EVM User's Guide: LM51770

LM51770 Buck-Boost Controller Evaluation Module

Description

The LM51770EVM-HV demonstrates a flexible high power buck-boost design using the LM51770. The evaluation module is configured to operate from an input voltage range of 36V to 48V and produce a regulated 48V output with up to 4A load current. The EVM operates with a switching frequency of 380kHz. Most settings of the device are easily adjusted or set through jumpers, such as: operation mode (PSM or fPWM), bias supply, and external clock synchronization.

Get Started

Connect EVM to power supply and load:

- Connect a power supply to the input connectors J1 and J3.
- Connect the load to the output connectors J2 and J4.

Features

- Wide input voltage range
- Ultra high (> 95%) peak power conversion efficiency
- Adjustable output voltage using feedback resistor divider
- Optional synchronization (SYNC)
- Easy configuration of current monitor or limiter
- Programmable input undervoltage lockout (UVLO) threshold and hysteresis
- Output constant voltage (CV) and constant current (CC) options
- Setting of configuration resistor R_{CFG} through DIP switches

Applications

- Battery backup unit (BBU)
- DC/DC modules

1 Evaluation Module Overview

1.1 Introduction

The LM51770EVM-HV evaluation module (EVM) is designed to conveniently evaluate the performance of the LM51770 wide-VIN buck-boost controller. The LM51770 is a wide-V_{IN} four switch buck-boost controller. The device provides a regulated output voltage if the input voltage is higher, equal or lower as the adjusted output voltage. In power safe mode, the device supports a superb efficiency over the full range of the output.

1.2 Kit Contents

- The EVM includes one LM51770EVM-HV PCB
- EVM Disclaimer Read Me

1.3 Specification

Table 1-1. Board Specifications

Parameter	Value
Input voltage	36V to 48V
Output voltage	47.5V (See with FB divider)
Maximum output current	4A
Default switching frequency	380kHz
Board size (four layers)	5.6 inch × 3.2 inch

Note

Voltage ratings of the used component allow to use input and output voltages up to 78V. Limitiations on current and input to output voltage ratio needs to be considered when adjusting this voltages.

Follow the required precautions when using voltages above 48V.

1.4 Device Information

The LM51770 is a four switch Buck-Boost controller. The device provides a regulated output voltage if the input voltage is higher, equal or lower as the adjusted output voltage. In power safe mode, the device supports a superb efficiency over the full range of the output.

- Wide input range from 3.5V to 78V (EVM max. 48V)
- Output voltage 3.3V to 78V (EVM max. 48V)
- Peak current regulation scheme
- Dynamic output voltage tracking
  - Digital PWM tracking input
  - Analog tracking input
- Minimum quiescent current
  - Low shut down Iq of 3µA
  - Low operating Iq of 25µA
- Operation mode selection for high light load efficiency
  - Power save burst mode
  - µSleep power save mode
- Integrated high voltage supply LDO

2 Hardware

2.1 Connector, Test Point, and Selection Switch Descriptions

This section provides the I/O connectors, jumpers, and test points of the EVM.

Connect the power supply to the input connectors J1 and J3.

Connect a load to the output connectors J2 and J4.

2.1.1 Connector Descriptions

Table 2-1. Connectors

Reference Designator	Description
J1	Input voltage positive connection
J2	Output voltage connection
J3	Input voltage return connection
J4	Output voltage return connection
J5	Input voltage positive and input voltage return test point
J6	Output voltage positive and output voltage return test point
J7	External BIAS input connection
J8	CFG connection
J9	FLT external connection
J10	RT external input connection
J11	IMONOUT connector

2.1.2 Jumper Descriptions

Table 2-2. Jumpers

Reference Designator	Pins	Description	Default Connection
JP1	Pin 1 to Pin 2 (GND)	Jumper in position GND and power save mode (PSM) is enabled.	
	Pin 2 to Pin 3 (VCC)	Jumper in position VCC and FPWM mode is enabled.	*
JP2	Pin 1 to Pin 2 (GND)	Jumper in position GND (SYNC pin tied GND) and frequency synchronization is disabled.	*
	Open	Jumper removed and external clock feed in on the SYNC pin. SYNC is enabled.	
	Pin 2 to Pin 3 (VCC)	Jumper in position VCC (SYNC pin tied VCC) and frequency synchronization is disabled.	
JP3	Pin 1 to Pin 2 (GND)	Jumper in position GND (DTRK pin tied GND) and digital voltage tracking is disabled.	*
	Open	Jumper removed and voltage feed in on the DTRK pin. DTRK is enabled in case the voltage on the DTRK pin is higher than the rising threshold of the VT(DTRK).	
	Pin 2 to Pin 3 (VCC)	Jumper in position VCC (DTRK pin tied VCC) and digital voltage tracking is disabled.	
JP4	Pin 1 to Pin 2 (VEXT)	Jumper in position VEXT and the input from J7-VEXT is connected to the BIAS pin.	
	Pin 3 to Pin 4 (VIN)	Jumper in position VIN. VIN (J1) is connected to the BIAS pin.	*
	Pin 5 to Pin 6 (VOUT)	Jumper in position VOUT. VOUT (J2) is connected to the BIAS pin.	
JP5	Pin 1 to Pin 2 (GND)	Jumper in position GND (EN/UVLO pin tied GND). The LM51770 is disabled.	
	Open	Jumper removed (the EN pin is tied to a resistor divider network consisting of R14 and R15). The EN/UVLO threshold is set with the resistor divider network.	*
	Pin 2 to Pin 3 (VIN)	Jumper in position VCC (EN/UVLO pin tied VCC). The LM51770 is enabled.	
JP6	Pin 1 / Pin2	Connection point for loop stability measurement (Bode plot).	
	Pin 3	GND	
	Pin 4 to Pin 5	Jumper in position selects internal feedback divider.	

2.1.3 Test Point Descriptions

Table 2-3. Test Points

Reference Designator	Description
TP1 (VIN)	Input voltage positive test point
TP2 (VOUT)	Output voltage positive test point
TP3 (GND)	Input voltage return test point
TP4 (GND)	Output voltage return test point
TP5	CSA test point
TP6	CSB test point
TP7	SW2 test point
TP8	ISNSP test point
TP9	BIAS test point
TP10	VCC test point
TP11	SYNC test point
TP12	SS/ATRK test point
TP13	COMP test point
TP14	HO1_LL
TP15	HO2_LL
TP16	GND
TP17	GND

2.1.4 Selection Switch Descriptions

2.1.4.1 S1 and S2 CFG Setting

These switches enable to set the resistor for the CFG pin. Find details in the *LM51770* data sheet.

Table 2-4. CFG Pin Configuration Overview

#(1)	DRSS	SCP - Hiccup Mode	Current Limit	PSM Entry Threshold
1	DISABLED	DISABLED	DISABLED	10%
2	ENABLED			
3	DISABLED	ENABLED		
4	ENABLED			
5	DISABLED	DISABLED	ENABLED	
6	ENABLED			
7	DISABLED	ENABLED		
8	ENABLED			
9	DISABLED	DISABLED	DISABLED	15%
10	ENABLED			
11	DISABLED	ENABLED		
12	ENABLED			
13	DISABLED	DISABLED	ENABLED	
14	ENABLED			
15	DISABLED	ENABLED		
16	ENABLED			

(1) Only close one switch.

2.1.5 Current Monitor and Current Limiter Configuration

This chapter descibes how to adopt the EVM to support Current Monitor and Current Limit function. The default setup is done for Current Monitoring.

To select the required components for IMONOUT and how to set various operation modes, refer to the LM51770 BuckBoost Quickstart Calculator Tool.

2.1.5.1 Current Monitor Configuration

For the current monitoring, these settings need to be done:

- CFG setting with Current limiter not enabled
- IMONOUT jumper J11 removed
- IMONOUT with resistor to GND - see Figure 2-1

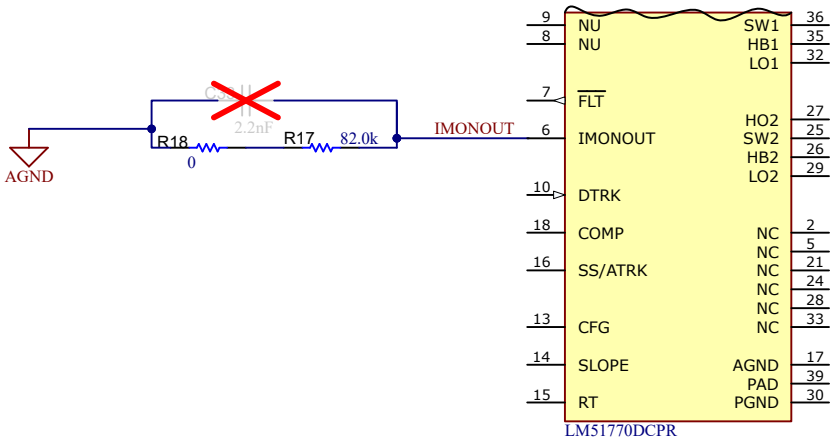


Figure 2-1. IMONOUT components for current monitor

2.1.5.2 Current Limiter Configuration

Current Limiter Configuration

For the current limiting below settings need to be done:

- CFG setting with Current limiter enabled
- IMONOUT jumper J11 removed
- SYNC connected to VCC for forward current limit
- IMONOUT with resistor and capacitor in series to GND (note: the EMV shows only placeholder for components, names, and symbols do not always reflect the component type and value that are placed there. For example 2.2nF and 700Ω

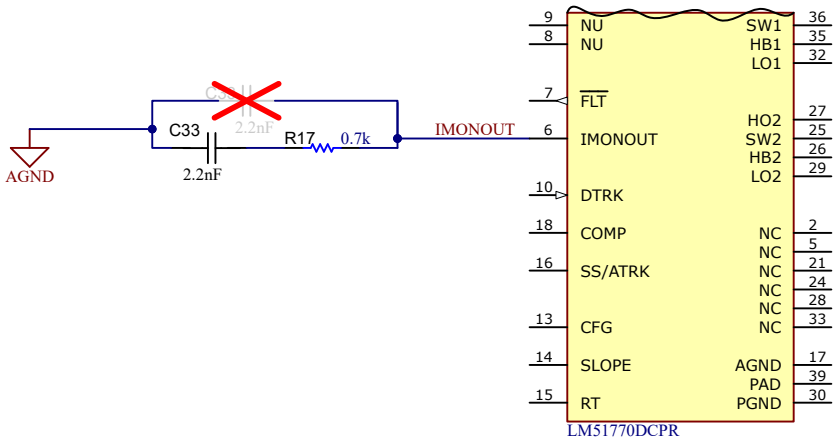


Figure 2-2. IMONOUT components for current limit

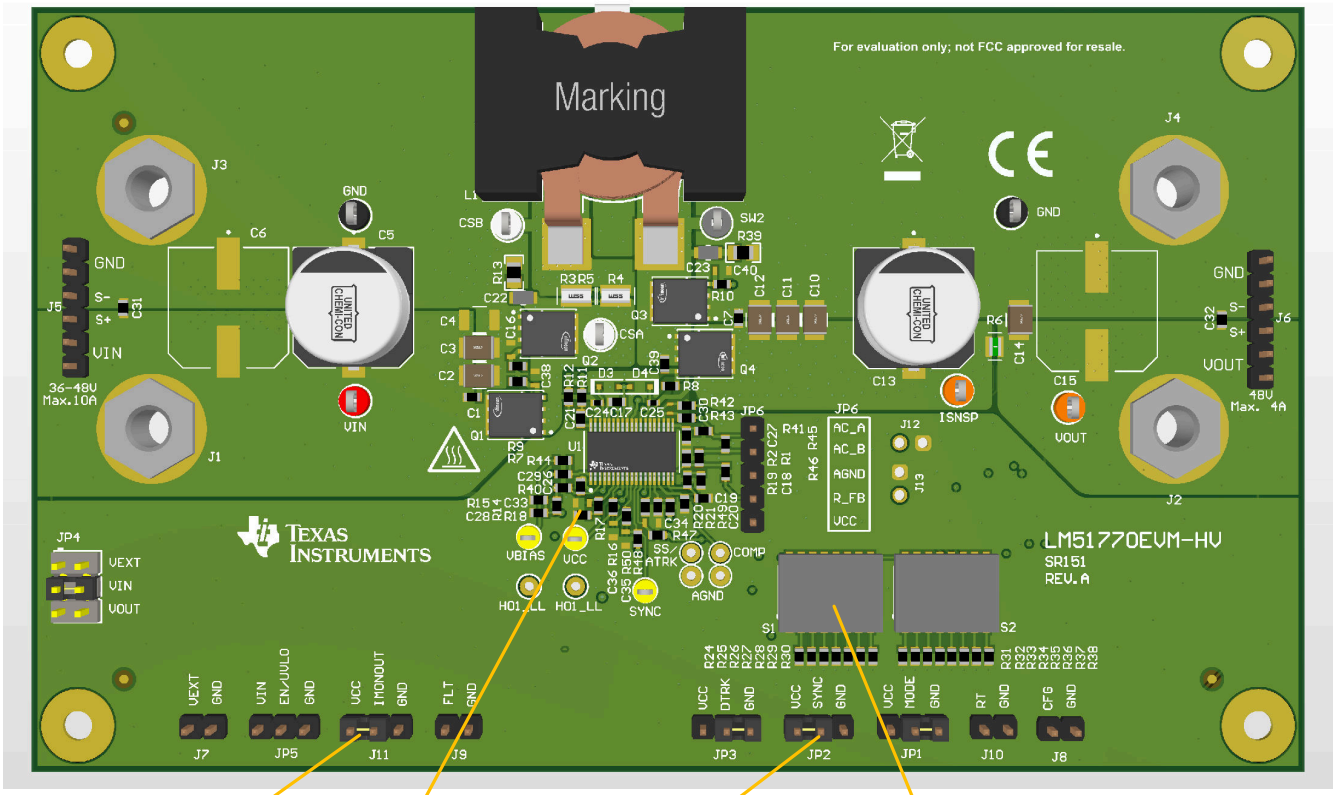


Figure 2-3. LM51770 Current Limit EVM Setup

3 Implementation Results

3.1 Test Setup and Procedure

3.1.1 Test Setup

Figure 3-1 shows a typical test setup to evaluate the LM51770EVM-HV

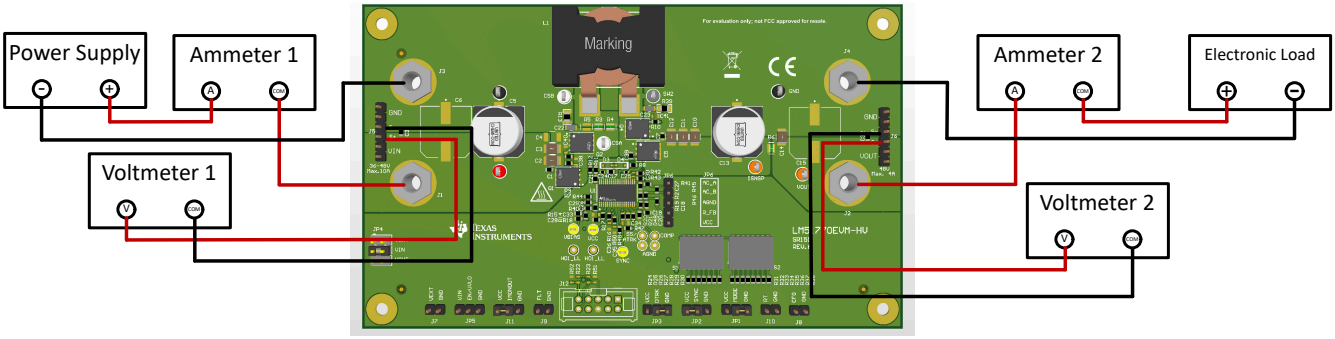


Figure 3-1. Typical EVM Connection Diagram

3.1.2 Test Procedure

1. Set the power supply current limit to 10A. Turn off the power supply. Connect the positive output of the power supply to J1 and the negative output to J3.
2. Connect the load to J2 for the positive connection and J4 for the negative connection.
3. Set the power supply voltage to 36V and the electronic load to 0.1A. The electronic load voltage must be in regulation with a nominal 48V output.
4. Slowly increase the load while monitoring the output voltage between J6-VOUT and J6-GND. The voltage must remain in regulation with a nominal 48V output as the load is increased up to 4A.
5. Slowly sweep the input voltage from 36V to 48V. The output voltage must remain in regulation with a nominal 48V output.
6. Slowly sweep the input voltage from 48V to 36V. The output voltage must remain in regulation with a nominal 48V output.
7. Decrease the load to 1A.
8. Decrease the input voltage down to 0V to shut down the Buck-Boost controller, and then turn off the load.

3.1.3 Precautions

CAUTION

Prolonged operation with low input at full power causes heating of the FETs (Q1 to Q4). Board surface is hot. Do not touch. Contact can cause burns.

3.2 Test Data and Performance Curves

3.2.1 Thermal Performance

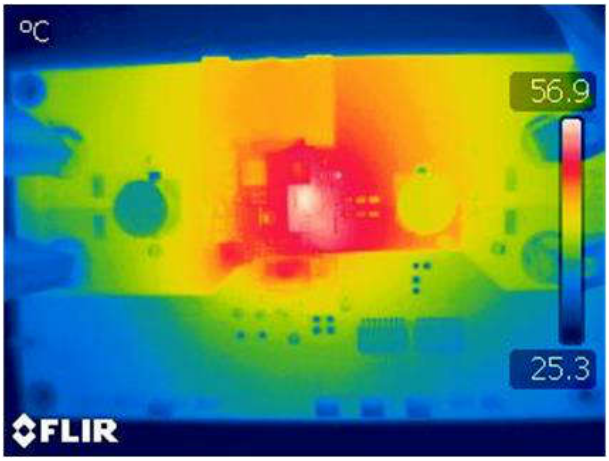


Figure 3-2. Thermal Image: V_{IN} = 36.0V, I_{OUT} = 4.0A, No Forced Air Cooling

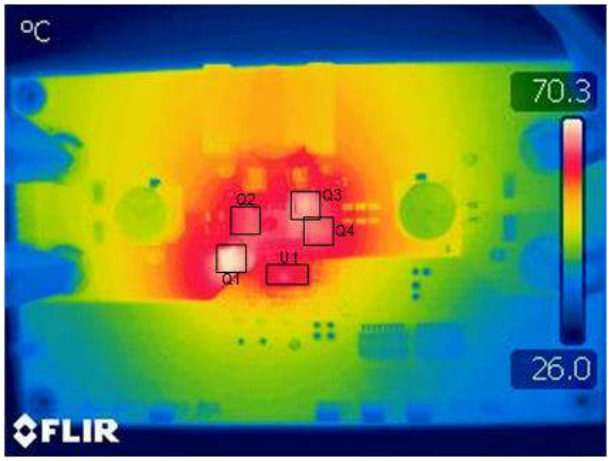


Figure 3-3. Thermal Image: V_{IN} = 40.0V, I_{OUT} = 4.0A, No Forced Air Cooling

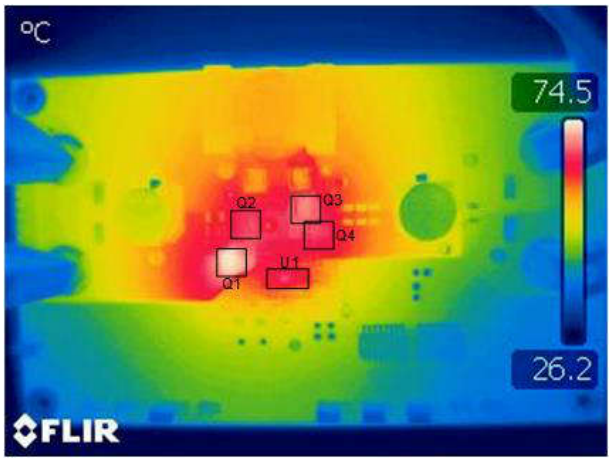


Figure 3-4. Thermal Image: V_{IN} = 48V, I_{OUT} = 4.0A, No Forced Air Cooling

3.2.2 Efficiency

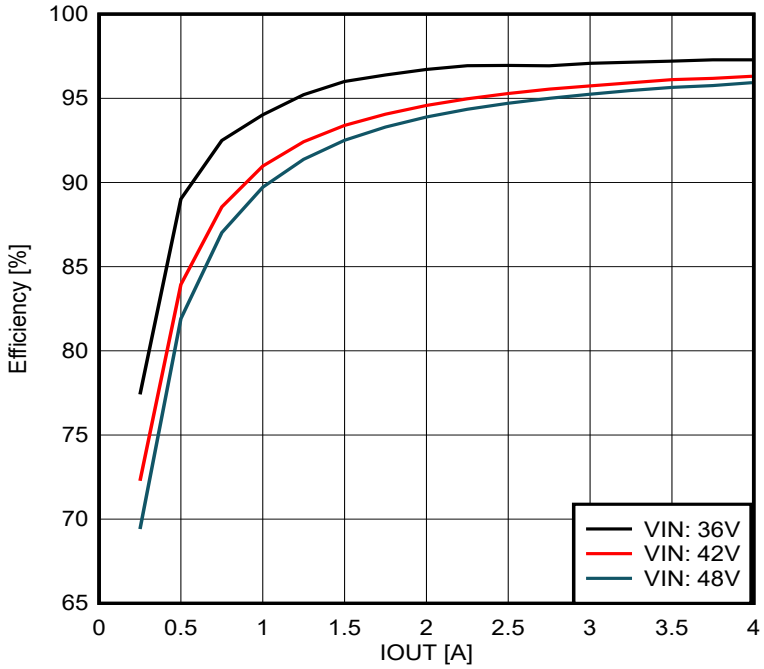


Figure 3-5. Efficiency vs. Output Current, V_O = 20V

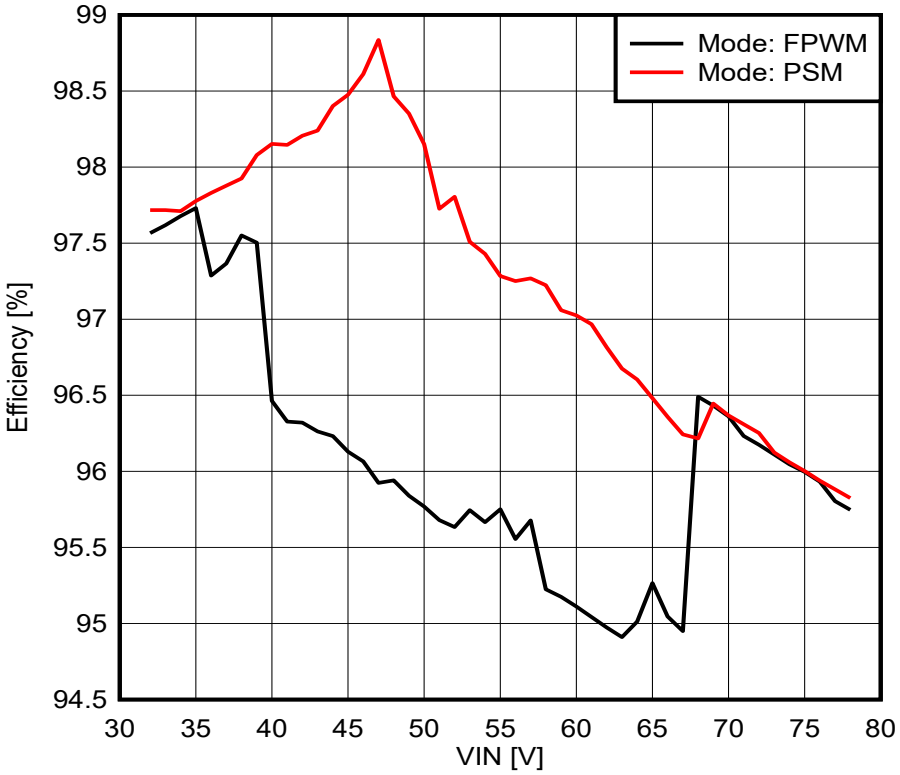


Figure 3-6. Efficiency vs. Input Voltage, V_O = 20V, I_O = 5A

3.2.3 Steady State Waveforms

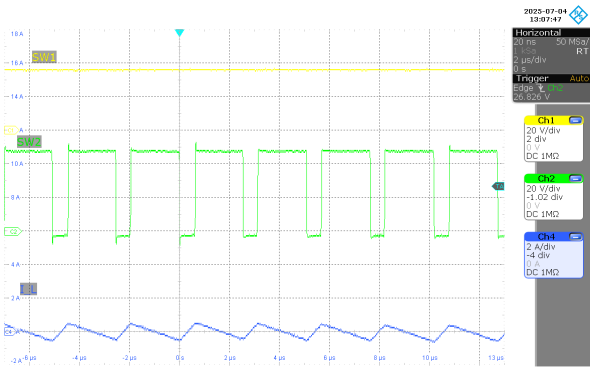


Figure 3-7. SW1, SW2, I_L (V_{IN} = 36V, I_{OUT} = 0A, FPWM Mode)

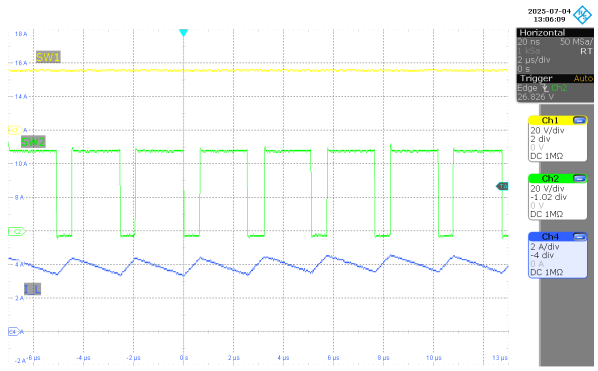


Figure 3-8. SW1, SW2, I_L (V_{IN} = 36V, I_{OUT} = 3.0A, FPWM Mode)

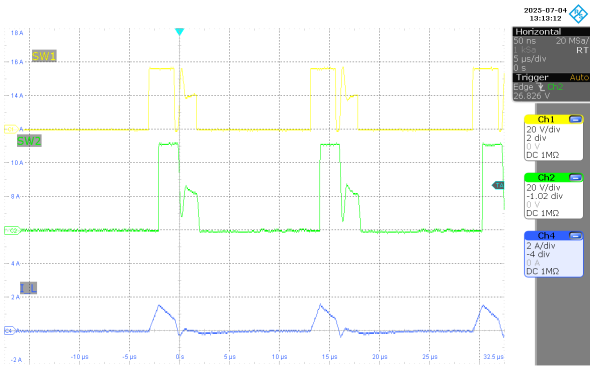


Figure 3-9. SW1, SW2, I_L (V_{IN} = 36V, I_{OUT} = 0A, PSM Mode)

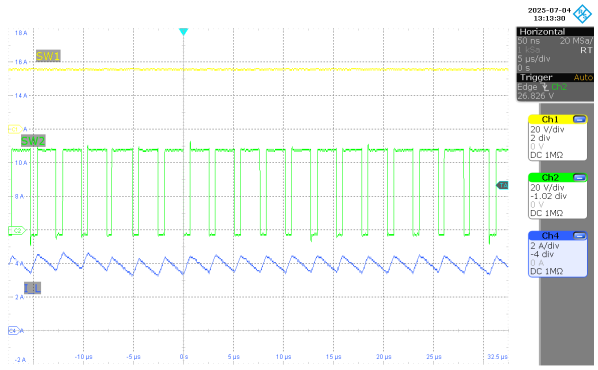


Figure 3-10. SW1, SW2, I_L (V_{IN} = 36V, I_{OUT} = 3.0A, PSMMode)

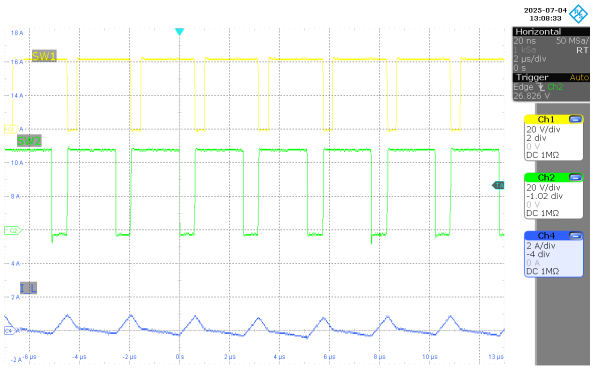


Figure 3-11. SW1, SW2, I_L (V_{IN} = 42V, I_{OUT} = 0A, FPWM Mode)

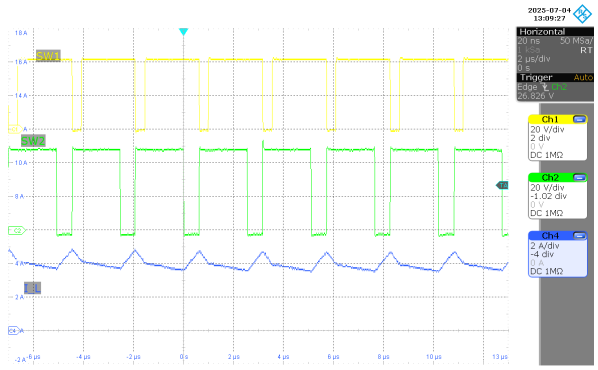


Figure 3-12. SW1, SW2, I_L (V_{IN} = 42V, I_{OUT} = 3.0A, FPWM Mode)

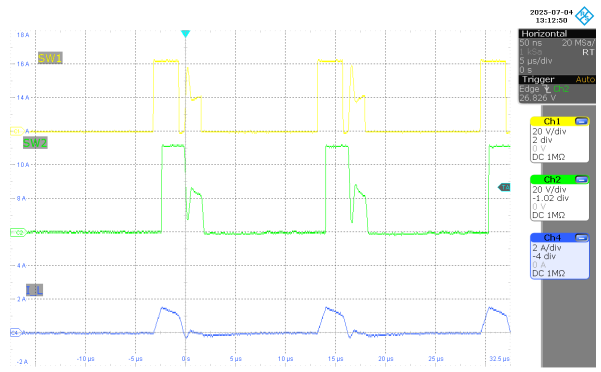


Figure 3-13. SW1, SW2, I_L (V_{IN} = 42V, I_{OUT} = 0A, PSM Mode)

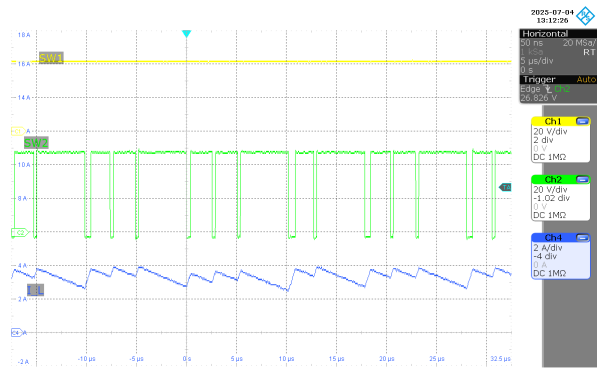


Figure 3-14. SW1, SW2, I_L (V_{IN} = 42V, I_{OUT} = 3.0A, PSM Mode)

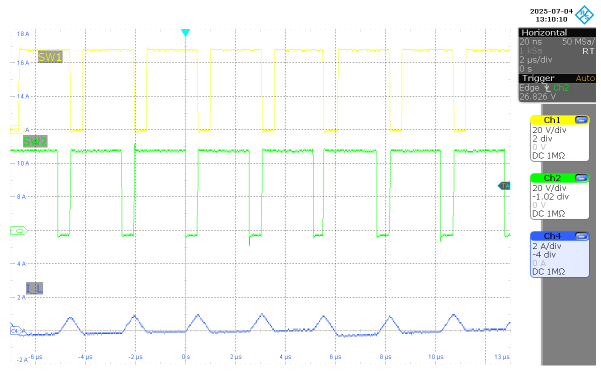


Figure 3-15. SW1, SW2, I_L (V_{IN} = 48V, I_{OUT} = 0A, FPWM Mode)

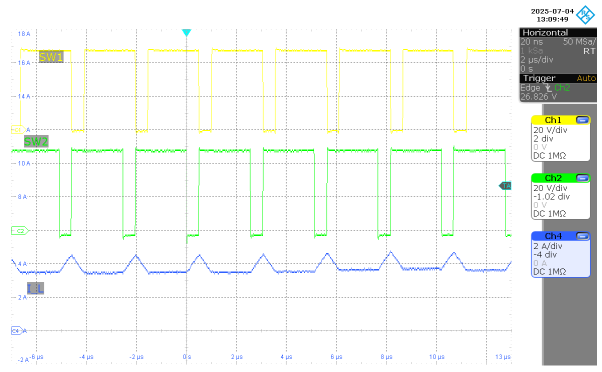


Figure 3-16. SW1, SW2, I_L (V_{IN} = 48V, I_{OUT} = 3.0A, FPWM Mode)

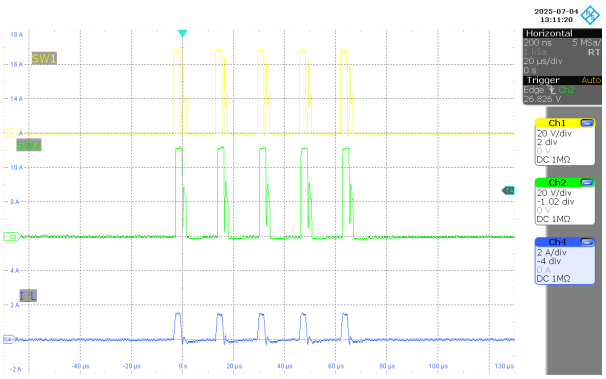


Figure 3-17. SW1, SW2, I_L (V_{IN} = 48V, I_{OUT} = 0A, PSM Mode)

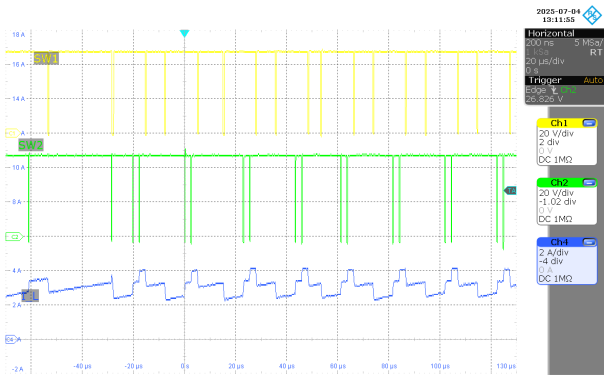


Figure 3-18. SW1, SW2, I_L (V_{IN} = 48V, I_{OUT} = 3.0A, PSM Mode)

3.2.4 Step Load Response

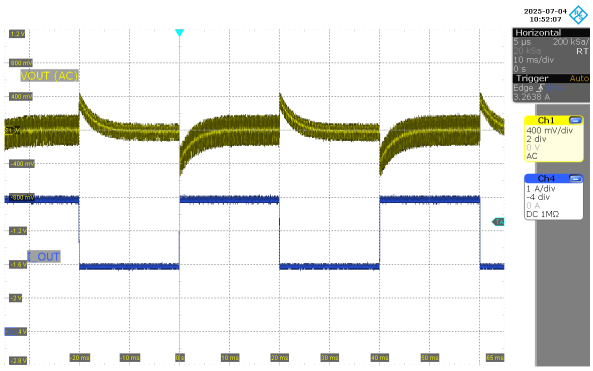


Figure 3-19. Load Step (V_{IN} = 36V, I_{OUT} = 2A – 4A)

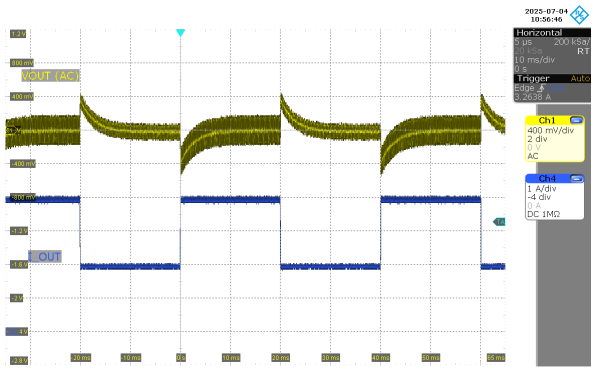


Figure 3-20. Load Step (V_{IN} = 42V, I_{OUT} = 2A – 4A)

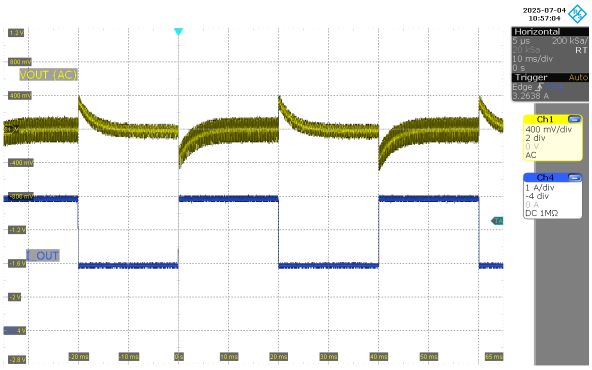


Figure 3-21. Load Step (V_{IN} = 48V, I_{OUT} = 2A – 4A)

3.2.5 AC Loop Response Curve

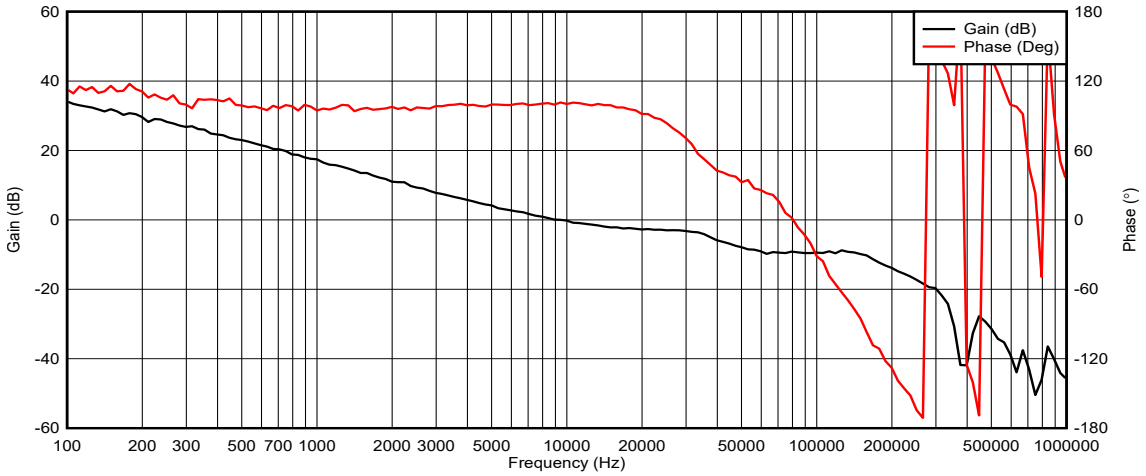


Figure 3-22. Control Loop Response, VIN = 36.0V, IOUT = 3.0A

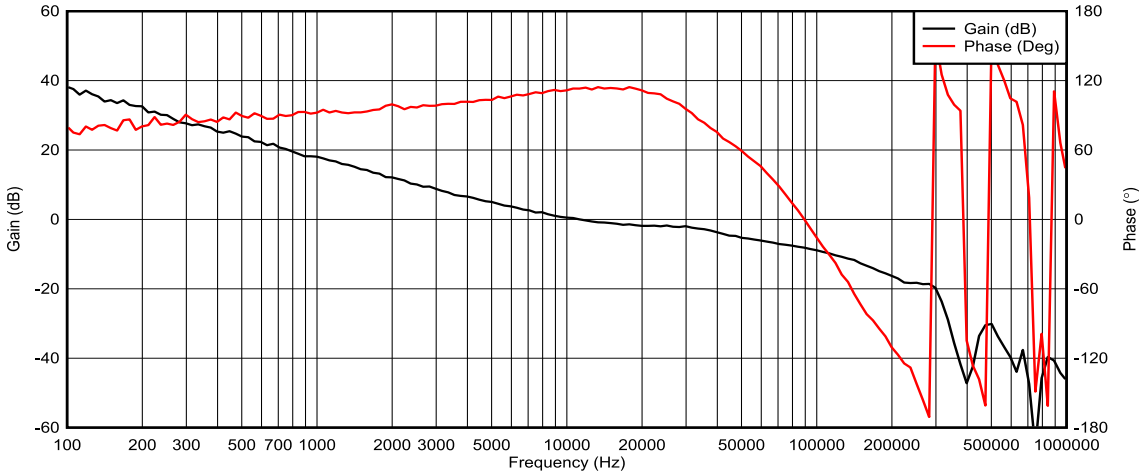


Figure 3-23. Control Loop Response, VIN = 48.0V, IOUT = 3.0A

4 Hardware Design Files

4.1 Schematic

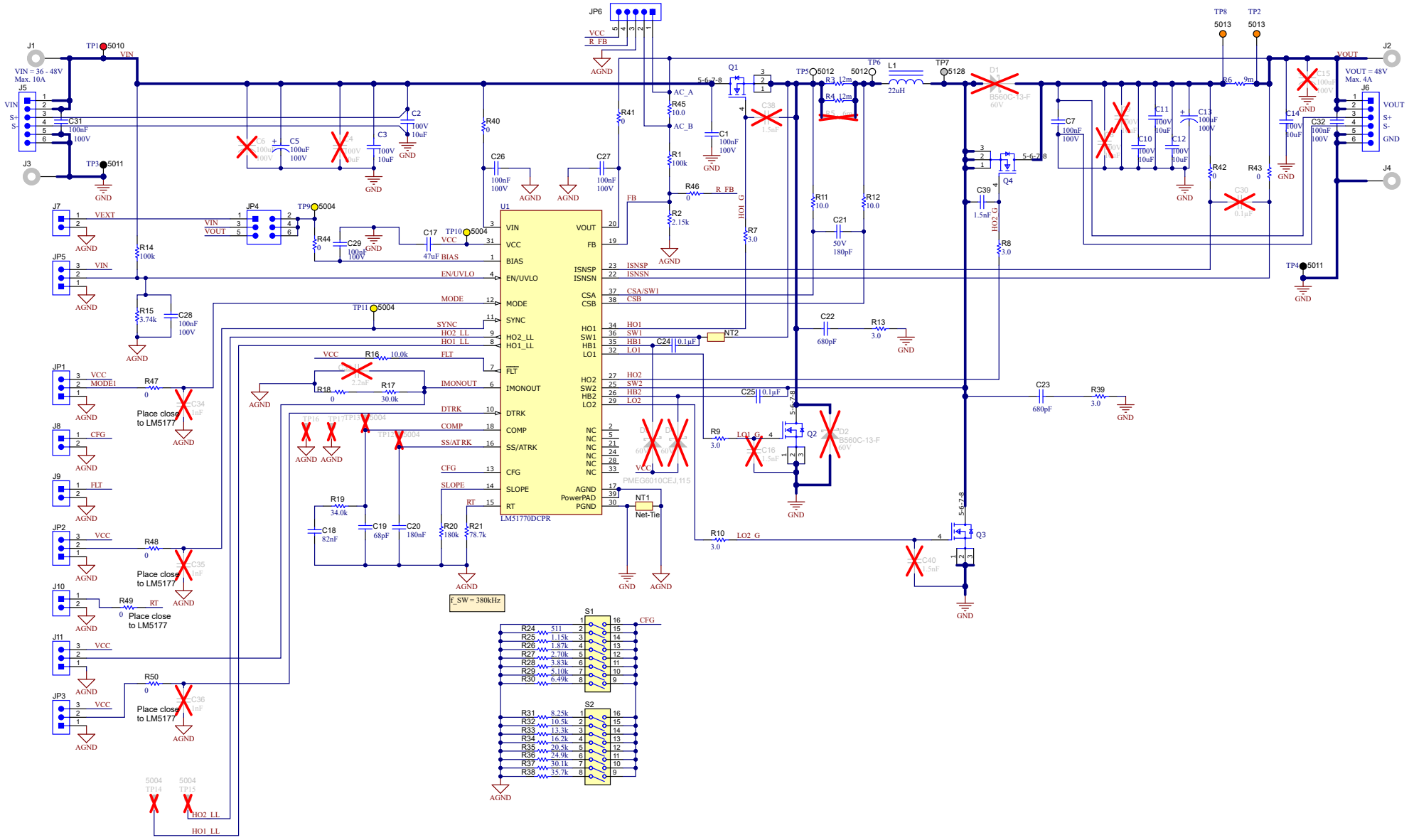
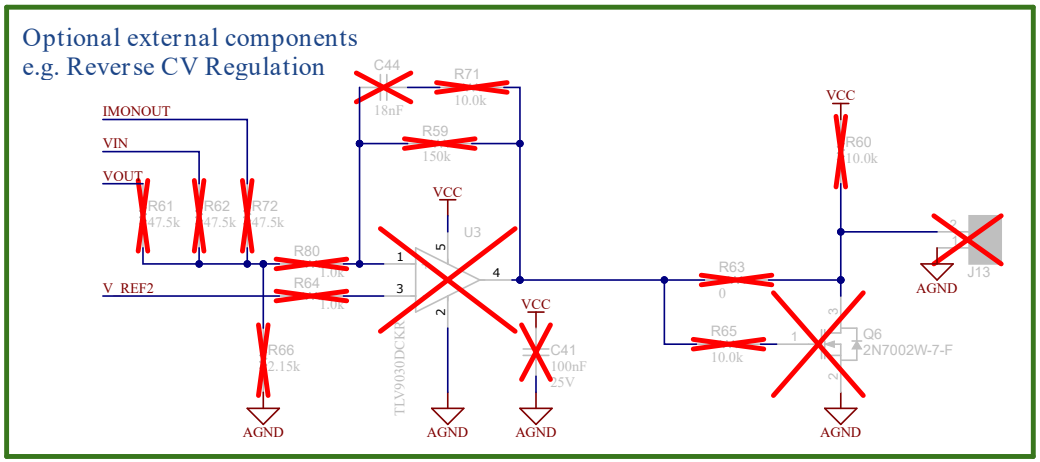
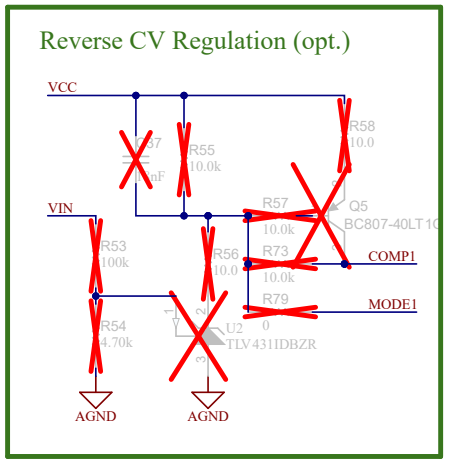


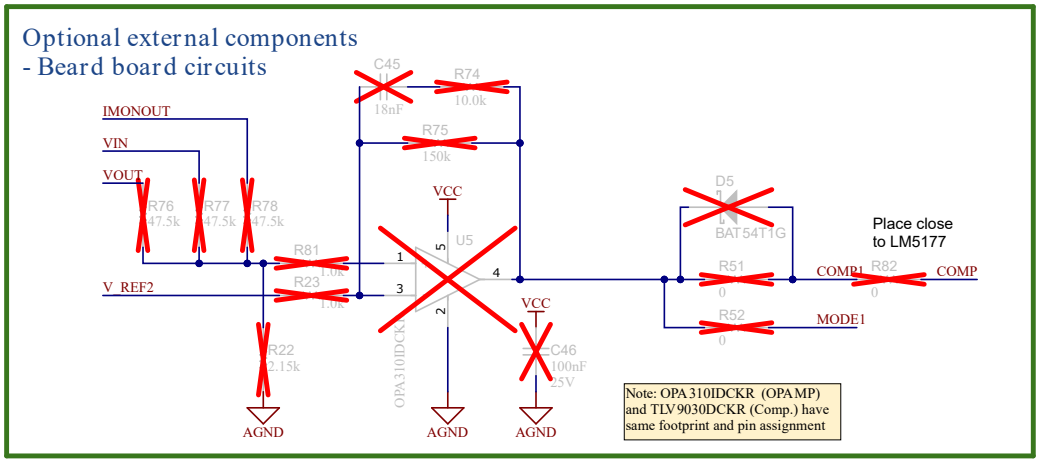
Figure 4-1. 4-Switch Buck-Boost Controller Schematic

Optional external components
- Beard board circuits

This sheet contains footprint placeholder for compoents to extend the controller functions. Components and values are generic and can be







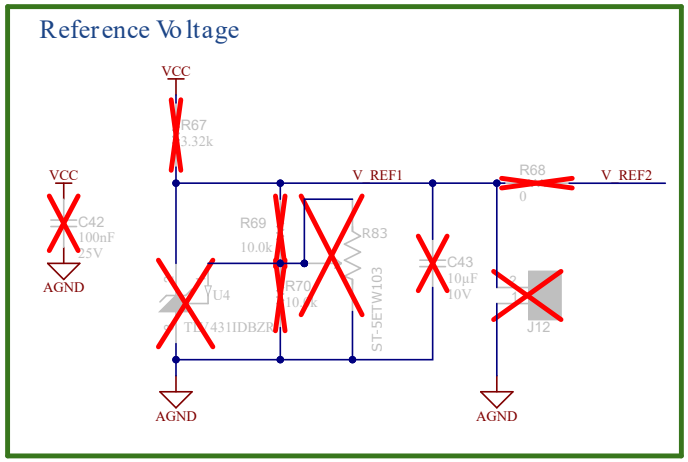


Figure 4-2. 4-Switch Buck-Boost Controller Schematic (optional components)

4.2 PCB Layout

Figure 4-3 through Figure 4-8 show the design of the LM51770EVM-HV PCB.

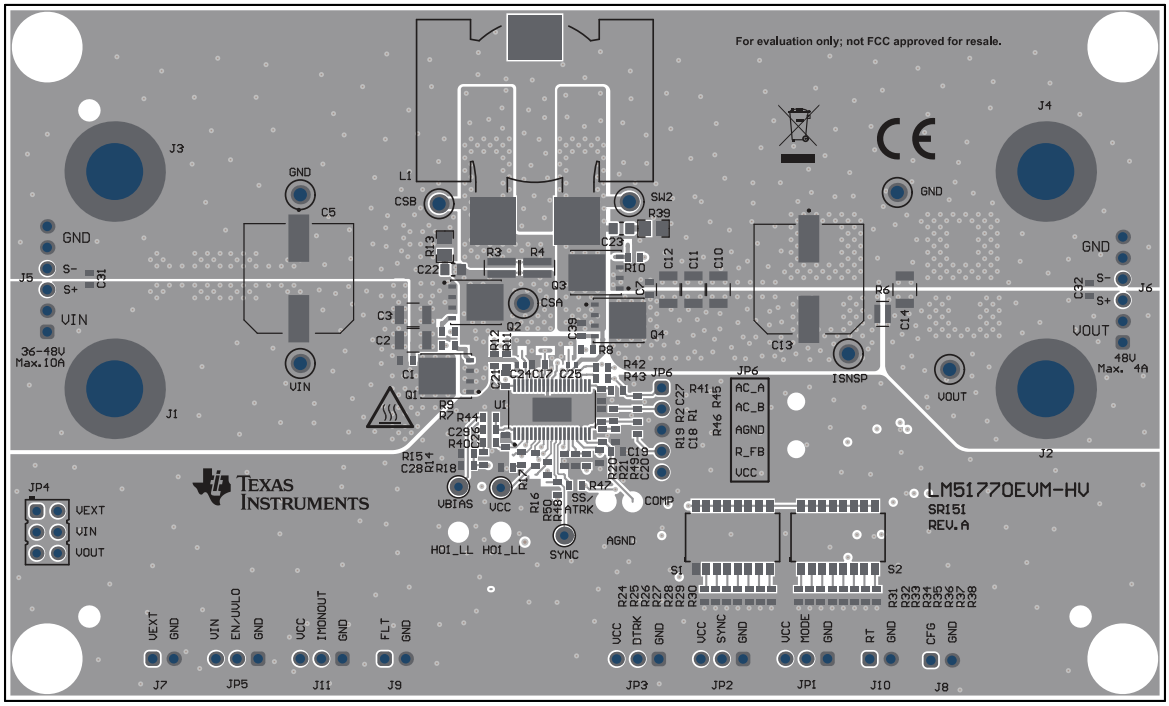


Figure 4-3. Top Silkscreen

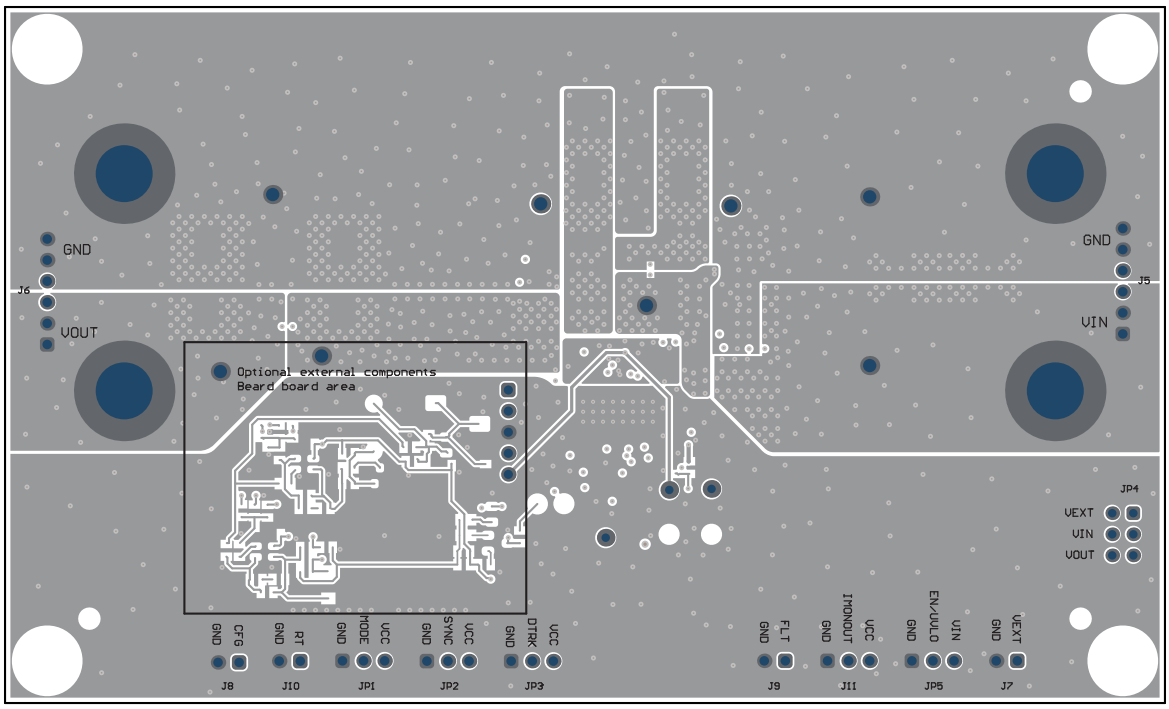


Figure 4-4. Bottom Silkscreen

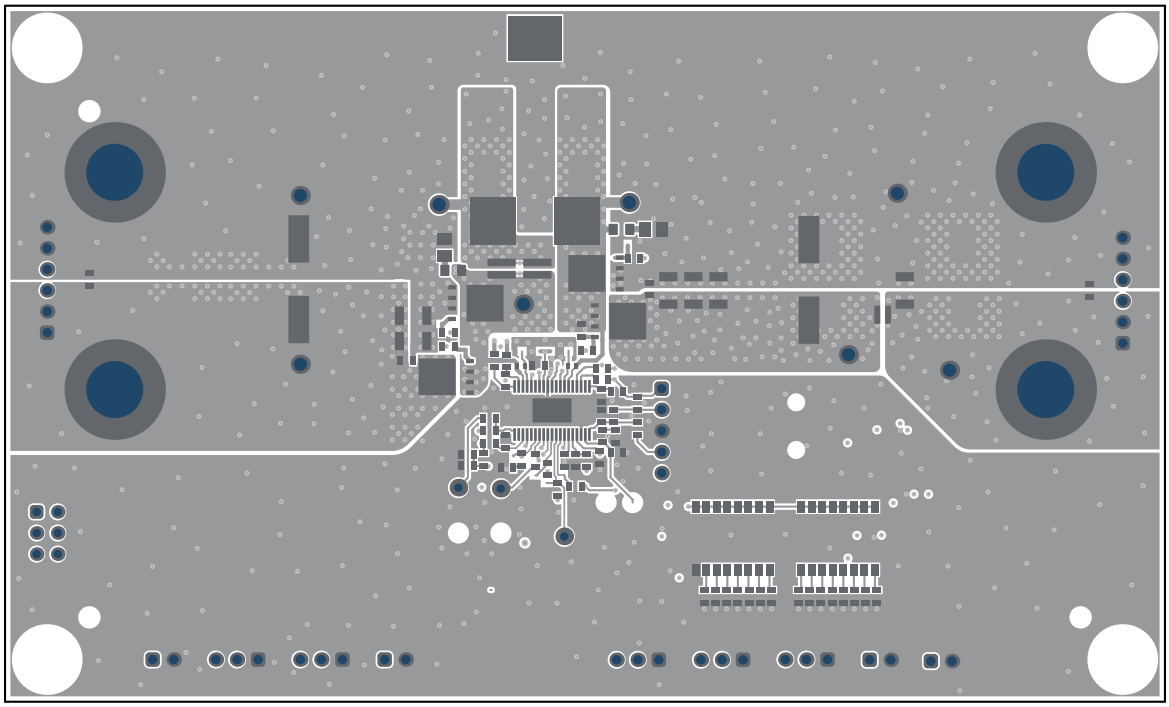


Figure 4-5. Top Layer

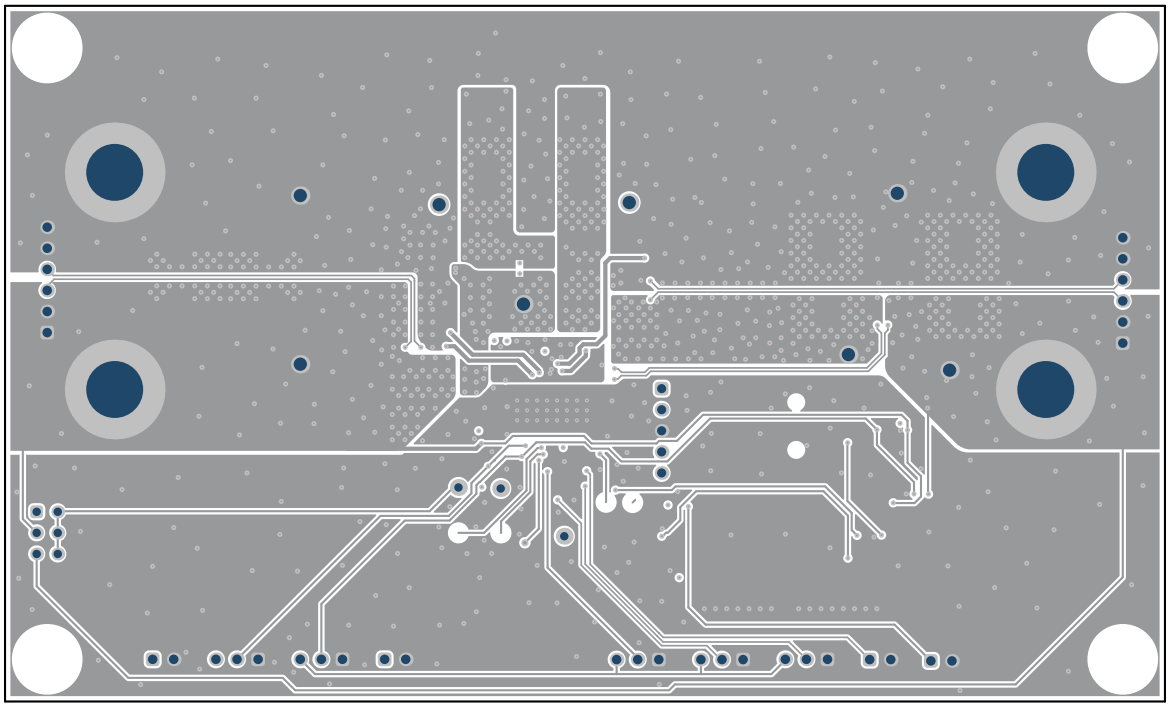


Figure 4-6. Mid-Layer 1

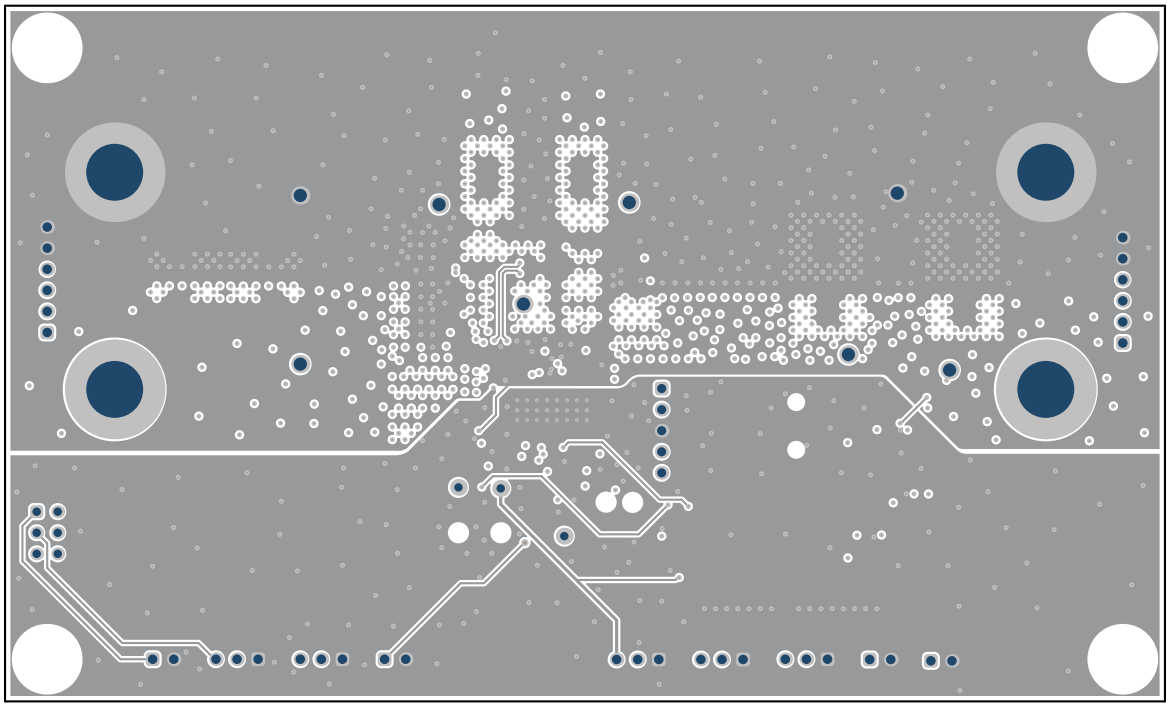


Figure 4-7. Mid-Layer 2

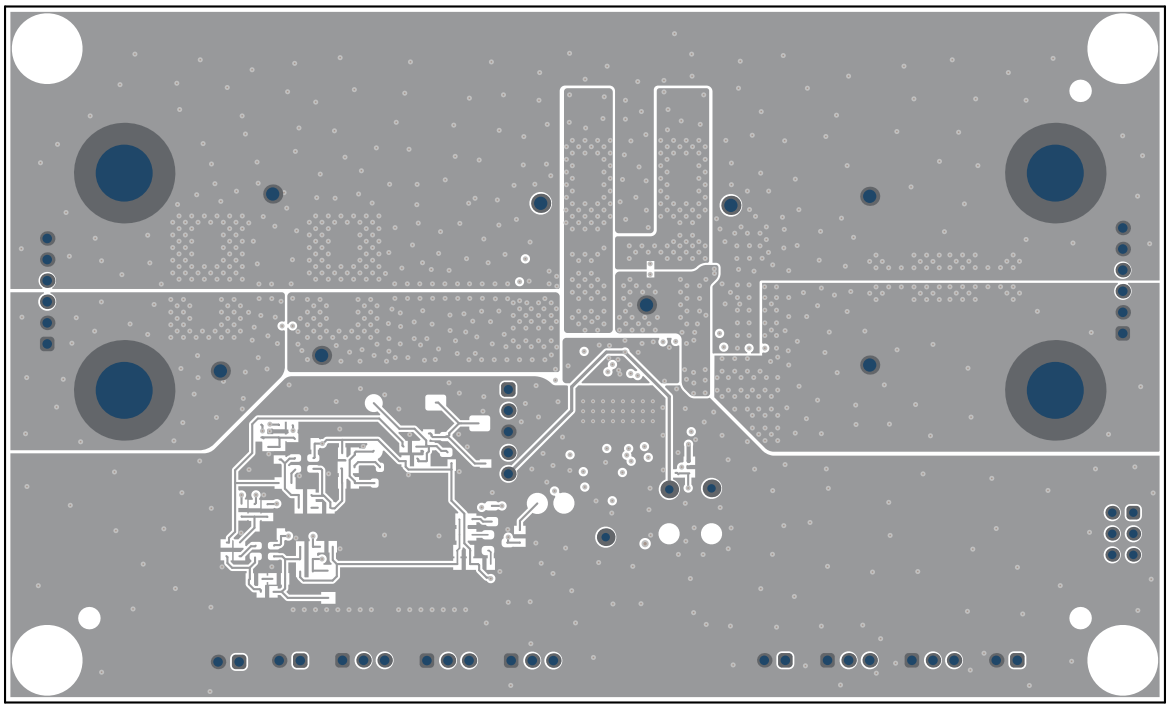


Figure 4-8. Bottom Layer

4.3 Bill of Materials

Table 4-1. Bill of Material

Designator	Quantity	Value	Description	PartNumber	Manufacturer
C1, C7, C26, C27, C28, C29, C31, C32	8	0.1uF	CAP, CERM, 0.1uF, 100V,+/- 10%, X7R, AEC-Q200 Grade 1, 0603	GCJ188R72A104KA01D	MuRata
C2, C3, C10, C11, C12, C14	6	10µF	10µF ±10% 100V Ceramic Capacitor X7R 1210 (3225 Metric)	C3225X7R2A106K250AC	TDK
C5, C13	2	100µF	100uF 100V 20% Aluminum Electrolytic Capacitors Radial, Can - SMD - 5000 Hrs @ 105°C	EMVY101ARA101MKE0S	United Chemi-Con
C17	1	47uF	CAP, CERM, 47uF, 6.3 V, +/- 20%, X5R, 0603	GRM188R60J476ME15D	MuRata
C18	1	0.082uF	CAP, CERM, 0.082uF, 16 V, +/- 10%, X7R, 0603	0603YC823KAT2A	AVX
C19	1	68pF	CAP, CERM, 68pF, 50 V, +/- 5%, C0G/NP0, 0603	C0603C680J5GACTU	Kemet
C20	1	0.18uF	CAP, CERM, 0.18uF, 25 V, +/- 10%, X7R, 0603	GRM188R71E184KA88D	MuRata
C21	1	180pF	CAP, CERM, 180pF, 50 V, +/- 5%, C0G/NP0, 0603	C0603C181J5GACTU	Kemet
C22, C23	2	680pF	CAP, CERM, 680pF, 50 V, +/- 1%, C0G/NP0, 0805	C0805C681F5GACTU	Kemet
C24, C25	2	0.1uF	CAP, CERM, 0.1µF, 50 V,+/- 10%, X7R, 0402	0402BB104KW500	Passive Plus
C39	1	1500pF	CAP, CERM, 1500pF, 100 V, +/- 10%, X7R, 0603	06031C152KAT2A	AVX
J1, J2, J3, J4	4		Standard Banana Jack, Uninsulated, 15A	108-0740-001	Cinch Connectivity
J5, J6	2		Header, 2.54 mm, 6x1, Gold, TH	61300611121	Wurth Elektronik
J7, J8, J9, J10	4		Header, 2.54 mm, 2x1, Gold, TH	61300211121	Wurth Elektronik

Table 4-1. Bill of Material (continued)

Designator	Quantity	Value	Description	PartNumber	Manufacturer
J11, JP1, JP2, JP3, JP5	5		Header, 2.54 mm, 3x1, Gold, TH	61300311121	Wurth Elektronik
JP4	1		Header, 2.54mm, 3x2, Gold, TH	HTSW-103-07-G-D	Samtec
JP6	1		Header, 2.54mm, 5x1, Gold, TH	61300511121	Wurth Elektronik
L1	1	22uH	Inductor, Shielded, Ferrite, 22uH, 18A, 0.00264ohm, SMD	7443642200	Wurth Elektronik
Q1, Q2, Q3, Q4	4		N-Channel 100V 44A (Tc) 2.5W (Ta), 52W (Tc) Surface Mount PG-TDSON-8-6	BSC146N10LS5ATMA1	Infineon
R1, R14	2	100k	RES, 100k, 1%, 0.1W, 0603	RC0603FR-07100KL	Yageo
R2	1	2.15k	RES, 2.15k, 1%, 0.1W, 0603	RC0603FR-072K15L	Yageo
R3, R4	2	12m	12mOhms ±1% 1.5W Chip Resistor Wide 1206 (3216 Metric), 0612 Automotive AEC-Q200, Current Sense Metal Foil	KRL3216E-C-R012-F-T5	Susumu
R6	1	9m	9mOhms ±1% 1W Chip Resistor Wide 0805 (2012 Metric), 0508 Automotive AEC-Q200, Current Sense Metal Foil	KRL2012E-M-R009-F-T5	Susumu
R7, R8, R9, R10	4	3	RES, 3.0, 5%, 0.1W, AEC-Q200 Grade 0, 0603	CRCW06033R00JNEA	Vishay-Dale
R11, R12	2	10	RES, 10.0, 1%, 0.25W, AEC-Q200 Grade 0, 0603	CRCW060310R0FKEAHP	Vishay-Dale
R13, R39	2	3	RES, 3.0, 5%, 0.125W, AEC-Q200 Grade 0, 0805	CRCW08053R00JNEA	Vishay-Dale
R15	1	3.74k	RES, 3.74k, 1%, 0.1W, 0603	RC0603FR-073K74L	Yageo
R16	1	10.0k	RES, 10.0k, 0.1%, 0.1W, 0603	RT0603BRD0710KL	Yageo America
R17	1	30.0k	RES, 30.0k, 1%, 0.1W, 0603	RC0603FR-0730KL	Yageo

Table 4-1. Bill of Material (continued)

Designator	Quantity	Value	Description	PartNumber	Manufacturer
R18, R40, R41, R42, R43, R44, R46, R47, R48, R49, R50	11	0	RES, 0, 1%, 0.1W, AEC-Q200 Grade 0, 0603	RMCF0603ZT0R00	Stackpole Electronics Inc
R19	1	34.0k	RES, 34.0k, 1%, 0.1W, AEC-Q200 Grade 0, 0603	ERJ-3EKF3402V	Panasonic
R20	1	180k	RES, 180k, 5%, 0.1W, AEC-Q200 Grade 0, 0603	CRCW0603180KJNEA	Vishay-Dale
R21	1	78.7k	RES, 78.7k, 1%, 0.1W, 0603	RC0603FR-0778K7L	Yageo
R24	1	511	RES, 511, 1%, 0.1W, AEC-Q200 Grade 0, 0603	CRCW0603511RFKEA	Vishay-Dale
R25	1	1.15k	RES, 1.15k, 1%, 0.1W, AEC-Q200 Grade 0, 0603	CRCW06031K15FKEA	Vishay-Dale
R26	1	1.87k	RES, 1.87k, 1%, 0.1W, 0603	RC0603FR-071K87L	Yageo
R27	1	2.70k	RES, 2.70k, 1%, 0.1W, 0603	RC0603FR-072K7L	Yageo
R28	1	3.83k	RES, 3.83k, 1%, 0.1W, AEC-Q200 Grade 0, 0603	CRCW06033K83FKEA	Vishay-Dale
R29	1	5.10k	RES, 5.10k, 1%, 0.1W, 0603	RC0603FR-075K1L	Yageo
R30	1	6.49k	RES, 6.49k, 1%, 0.1W, 0603	RC0603FR-076K49L	Yageo
R31	1	8.25k	RES, 8.25k, 1%, 0.1W, 0603	RC0603FR-078K25L	Yageo
R32	1	10.5k	RES, 10.5k, 1%, 0.1W, AEC-Q200 Grade 0, 0603	CRCW060310K5FKEA	Vishay-Dale
R33	1	13.3k	RES, 13.3k, 1%, 0.1W, 0603	RC0603FR-0713K3L	Yageo
R34	1	16.2k	RES, 16.2k, 1%, 0.1W, AEC-Q200 Grade 0, 0603	CRCW060316K2FKEA	Vishay-Dale
R35	1	20.5k	RES, 20.5k, 1%, 0.1W, 0603	RC0603FR-0720K5L	Yageo
R36	1	24.9k	RES, 24.9k, 1%, 0.1W, AEC-Q200 Grade 0, 0603	CRCW060324K9FKEA	Vishay-Dale
R37	1	30.1k	RES, 30.1k, 1%, 0.1W, AEC-Q200 Grade 0, 0603	CRCW060330K1FKEA	Vishay-Dale
R38	1	35.7k	RES, 35.7k, 1%, 0.1W, AEC-Q200 Grade 0, 0603	CRCW060335K7FKEA	Vishay-Dale

Table 4-1. Bill of Material (continued)

Designator	Quantity	Value	Description	PartNumber	Manufacturer
R45	1	10	RES, 10.0, 1%, 0.1W, 0603	RC0603FR-0710RL	Yageo
S1, S2	2		Switch, SPST, 8 Pos, 25mA, 24VDC, SMD	218-8LPST	CTS Electrocomponents
TP1	1		Test Point, Multipurpose, Red, TH	5010	Keystone Electronics
TP2, TP8	2		Test Point, Multipurpose, Orange, TH	5013	Keystone Electronics
TP3, TP4	2		Test Point, Multipurpose, Black, TH	5011	Keystone Electronics
TP5, TP6	2		Test Point, Multipurpose, White, TH	5012	Keystone Electronics
TP7	1		Test Point, Multipurpose, Grey, TH	5128	Keystone Electronics
TP9, TP10, TP11	3		Test Point, Miniature, Yellow, TH	5004	Keystone Electronics
U1	1		78V Wide VIN Bidirectional 4-Switch Buck-Boost Controller	LM51770DCPR	Texas Instruments
C4, C8, C9	0	10µF	10µF ±10% 100V Ceramic Capacitor X7R 1210 (3225 Metric)	C3225X7R2A106K250AC	TDK
C6, C15	0	100µF	100uF 100V 20% Aluminum Electrolytic Capacitors Radial, Can - SMD - 5000 Hrs @ 105°C	EMVY101ARA101MKE0S	United Chemi-Con
C16, C40	0	1500pF	CAP, CERM, 1500pF, 100V, +/- 10%, X7R, 0603	06031C152KAT2A	AVX
C30	0	0.1uF	CAP, CERM, 0.1µF, 50V,+/- 10%, X7R, 0402	0402BB104KW500	Passive Plus
C33	0	2200pF	CAP, CERM, 2200pF, 100V, +/- 5%, X7R, 0603	06031C222JAT2A	AVX
C34, C35, C36	0	1000pF	CAP, CERM, 1000pF, 100V, +/- 5%, X7R, 0603	06031C102JAT2A	AVX

Table 4-1. Bill of Material (continued)

Designator	Quantity	Value	Description	PartNumber	Manufacturer
C37, C44, C45	0	0.018uF	CAP, CERM, 0.018uF, 100V, +/- 10%, X7R, 0603	C0603C183K1RACTU	Kemet
C38	0	1500pF	CAP, CERM, 1500pF, 100V, +/- 10%, X7R, AEC-Q200 Grade 1, 0603	CGA3E2X7R2A152K080AA	TDK
C41, C42, C46	0	0.1uF	CAP, CERM, 0.1uF, 25V, +/- 10%, X7R, 0603	C0603X104K3RACTU	Kemet
C43	0	10uF	CAP, CERM, 10µF, 10V,+/- 10%, X5R, 0603	GRM188R61A106KE69D	MuRata
D1, D2	0	60V	Diode, Schottky, 60V, 5A, SMC	B560C-13-F	Diodes Inc.
D3, D4	0	60V	Diode, Schottky, 60V, 1A, SOD-323F	PMEG6010CEJ,115	Nexperia
D5	0	30V	Diode, Schottky, 30V, 0.2A, SOD-123	BAT54T1G	ON Semiconductor
J12, J13	0		Header, 2.54mm, 2x1, Gold, TH	61300211121	Wurth Elektronik
Q5	0	45 V	Transistor, PNP, 45V, 0.5A, AEC-Q101, SOT-23	BC807-40LT1G	ON Semiconductor
Q6	0	60V	MOSFET, N-CH, 60V, 0.115A, SOT-323	2N7002W-7-F	Diodes Inc.
R5	0	6m	6mOhms ±1% 1W Chip Resistor Wide 0805 (2012 Metric), 0508 Automotive AEC-Q200, Current Sense Metal Foil	KRL2012E-M-R006-F-T5	Susumu
R22, R66	0	2.15k	RES, 2.15k, 1%, 0.1W, 0603	RC0603FR-072K15L	Yageo
R23, R64, R80, R81	0	1.0k	RES, 1.0k, 5%, 0.1W, 0603	RC0603JR-071KL	Yageo
R51, R52, R63, R68, R79, R82	0	0	RES, 0, 1%, 0.1W, AEC-Q200 Grade 0, 0603	RMCF0603ZT0R00	Stackpole Electronics Inc
R53	0	100k	RES, 100k, 1%, 0.1W, 0603	RC0603FR-07100KL	Yageo
R54	0	4.70k	RES, 4.70k, 1%, 0.1W, 0603	RC0603FR-074K7L	Yageo

Table 4-1. Bill of Material (continued)

Designator	Quantity	Value	Description	PartNumber	Manufacturer
R55, R57, R71, R73, R74	0	10.0k	RES, 10.0k, 1%, 0.1W, AEC-Q200 Grade 0, 0603	CRCW060310K0FKEA	Vishay-Dale
R56, R58	0	10	RES, 10.0, 1%, 0.1W, 0603	RC0603FR-0710RL	Yageo
R59, R75	0	150k	RES, 150k, 1%, 0.1W, 0603	RC0603FR-07150KL	Yageo
R60, R65, R69, R70	0	10.0k	RES, 10.0k, 0.1%, 0.1W, 0603	RT0603BRD0710KL	Yageo America
R61, R62, R72, R76, R77, R78	0	47.5k	RES, 47.5k, 1%, 0.1W, 0603	RC0603FR-0747K5L	Yageo
R67	0	3.32k	RES, 3.32k, 1%, 0.1W, 0603	RC0603FR-073K32L	Yageo
R83	0	10kΩ	10kOhms 0.25W, 1/4W Gull Wing Surface Mount Trimmer Potentiometer Cermet 14.0 Turn Top Adjustment	ST-5ETW103	Nidec Copal Electronics
TP12, TP13, TP14, TP15	0		Test Point, Miniature, Yellow, TH	5004	Keystone Electronics
TP16, TP17	0		Test Point, Miniature, Black, TH	5001	Keystone Electronics
U2, U4	0		Low Voltage Adjustable Precision Shunt Regulator, 39ppm / degC, 15mA, -40 to 85degC, 3-pin SOT-23 (DBZ), Green (RoHS & no Sb/Br)	TLV431IDBZR	Texas Instruments
U3	0		Single low-voltage comparator with push-pull output 5-SC70 -40 to 125	TLV9030DCKR	Texas Instruments
U5	0		Single, 5.5V, 3MHz high-output-current (150mA) fast-shutdown (1µs) operational amplifier 5-SC70 -40 to 125	OPA310IDCKR	Texas Instruments

5 Additional Information

5.1 Trademarks

All trademarks are the property of their respective owners.

STANDARD TERMS FOR EVALUATION MODULES

1. *Delivery:* TI delivers TI evaluation boards, kits, or modules, including any accompanying demonstration software, components, and/or documentation which may be provided together or separately (collectively, an “EVM” or “EVMs”) to the User (“User”) in accordance with the terms set forth herein. User's acceptance of the EVM is expressly subject to the following terms.

   1.1 EVMs are intended solely for product or software developers for use in a research and development setting to facilitate feasibility evaluation, experimentation, or scientific analysis of TI semiconductors products. EVMs have no direct function and are not finished products. EVMs shall not be directly or indirectly assembled as a part or subassembly in any finished product. For clarification, any software or software tools provided with the EVM (“Software”) shall not be subject to the terms and conditions set forth herein but rather shall be subject to the applicable terms that accompany such Software

   1.2 EVMs are not intended for consumer or household use. EVMs may not be sold, sublicensed, leased, rented, loaned, assigned, or otherwise distributed for commercial purposes by Users, in whole or in part, or used in any finished product or production system.

2 *Limited Warranty and Related Remedies/Disclaimers*:

   2.1 These terms do not apply to Software. The warranty, if any, for Software is covered in the applicable Software License Agreement.

   2.2 TI warrants that the TI EVM will conform to TI's published specifications for ninety (90) days after the date TI delivers such EVM to User. Notwithstanding the foregoing, TI shall not be liable for a nonconforming EVM if (a) the nonconformity was caused by neglect, misuse or mistreatment by an entity other than TI, including improper installation or testing, or for any EVMs that have been altered or modified in any way by an entity other than TI, (b) the nonconformity resulted from User's design, specifications or instructions for such EVMs or improper system design, or (c) User has not paid on time. Testing and other quality control techniques are used to the extent TI deems necessary. TI does not test all parameters of each EVM. User's claims against TI under this Section 2 are void if User fails to notify TI of any apparent defects in the EVMs within ten (10) business days after delivery, or of any hidden defects with ten (10) business days after the defect has been detected.

   2.3 TI's sole liability shall be at its option to repair or replace EVMs that fail to conform to the warranty set forth above, or credit User's account for such EVM. TI's liability under this warranty shall be limited to EVMs that are returned during the warranty period to the address designated by TI and that are determined by TI not to conform to such warranty. If TI elects to repair or replace such EVM, TI shall have a reasonable time to repair such EVM or provide replacements. Repaired EVMs shall be warranted for the remainder of the original warranty period. Replaced EVMs shall be warranted for a new full ninety (90) day warranty period.

WARNING

Evaluation Kits are intended solely for use by technically qualified, professional electronics experts who are familiar with the dangers and application risks associated with handling electrical mechanical components, systems, and subsystems.

User shall operate the Evaluation Kit within TI’s recommended guidelines and any applicable legal or environmental requirements as well as reasonable and customary safeguards. Failure to set up and/or operate the Evaluation Kit within TI’s recommended guidelines may result in personal injury or death or property damage. Proper set up entails following TI’s instructions for electrical ratings of interface circuits such as input, output and electrical loads.

NOTE:

EXPOSURE TO ELECTROSTATIC DISCHARGE (ESD) MAY CAUSE DEGREDATION OR FAILURE OF THE EVALUATION KIT; TI RECOMMENDS STORAGE OF THE EVALUATION KIT IN A PROTECTIVE ESD BAG.

3 *Regulatory Notices:*

3.1 *United States*

3.1.1 *Notice applicable to EVMs not FCC-Approved:*

FCC NOTICE: This kit is designed to allow product developers to evaluate electronic components, circuitry, or software associated with the kit to determine whether to incorporate such items in a finished product and software developers to write software applications for use with the end product. This kit is not a finished product and when assembled may not be resold or otherwise marketed unless all required FCC equipment authorizations are first obtained. Operation is subject to the condition that this product not cause harmful interference to licensed radio stations and that this product accept harmful interference. Unless the assembled kit is designed to operate under part 15, part 18 or part 95 of this chapter, the operator of the kit must operate under the authority of an FCC license holder or must secure an experimental authorization under part 5 of this chapter.

3.1.2 *For EVMs annotated as FCC – FEDERAL COMMUNICATIONS COMMISSION Part 15 Compliant:*

CAUTION

This device complies with part 15 of the FCC Rules. Operation is subject to the following two conditions: (1) This device may not cause harmful interference, and (2) this device must accept any interference received, including interference that may cause undesired operation.

Changes or modifications not expressly approved by the party responsible for compliance could void the user's authority to operate the equipment.

FCC Interference Statement for Class A EVM devices

NOTE: This equipment has been tested and found to comply with the limits for a Class A digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference when the equipment is operated in a commercial environment. This equipment generates, uses, and can radiate radio frequency energy and, if not installed and used in accordance with the instruction manual, may cause harmful interference to radio communications. Operation of this equipment in a residential area is likely to cause harmful interference in which case the user will be required to correct the interference at his own expense.

FCC Interference Statement for Class B EVM devices

NOTE: This equipment has been tested and found to comply with the limits for a Class B digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference in a residential installation. This equipment generates, uses and can radiate radio frequency energy and, if not installed and used in accordance with the instructions, may cause harmful interference to radio communications. However, there is no guarantee that interference will not occur in a particular installation. If this equipment does cause harmful interference to radio or television reception, which can be determined by turning the equipment off and on, the user is encouraged to try to correct the interference by one or more of the following measures:

- *Reorient or relocate the receiving antenna.*
- *Increase the separation between the equipment and receiver.*
- *Connect the equipment into an outlet on a circuit different from that to which the receiver is connected.*
- *Consult the dealer or an experienced radio/TV technician for help.*

3.2 *Canada*

3.2.1 *For EVMs issued with an Industry Canada Certificate of Conformance to RSS-210 or RSS-247*

Concerning EVMs Including Radio Transmitters:

This device complies with Industry Canada license-exempt RSSs. Operation is subject to the following two conditions:

(1) this device may not cause interference, and (2) this device must accept any interference, including interference that may cause undesired operation of the device.

Concernant les EVMs avec appareils radio:

Le présent appareil est conforme aux CNR d'Industrie Canada applicables aux appareils radio exempts de licence. L'exploitation est autorisée aux deux conditions suivantes: (1) l'appareil ne doit pas produire de brouillage, et (2) l'utilisateur de l'appareil doit accepter tout brouillage radioélectrique subi, même si le brouillage est susceptible d'en compromettre le fonctionnement.

Concerning EVMs Including Detachable Antennas:

Under Industry Canada regulations, this radio transmitter may only operate using an antenna of a type and maximum (or lesser) gain approved for the transmitter by Industry Canada. To reduce potential radio interference to other users, the antenna type and its gain should be so chosen that the equivalent isotropically radiated power (e.i.r.p.) is not more than that necessary for successful communication. This radio transmitter has been approved by Industry Canada to operate with the antenna types listed in the user guide with the maximum permissible gain and required antenna impedance for each antenna type indicated. Antenna types not included in this list, having a gain greater than the maximum gain indicated for that type, are strictly prohibited for use with this device.

Concernant les EVMs avec antennes détachables

Conformément à la réglementation d'Industrie Canada, le présent émetteur radio peut fonctionner avec une antenne d'un type et d'un gain maximal (ou inférieur) approuvé pour l'émetteur par Industrie Canada. Dans le but de réduire les risques de brouillage radioélectrique à l'intention des autres utilisateurs, il faut choisir le type d'antenne et son gain de sorte que la puissance isotrope rayonnée équivalente (p.i.r.e.) ne dépasse pas l'intensité nécessaire à l'établissement d'une communication satisfaisante. Le présent émetteur radio a été approuvé par Industrie Canada pour fonctionner avec les types d'antenne énumérés dans le manuel d'usage et ayant un gain admissible maximal et l'impédance requise pour chaque type d'antenne. Les types d'antenne non inclus dans cette liste, ou dont le gain est supérieur au gain maximal indiqué, sont strictement interdits pour l'exploitation de l'émetteur

3.3 *Japan*

3.3.1 *Notice for EVMs delivered in Japan:* Please see http://www.tij.co.jp/lsds/ti_ja/general/eStore/notice_01.page 日本国内に輸入される評価用キット、ボードについては、次のところをご覧ください。

https://www.ti.com/ja-jp/legal/notice-for-evaluation-kits-delivered-in-japan.html

3.3.2 *Notice for Users of EVMs Considered "Radio Frequency Products" in Japan:* EVMs entering Japan may not be certified by TI as conforming to Technical Regulations of Radio Law of Japan.

If User uses EVMs in Japan, not certified to Technical Regulations of Radio Law of Japan, User is required to follow the instructions set forth by Radio Law of Japan, which includes, but is not limited to, the instructions below with respect to EVMs (which for the avoidance of doubt are stated strictly for convenience and should be verified by User):

1. Use EVMs in a shielded room or any other test facility as defined in the notification #173 issued by Ministry of Internal Affairs and Communications on March 28, 2006, based on Sub-section 1.1 of Article 6 of the Ministry's Rule for Enforcement of Radio Law of Japan,
2. Use EVMs only after User obtains the license of Test Radio Station as provided in Radio Law of Japan with respect to EVMs, or
3. Use of EVMs only after User obtains the Technical Regulations Conformity Certification as provided in Radio Law of Japan with respect to EVMs. Also, do not transfer EVMs, unless User gives the same notice above to the transferee. Please note that if User does not follow the instructions above, User will be subject to penalties of Radio Law of Japan.

【無線電波を送信する製品の開発キットをお使いになる際の注意事項】 開発キットの中には技術基準適合証明を受けていないものがあります。 技術適合証明を受けていないもののご使用に際しては、電波法遵守のため、以下のいずれかの措置を取っていただく必要がありますのでご注意ください。

1. 電波法施行規則第6条第1項第1号に基づく平成18年3月28日総務省告示第173号で定められた電波暗室等の試験設備でご使用いただく。
2. 実験局の免許を取得後ご使用いただく。
3. 技術基準適合証明を取得後ご使用いただく。

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3.3.3 *Notice for EVMs for Power Line Communication:* Please see http://www.tij.co.jp/lsds/ti_ja/general/eStore/notice_02.page

電力線搬送波通信についての開発キットをお使いになる際の注意事項については、次のところをご覧ください。https://www.ti.com/ja-jp/legal/notice-for-evaluation-kits-for-power-line-communication.html

3.4 *European Union*

3.4.1 *For EVMs subject to EU Directive 2014/30/EU (Electromagnetic Compatibility Directive)*:

This is a class A product intended for use in environments other than domestic environments that are connected to a low-voltage power-supply network that supplies buildings used for domestic purposes. In a domestic environment this product may cause radio interference in which case the user may be required to take adequate measures.

4 *EVM Use Restrictions and Warnings:*

4.1 EVMS ARE NOT FOR USE IN FUNCTIONAL SAFETY AND/OR SAFETY CRITICAL EVALUATIONS, INCLUDING BUT NOT LIMITED TO EVALUATIONS OF LIFE SUPPORT APPLICATIONS.

4.2 User must read and apply the user guide and other available documentation provided by TI regarding the EVM prior to handling or using the EVM, including without limitation any warning or restriction notices. The notices contain important safety information related to, for example, temperatures and voltages.

4.3 *Safety-Related Warnings and Restrictions:*

4.3.1 User shall operate the EVM within TI's recommended specifications and environmental considerations stated in the user guide, other available documentation provided by TI, and any other applicable requirements and employ reasonable and customary safeguards. Exceeding the specified performance ratings and specifications (including but not limited to input and output voltage, current, power, and environmental ranges) for the EVM may cause personal injury or death, or property damage. If there are questions concerning performance ratings and specifications, User should contact a TI field representative prior to connecting interface electronics including input power and intended loads. Any loads applied outside of the specified output range may also result in unintended and/or inaccurate operation and/or possible permanent damage to the EVM and/or interface electronics. Please consult the EVM user guide prior to connecting any load to the EVM output. If there is uncertainty as to the load specification, please contact a TI field representative. During normal operation, even with the inputs and outputs kept within the specified allowable ranges, some circuit components may have elevated case temperatures. These components include but are not limited to linear regulators, switching transistors, pass transistors, current sense resistors, and heat sinks, which can be identified using the information in the associated documentation. When working with the EVM, please be aware that the EVM may become very warm.

4.3.2 EVMs are intended solely for use by technically qualified, professional electronics experts who are familiar with the dangers and application risks associated with handling electrical mechanical components, systems, and subsystems. User assumes all responsibility and liability for proper and safe handling and use of the EVM by User or its employees, affiliates, contractors or designees. User assumes all responsibility and liability to ensure that any interfaces (electronic and/or mechanical) between the EVM and any human body are designed with suitable isolation and means to safely limit accessible leakage currents to minimize the risk of electrical shock hazard. User assumes all responsibility and liability for any improper or unsafe handling or use of the EVM by User or its employees, affiliates, contractors or designees.

4.4 User assumes all responsibility and liability to determine whether the EVM is subject to any applicable international, federal, state, or local laws and regulations related to User's handling and use of the EVM and, if applicable, User assumes all responsibility and liability for compliance in all respects with such laws and regulations. User assumes all responsibility and liability for proper disposal and recycling of the EVM consistent with all applicable international, federal, state, and local requirements.

5. *Accuracy of Information:* To the extent TI provides information on the availability and function of EVMs, TI attempts to be as accurate as possible. However, TI does not warrant the accuracy of EVM descriptions, EVM availability or other information on its websites as accurate, complete, reliable, current, or error-free.

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