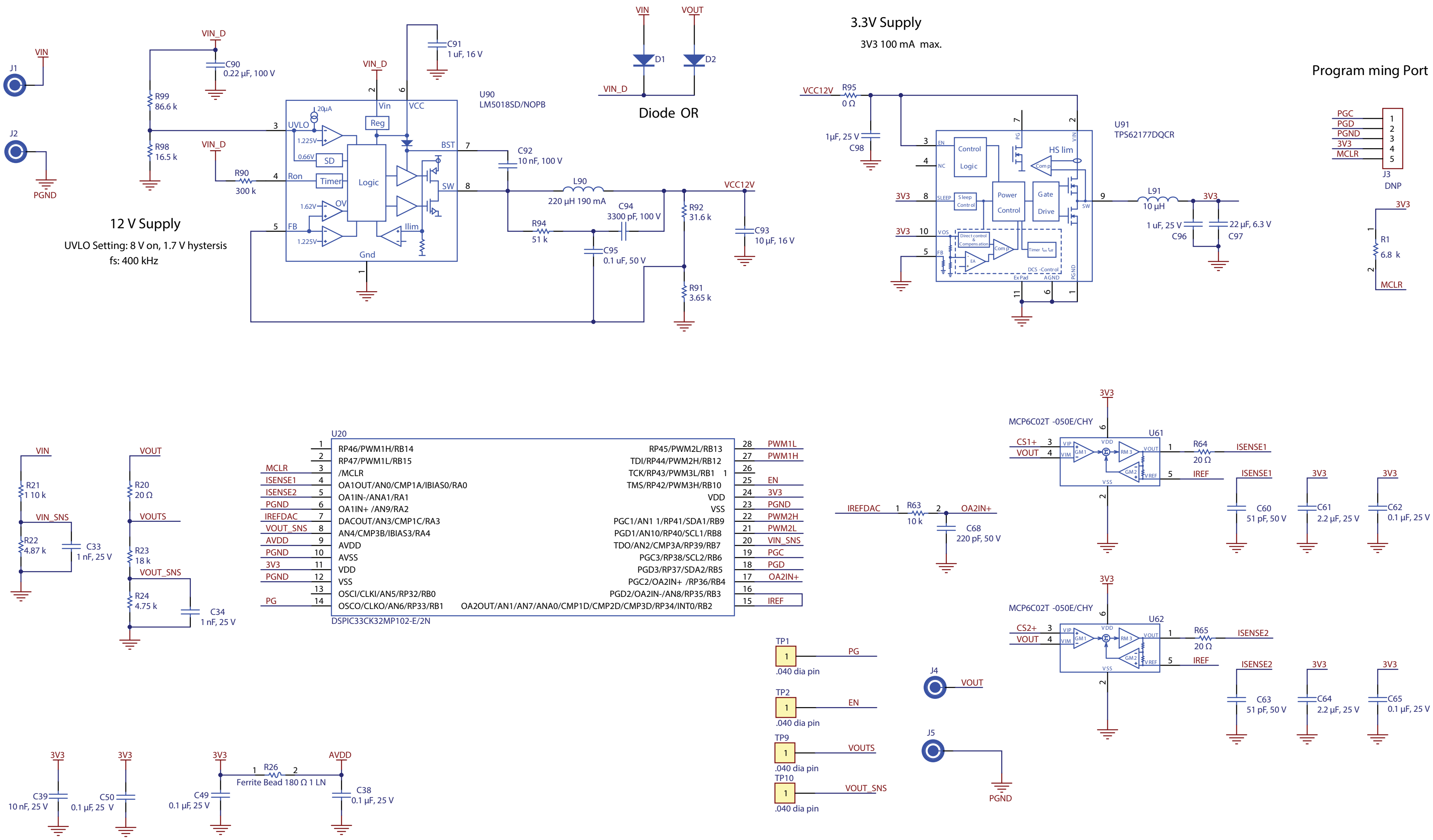


Figure 19: EPC9151 Controller schematic

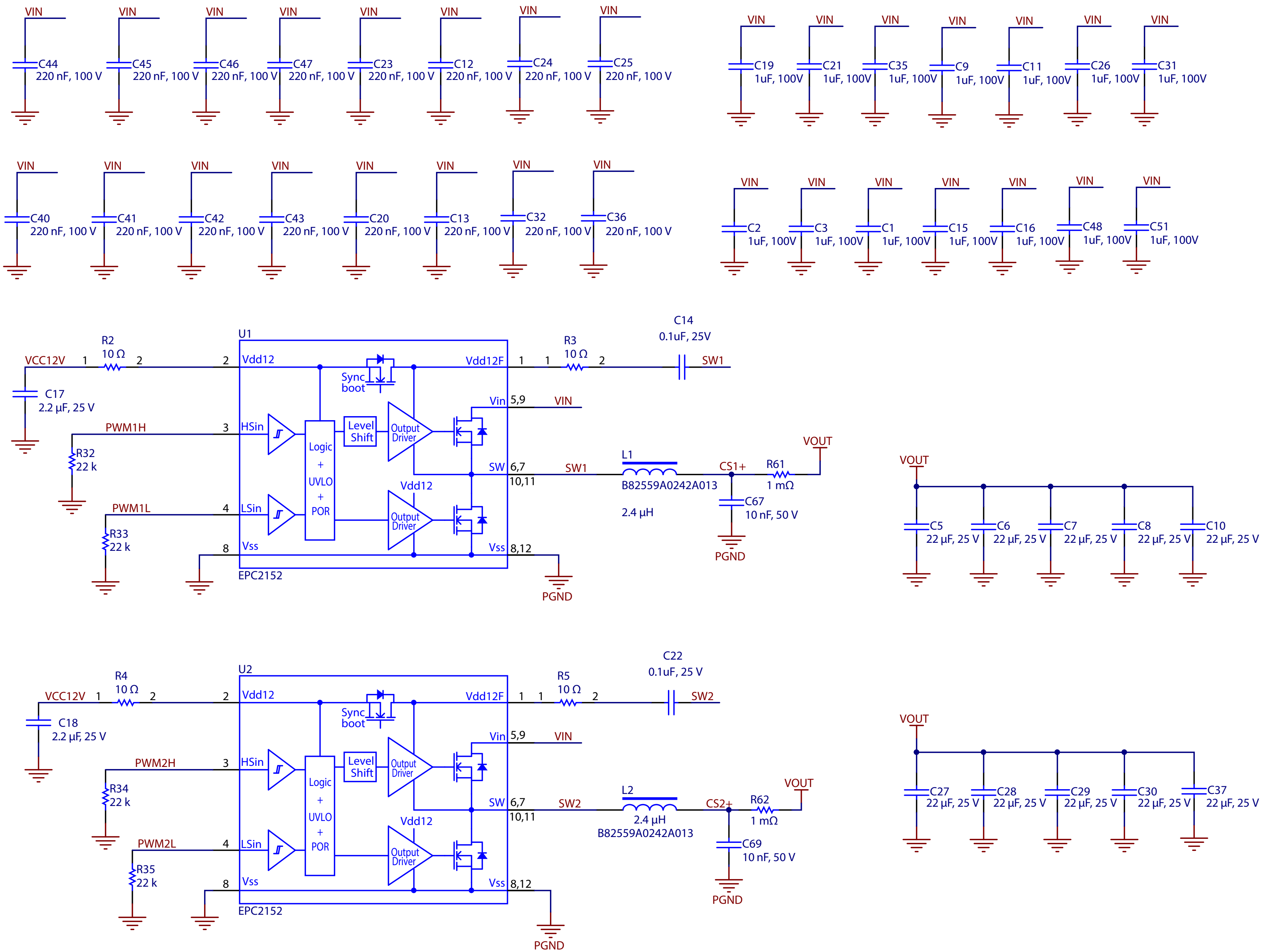


Figure 20: EPC9151 Power Stage schematic

EPC would like to acknowledge Microchip Technology Inc. (**www.microchip.com**) for their support of this project.

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The EPC9151 system features the **dsPIC33CK32MP102** 16-Bit Digital Signal Controller with High-Speed ADC, Op Amps, Comparators and High-Resolution PWM. Learn more at **www.microchip.com**.