LM5170-Q1 EVM User Guide

The LM5170EVM-BIDIR Evaluation Module (EVM) is designed to showcase the LM5170-Q1 high performance dual-channel bidirectional controller suitable for, but not limited to, the automotive 48-V to 12-V dual battery system applications.

The EVM can be configured to achieve a bidirectional power converter in the form of either the current source or voltage source. The direction of power flow can be controlled either by an external command signal or by the on-board jumper. Through the onboard interface headers, the EVM can be operated by a DSP, an FPGA, an MCU, or other digital controllers. Two EVMs can be paralleled to make a 3 or 4 phases interleaved converter for higher power. More EVMs can be paralleled for greater number of phases. Many convenient jumper headers are also included for versatile configurations of the EVM.

Refer to the *LM5170-Q1 Multiphase Bidirectional Current Controller Datasheet* (SNVSAQ6) for detailed technical information of the LM5170-Q1 device.

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1 Features and Electrical Performance

The EVM supports the following features and performance capabilities:

- Input Operating Voltage Ranges
  - The 48VDC-Port 6 V to 75 V, in the Buck Mode
  - The 12VDC-Port 3 V to 48 V, in the Boost Mode
- Output Voltage Regulation (With the Onboard Outer Voltage Loop Control Activated)
  - 14.5-V Output Voltage at the 12VDC-Port, in the Buck Mode
  - 50.5-V Output Voltage at the 48VDC-Port, in the Boost Mode
- Operating Current
  - 60-Adc Maximum from or into the 12VDC-Port
  - Typical 1% Current Regulation Accuracy
  - Typical 1% Current Monitor Accuracy
- Switching Frequency:
  - Standalone Fsw = 100 kHz
  - Able to Synchronize to an External Clock from 80 kHz to 120 kHz.
- Maximum Efficiency: >97%
- OVP Threshold
  - 75 V at the 48VDC-Port
  - 22 V at the 12VDC-Port
  - Synchronous Rectifier Diode Emulation Function Preventing Negative Current
- Other Convenient Features
  - Optional Onboard Wide-VIN™ LM5118-Q1 Buck-Boost Converter as the +10-V Supply
  - Onboard Ultra Low IQ TPS709-Q1 LDOs for +3.3-V and +5.0-V Bias Voltages for Convenient EVM Configurations and for Biasing the External MCU through Headers.
  - Onboard LM26LV Temperature Sensors Monitoring Local Temperatures of Power MOSFETs, With Optional Overtemperature Shutdown and LED Indicator.
  - LED indicators of Buck and Boost Operating Modes.
  - Optional Channel Current Shunt AC Filters for Accurate DVM Reading (Unpopulated).

The electrical performance of the EVM is show in Table 1. Figure 1 shows the simplified EVM schematic.

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Table 1. Electrical Performance

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
INPUT CHARACTERISTICS					
48VDC-Port	Buck mode operation (DIR > 2 V)	6	48	70	V
12VDC-Port	Boost mode operation (DIR < 1 V)	3	12	48	V
OUTPUT CHARACTERISTICS					
Current delivery	12VDC-Port input or output current (dual-channel enabled)	0		60	A
Current regulation accuracy	12VDC-Port current vs ISETA command voltage		1%		
Channel current monitor accuracy	When onboard IOUT1 and IOUT2 termination filter activated		1%		
48VDC-Port	Boost mode operation (DIR < 1 V, onboard analog output voltage loop closed)		50.5		V
12VDC-Port	Buck mode operation (DIR > 2 V, onboard analog output voltage loop closed)		14.5		V
SYSTEM CHARACTERISTICS					
Switching frequency			100		kHz
External clock synchronization		80		120	kHz
Full load efficiency			97%		
Junction temperature, T_J		–40		150	°C

2 Setup

2.1 EVM Configurations

Figure 2 shows the EVM board top view and circuit layout partitions. The EVM has the following ports:

- 48VDC-Port: Connected to 48-V battery rail
- 12VDC-Port: Connected to 12-V battery rail
- J17 (60-Pin Header): Interfacing the external control commands or MCU
- J18 (60-Pin Header): Interfacing the slave EVM's J17 in a 4-phase system consisting of two EVMs
- Master Enable Using J17-pin 5: Providing a voltage of 2.5 V to 6 V to operate the EVM.
- Channel Current Setting: Analog programming at J17-pin 11, and digital programming at J17-pin 13.

Table 2 through Table 5 list the functions of the EVM jumpers and headers. They offer flexible configurability and programmability of the EVM for various use cases including but not limited to the following:

- A unidirectional or bidirectional current source
- A unidirectional or bidirectional voltage source
- Dynamic phase adding and shedding in a 4-phase system consisting of two EVMs
- Dynamic MOSFETs dead time adjustment
- Individual channel current monitoring or total current monitoring
- Programmable undervoltage lockout (unpopulated)
- Synchronization to external clock
- External shutdown command through nFAULT pin (J17-pin45)

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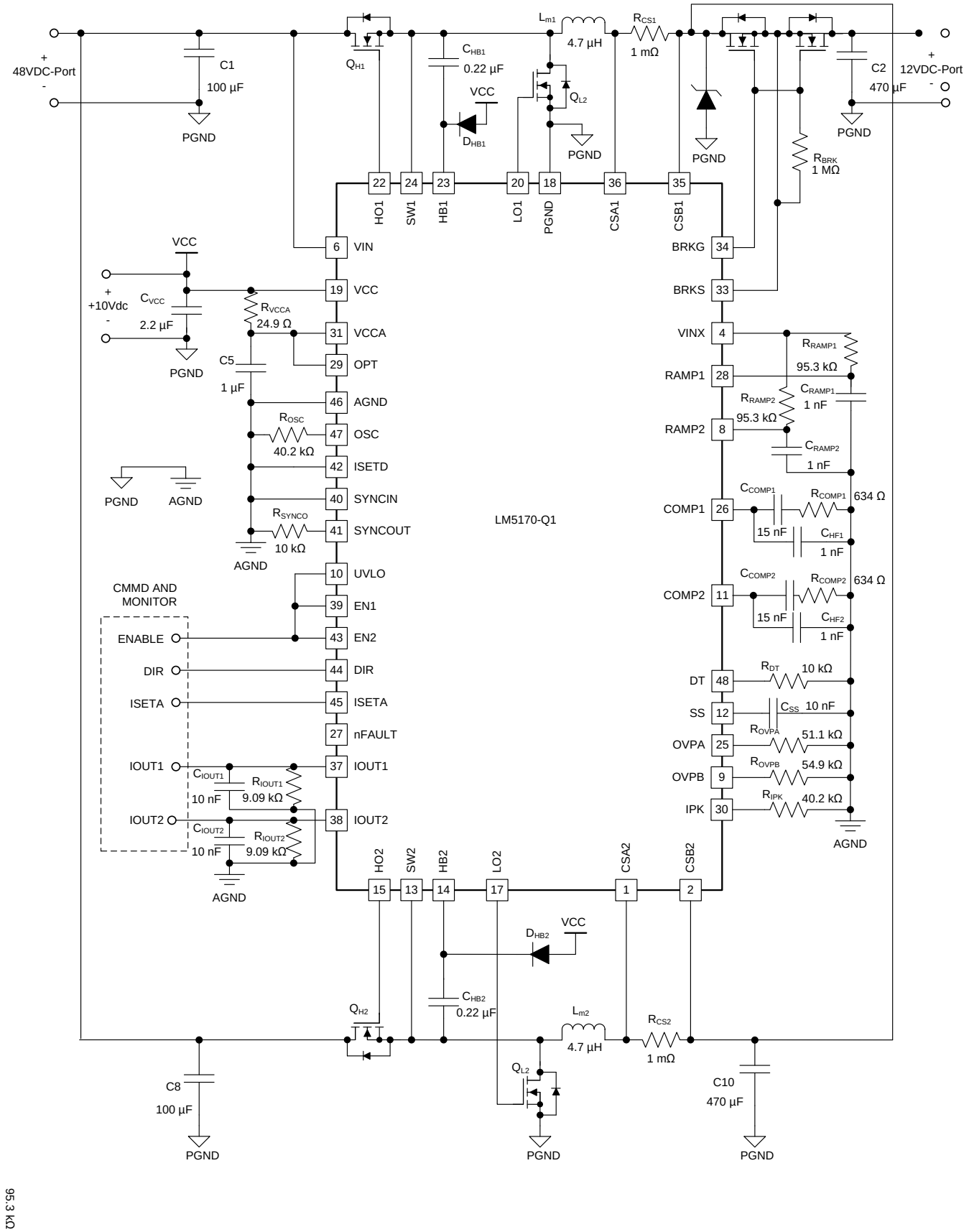


Figure 1. Simplified EVM Schematic

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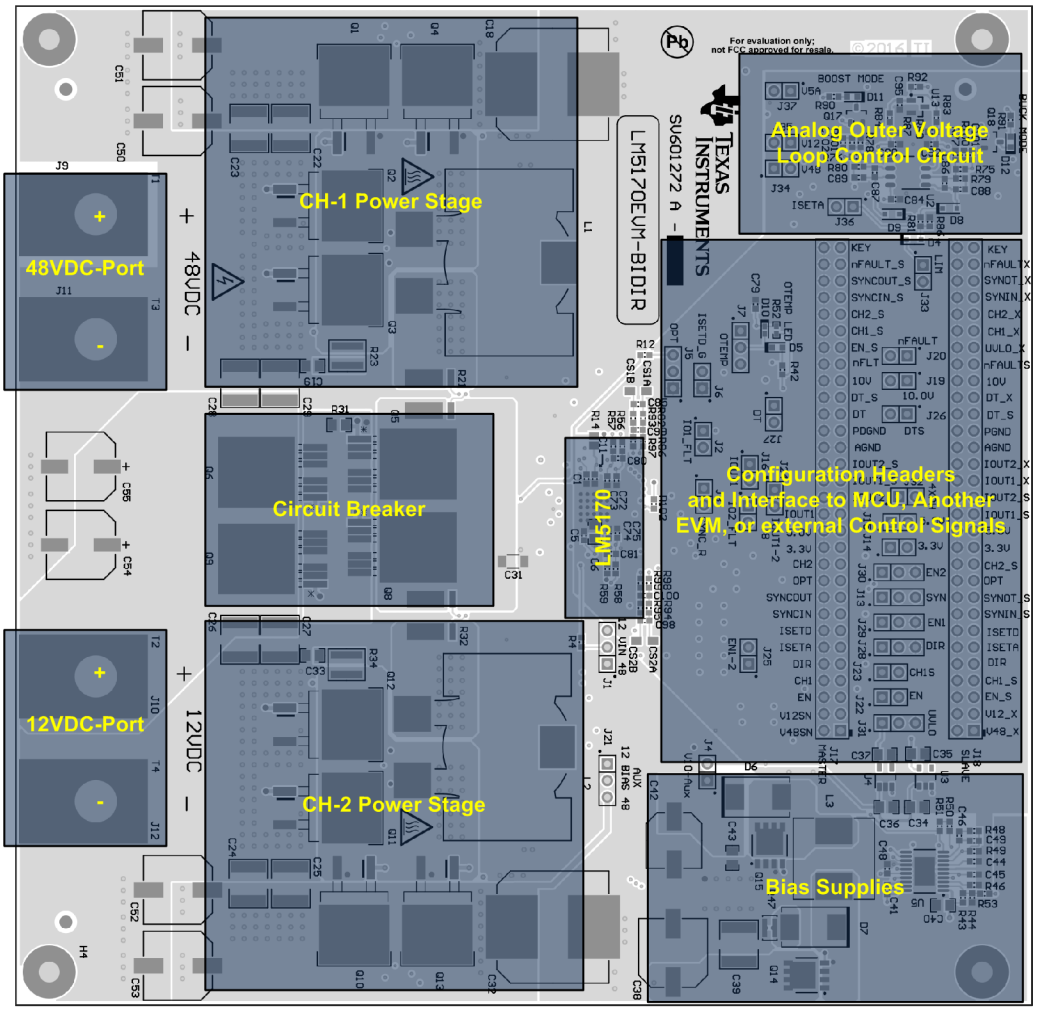


Figure 2. EVM Board Top View and Layout Partitions

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Table 2. Three-Pin Header Settings

HEADER	SIGNAL	PINS	FUNCTION DESCRIPTION	DEFAULT
J1	—	--(1)	No UVLO Programming	Y
		(1,2)(2)	48VDC-Port UVLO Control	
		(2,3)(3)	12VDC-Port UVLO Control	
J5	OPT	--	External interleaving control through J17	
		(1,2)	CH-2 240 degree delay from CH-1	
		(2,3)	CH-2 180 degree delay from CH-1	Y
J7	OTEMP	--	Onboard Overtemperature protection disabled	Y
		(1,2)	Overtemperature protection in hiccup mode	
		(2,3)	Overtemperature protection in latched shutdown	
J13	SYNC	--	Slave EVM not sync to master EVM	Y
		(1,2)	Slave EVM sync to master via J18	
		(2,3)	Slave EVM sync to external Clock	
J21	BIAS	--	Use external 10V supply	
		(1,2)	Onboard +10V produced from the 12VDC-Port	
		(2,3)	Onboard +10V produced from the 48VDC-Port	Y
J28	DIR	--	External DIR control through J17	
		(1,2)	Onboard DIR command for buck operation	Y
		(2,3)	Onboard DIR command for boost operation	
J29	EN1	--	External CH-1 enable control through J17	
		(1,2)	Onboard CH-1 enable	Y
		(2,3)	Onboard CH-1 disable	
J30	EN2	--	External CH-1 enable control through J17, overridden by J25.	Y
		(1,2)	Onboard CH-2 enable	
		(2,3)	Onboard CH-2 disable	
J31	UVLO	--	External EVM enable through J17	Y
		(1,2)	Onboard EVM enable, if external 3.3V is supplied to J17-pin23.	
		(2,3)	EVM disable	

(1) – = All jumper pins open.
(2) (1,2) = Pins 1 and 2 closed.
(3) (2,3) = Pins 2 and 3 closed.

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Table 3. Two-Pin Header Settings

HEADER	SIGNAL	PINS	FUNCTION DESCRIPTION	DEFAULT
J2	IOUT1	O(1)	External IOUT1 termination	
		C(2)	Onboard IOUT1 termination	Y
J3	SYNCOUT	O	Enable the fault detection	Y
		C	Disable the fault detection disabled	
J4	VCC	O	An external 10-V supply as VCC supply	Y
		C	The onboard 10-V regulator as VCC supply	
J6	ISETD	O	ISETD input disabled	
		C	ISETD input is enabled	Y
J8	IOUT2	O	External IOUT2 signal termination	
		C	Onboard IOUT2 signal termination	Y
J14	3.3 V	O	Onboard 3.3-V bias voltage disconnected from the slave EVM	Y
		C	Onboard 3.3-V bias voltage feeding the slave EVM	
J15	5 V	O	Onboard 5-V bias voltage disconnected from the slave EVM	Y
		C	Onboard 5-V bias voltage feeding the slave EVM	
J16	IOUT_All	O	Independent channel monitor	Y
		C	Combined total monitor in master/slave configuration. Requiring J25 to be closed too.	
J19	10 V	O	10-V bias voltage disconnected from the slave EVM	Y
		C	10-V bias voltage feeding the slave EVM	
J20	nFAULT	O	Independent master/slave nFAULT signal	Y
		C	Combined master/slave nFAULT signal	
J22	EN	O	Independent enable control of the master and slave EVMs	Y
		C	Combined enable control of the master and slave EVMs	
J23	CH1S	O	Independent slave EVM CH-1 enable	Y
		C	Combined master/slave channel enable	
J24	IOUT1-2	O	Independent channel current monitors	Y
		C	Combined dual-channel current monitor	
J25	EN1-2	O	Independent channel enable	Y
		C	Combined dual-channel enable	
J26	DTS	O	Independent DT adjustment input for the slave EVM	Y
		C	Combined DT adjustment for both the master and slave EVMs	
J27	DT	O	External programmable DT adjustment input	Y
		C	Onboard DT setting	
J32	OPT/ EN2_slave	O	3- and 4-phase transition disabled	Y
		C	3- and 4-phases transition enabled	
J33	ILIM	O	External current limit control input	Y
		—	Do not close	
J34	48VDC Sense	O	Boost analog outer voltage loop control disabled	Y
		C	Boost analog outer voltage loop control enabled	
J35	12VDC Sense	O	Buck analog outer voltage loop control disabled	Y
		C	Buck analog outer voltage loop control enabled	
J36	ISETA	O	Analog outer voltage loop control disabled	Y
		C	Analog outer voltage loop control enabled	
J37	5 V	O	Analog outer voltage loop control disabled	Y
		C	Analog outer voltage loop control enabled	

(1) Jumper pins open.
(2) Jumper pins closed.

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Table 4. J17 60-Pin Header Description[1]

PIN	SIGNAL	I/O	DESCRIPTION
1	V48SN	O[2]	48V-port voltage sense during operation
3	V12SN	O	12V-port voltage sense during operation
5	EN (MASTER ENABLE)	I[3]	Master EVM enable (connect to the UVLO pin of the IC)
7	CH1	I	CH-1 control (connect to the EN1 pin of the IC)
9	DIR	I	Direction command
11	ISETA	I	Channel current setting (analog voltage)
13	ISETD	I	Channel current setting (PWM signal)
15	SYNCIN	I	Input of the external clock to be synchronized to
17	SYNCOUT	O	Clock output signal
19	OPT	I	Interleave angle setting
21	CH2	I	CH-2 control (connect to the EN2 pin of the IC)
23	+3.3 V	O	Output of onboard +3.3-V voltage
25	+5 V	O	Output of onboard +5-V voltage
27	IOUT1	O	CH-1 monitor
29	IOUT2	O	CH-2 current monitor
31	IOUT1_S	O	Slave EVM CH-1 monitor in 3 or 4 phases
33	IOUT2_S	O	Slave EVM CH-2 current monitor in 3 or 4 phases
35	AGND	I/O	Reference GND for control signals
37	PGND	O	Power ground of the DC-DC converter
39	DT	I	Dead time adjustment pin
41	DT_S	I	Slave dead time adjustment pin
43	+10 V	I/O	Input of +10-V bias supply, or output of onboard +10-V bias supply
45	nFAULT	I/O	Fault report flag, or external shutdown command pin
47	ENABLE_S	I	Slave EVM enable (connect to the UVLO pin of the slave IC)
49	CH1_S	I	Slave EVM CH-1 control (connect to the EN1 pin of the slave IC)
51	CH2_S	I	Slave EVM CH-2 control (connect to the EN2 pin of the slave IC)
53	SYNCIN_S	I	Input of the external clock for the slave to be synchronized to
55	SYNCOUT_S	O	Slave EVM clock output signal
57	nFAULT_S	I/O	Slave EVM fault report flag, or external shut down command input pin
59	KEY	—	No Connect
All even number pins	AGND	I/O	All signals' return

(1) J17 is the interface connector to MCU, or external digital controller, or to the master EVM's J18 if the host EVM serves as a slave in the multiphase configuration.
(2) I = input pin
(3) O = output pin

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Table 5. J18 60-Pin Header Description[1]

PIN	SIGNAL	I/O	DESCRIPTION
1	V48_X	—	No Connect
3	V12_X	—	No Connect
5	ENABLE_S	I[2]	Slave EVM enable (connect to the UVLO pin of the slave IC)
7	CH1_S	I	Slave EVM CH-1 control (connect to the EN1 pin of the IC)
9	DIR	I	Direction command
11	ISETA	I	Channel current setting (analog voltage)
13	ISETD	I	Channel current setting (PWM signal)
15	SYNCIN_S	I	The external clock input for the slave
17	SYNCOUT_S	O[3]	Slave EVM clock output signal
19	OPT	I	Interleave angle setting
21	CH2_S	I	Slave EVM CH-2 control (connect to the EN1 pin of the IC)
23	+3.3 V	I	Output of onboard +3.3-V voltage
25	+5 V	I	Output of onboard +5-V voltage
27	IOUT1_S	O	Slave EVM CH-1 monitor in 3 or 4 phases
29	IOUT2_S	O	Slave EVM CH-2 current monitor in 3 or 4 phases
31	IOUT1_X	—	Not used
33	IOUT2_X	—	Not used
35	AGND	I/O	Reference GND for control signals
37	PGND	O	Power ground of the DC-DC converter
39	DT_S	I	Slave EVM dead time adjustment pin
41	DT_X	—	No Connect
43	+10 V	I	Input of +10-V bias supply, or output of onboard +10-V bias supply
45	nFAULT_X	I/O	Slave EVM fault report flag, or external shutdown command pin
47	UVLO_X	—	No Connect
49	CH1_X	—	No Connect
51	CH2_X	—	No Connect
53	SYNCIN_X	—	No Connect
55	SYNCOUT_X	—	No Connect
57	nFAULT_X	—	No Connect
59	KEY	—	No Connect
All even number pins	AGND	I/O	All signals' return

(1) J18 is the interface connector to the slave EVM in the multiphase configuration if the host EVM serves as the master. All control commands and control signals are sent through J18 to the slave EVM's J17.

(2) I = input pin

(3) O = output pin

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2.2 Bench Setup

Figure 3 shows the typical bench setup to operate the EVM in the bidirectional power system environment. The combination of the Electronic Load (E-Load) and bench Power Supply (PS) emulates a battery capable of both sourcing and sinking current. A relatively Higher Voltage Power Supply (HV-PS) and E-Load (HV-E-Load) should be used for the 48VDC-port, and a Lower Voltage Power Supply (LV-PS) and E-Load (LV-E-Load) for the 12VDC-port. The external control signals shown as dashed lines can also be created with the onboard headers.

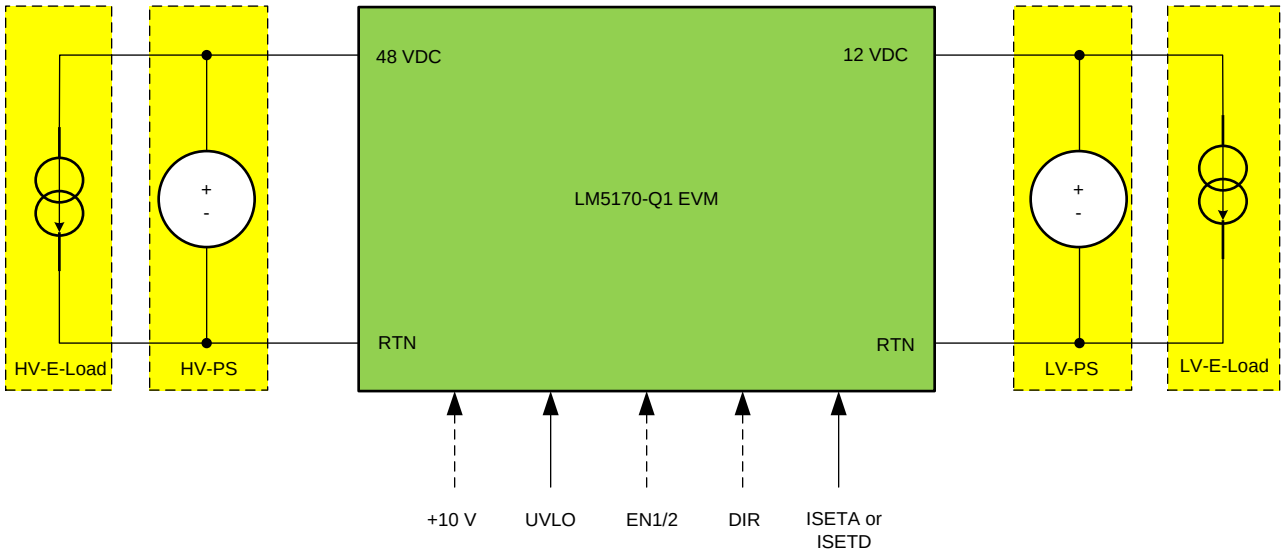


Figure 3. Bidirectional Converter Bench Setup

To operate the EVM to full power, the initial setup should follow the guidelines below:

- Set the LV-E-Load to Constant Current (CC) of 62 A
- Set the LV-PS voltage at 12 V, and the current limit at 63 A
- Set the HV-E-Load to CC of 14 A
- Set the HV-PS voltage at 48 V, and the current limit at 15 A

Note that in Buck Mode operation, the HV-E-load can be turned off, and in Boost Mode operation, the LV-E-load can be turned off. If the output voltage loop is closed, the LV-PS can be disconnected in Buck Mode operation. In Boost Mode operation, the HV-PS is required for Boost start-up, which is limited by the onboard circuit breaker function. If the circuit breaker MOSFETS are shorted and J3 is closed, the HV-PS is not needed for Boost Mode operation.

2.3 Test Equipment

Power Supplies: HV-PS should be capable of 80V/20A, and LV-PS 40V/80A. To operate 2 EVMs in 4 phase configuration, the HV-PS and LV-PS capabilities should be doubled. Bench power supplies to generate UVLO, ISETA, DIR, and EN1 and EN2 signals should be capable of 5V/0.1A.

Electronic Loads: The HV-E-Load should be capable of 80V/20A, and LV-E-Load 40V/80A. To operate 2 EVMs in 4 phase configuration, the E-Loads' capabilities should be doubled.

Meters: Because most current meters are rated only to 10 A, shunts are recommended to measure the current using a DVM.

Oscilloscope: An oscilloscope and 10x probes with at least 20-MHz bandwidth is required. Current probe capable of 50 A is required to monitor the inductor current via a wire loop inserted to the non-switching side of the inductor.

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3 Test Procedure

Please read the LM5170-Q1 datasheet (SNVSAQ6) and this user guide before using the EVM. A typical EVM test bench setup is shown in Figure 2. The power supplies and loads should be capable of handling the input and output voltage and current rating of the board.

The EVM operation requires the four external control signals, which are UVLO, DIR, EN1/2, and ISETA or ISETD (refer to Figure 3).

- UVLO: The master enable command. Apply a voltage > 2.5 V and < 6 V between J17-pins 5 and 6 to enable the EVM. Pulling the voltage at J17-pin 5 low will keep the EVM in shutdown mode.
- DIR: the current direction command. Apply a voltage > 2 V at J17-pin 9 or J18-pin 9 to operate the EVM in Buck Mode. Apply a voltage < 1 V at the same pin to operate the EVM in Boost Mode. DIR command can also be programmed using J28. Note that DIR must be either active high or low to operate the EVM. If the DIR signal is floating, the EVM will not run.
- EN1 and EN2: The channel switching enable commands. Apply a voltage > 2 V at J17-pin 7 will turn on CH-1 converter, and at J17-pin 21 will turn on CH-2 converter. Removing the voltage at the EN1 and EN2 pins to disable each channel. The channel enable can also be controlled by J29, J30 and J25.
- ISETA or ISETD: The Channel current regulation setting. Applying an analog voltage across J17-pins 11 and 12, or J18-pins 11 and 12, or a PWM signal across J17-pins 13 and 14, or J18-pins 13 and 14, the EVM will regulate the channel DC current, which is also the power inductor dc current, to a level proportional the ISETA voltage or ISETD PWM duty ratio. ISETA is controlled by the onboard analog outer voltage control loop when it is closed. Note that, ISETA=1.5 V, or ISETD PWM duty ratio of 48%, will command the EVM to produce 60 A into or out of the 12VDC-port, depending on the operation mode.

For initial test, TI recommends using the onboard 10-V bias supply by closing the J4 and J21-pins 2 and 3. The user can also apply an external 10-V bias supply between J17-Pins 43 and 44, but remember to open J4 and J21 in order to disable the onboard 10-V bias supply.

3.1 Buck Mode Power-Up and Power-Down Sequence

1. Refer to Table 2 through Table 5 for proper jumper settings
2. Turn on the HV-PS power supply.
3. Turn on the LV-PS power supply and LV-E-Load.
4. Apply a voltage > 2.5 V and < 6 V at J17-pin 5 (Master Enable).
5. Apply an analog voltage gradually rising from 0V to 1.5V at J17-pin 11 or J18-pin 11 (ISETA), or a PWM signal of duty ratio of 0 to 48% at J17-pin 13 or J18-pin 13.
6. Perform the test.
7. After the tests are done, turn off the ISETA or ISETD signal, remove the voltage at J17-pin 5, and turn off the E-Load, LV-PS and HV-PS.

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3.2 Boost Mode Power-Up and Power-Down Sequence

1. Refer to Table 2 through Table 5 for proper jumper settings.
2. Turn on the HV-PS power supply and HV-E-Load.
3. Turn on the LV-PS power supply.
4. Apply a voltage > 2.5 V and < 6 V at J17-pin 5 (Master Enable).
5. Apply an analog voltage gradually rising from 0 V to 1.5 V at J17-pin 11 or J18-pin 11 (ISETA), or a PWM signal of duty ratio of 0 to 48% at J17-pin 13 or J18-pin 13.
6. Perform the test.
7. After the tests are done, turn off the ISETA or ISETD signal, remove the voltage at J17-pin 5, and turn off the E-Load, HV-PS and LV-PS.

3.3 Bidirectional Operation Power-Up and Power-Down Sequence

1. Refer to Table 2 through Table 5 for proper jumper settings.
2. Turn on the HV-PS power supply and HV-E-Load.
3. Turn on the HV-PS power supply and HV-E-Load.
4. Apply a voltage > 2.5 V and < 6 V at J17-pin 5 (Master Enable).
5. Apply the direction command (DIR) at J17-pin 9 or J18-pin 9.
6. Apply an analog voltage gradually rising from 0 V to 1.5 V at J17-pin 11 or J18-pin 11 (ISETA), or a PWM signal of duty ratio of 0 to 48% at J17-pin 13 or J18-pin 13.
7. Dynamically flip the DIR signal state between 0 (DIR < 1 V) and 1 (DIR > 2 V), the EVM will operate in dynamic bidirectional transition mode.
8. Perform the test.
9. After the tests are done, turn off the ISETA or ISETD signal, turn off the DIR signal, remove the voltage at J17-pin 5, and turn off the E-Load, HV-PS and LV-PS.

3.4 Operating the EVM With the Onboard Analog Loop Control Circuit

1. J34 through J37 headers must be closed to activate the onboard analog voltage loop control circuit.
2. To operate the EVM as a regulated voltage source, follow the power up and power down sequence for buck mode or boost mode operation whichever is appropriate.
3. Note that with the circuit breaker MOSFETs employed by the EVM, HVPS should be applied for boost start-up. After the start-up, it can be turned off. Only after the circuit breaker MOSFETs are replaced with a direct short across the breaker will the EVM not require the HV-PS to assist boost start-up.

3.5 Operating the EVM With External MCU or Other Digital Circuit

1. Onboard analog voltage loop control circuit must be disconnected.
2. Use J17 header to interface the external MCU or other control circuit.
3. Follow the power-up and power-down sequence for buck mode or boost mode operation.

Signals required from an MCU or other digital control circuit include UVLO, EN1/EN2, DIR, ISETA or ISETD. Contact TI for info on operating the EVM with the MSP431 Launchpad or C2000 MCU.

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4 Test Data

4.1 Efficiency

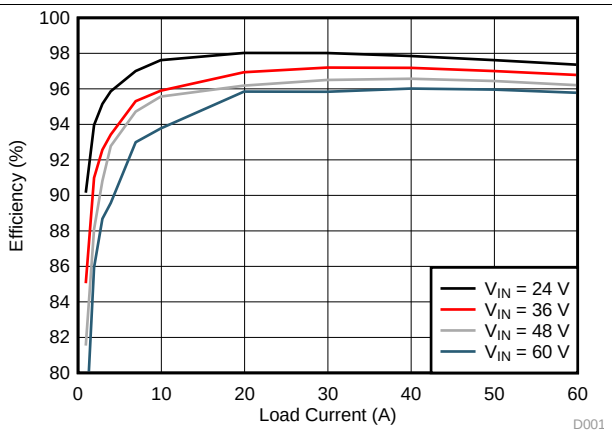


Figure 4. Buck Mode Efficiency vs Input Voltage and Load Current: V_{OUT} = 14.5 V

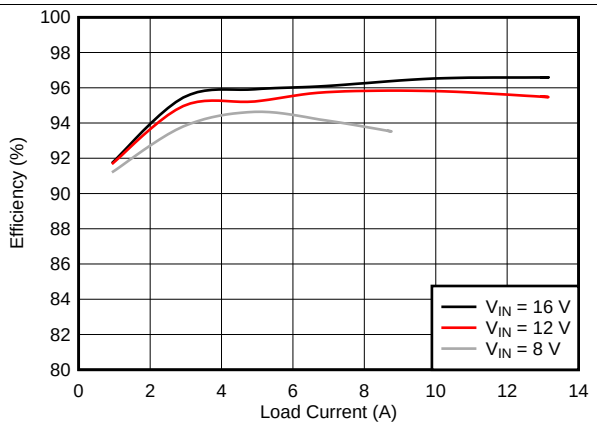


Figure 5. Boost Mode Efficiency vs Input Voltage and Load Current: V_{OUT} = 50.5 V

4.2 Current Regulation and Monitoring

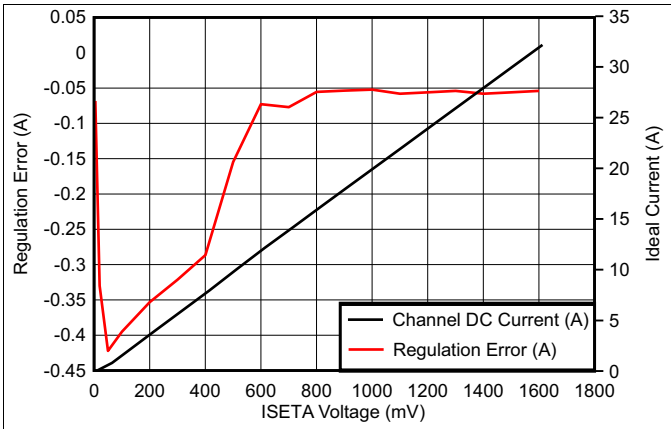


Figure 6. Channel DC Current Regulation vs ISETA: Buck Mode

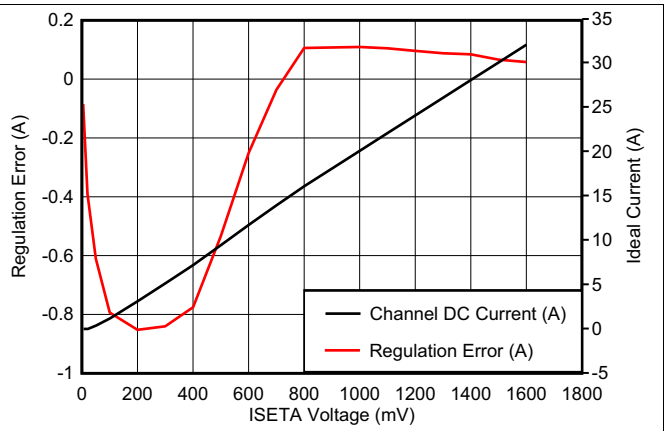


Figure 7. Channel DC Current Regulation vs ISETA: Boost Mode

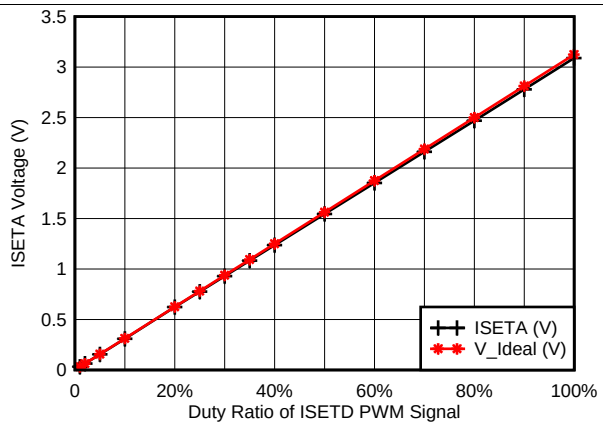


Figure 8. ISETD to ISETA Conversion

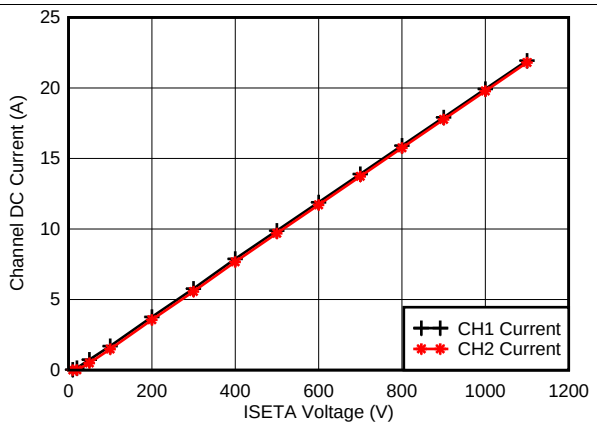


Figure 9. Current Sharing Between Two Channels

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4.3 Typical Master Enable Power Up and Shutdown

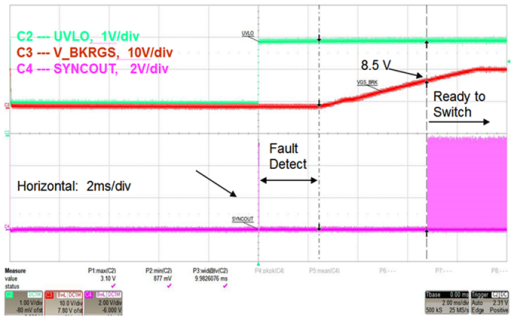


Figure 10. EVM Enable Power-Up Sequence

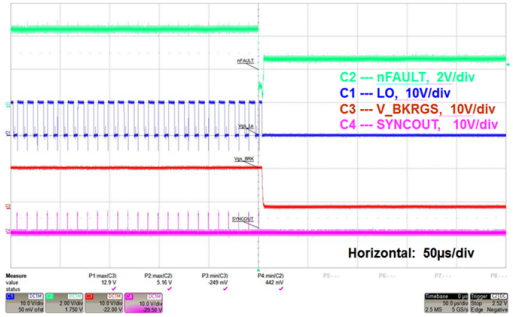


Figure 11. EVM Shutdown by nFAULT

4.4 Channel Enable and Disable

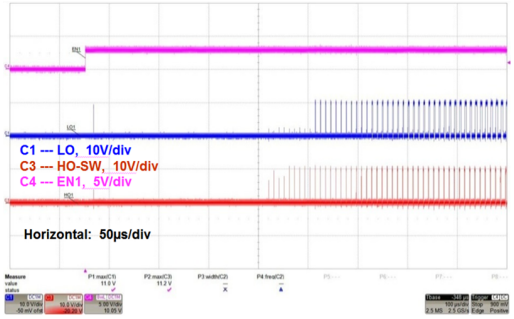


Figure 12. Buck Mode Enable

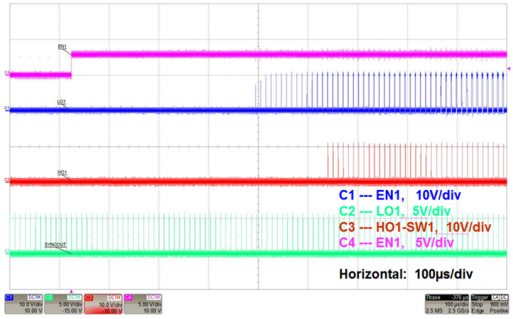


Figure 13. Boost Mode Enable

4.5 Dual-Channel Interleaving Operation

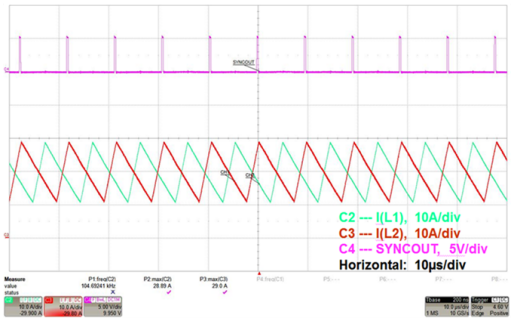


Figure 14. Dual-Channel Interleaving Operation in Buck Mode: 20 A Per Channel

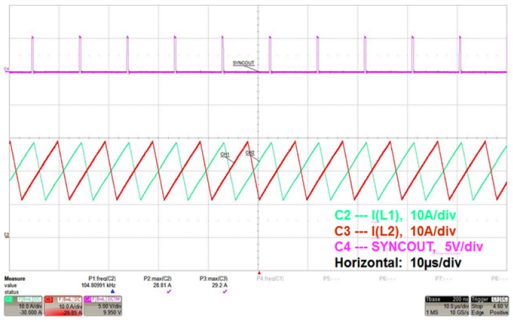


Figure 15. Dual-Channel Interleaving Operation in Boost Mode: 20 A Per Channel

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4.6 ISETA Tracking

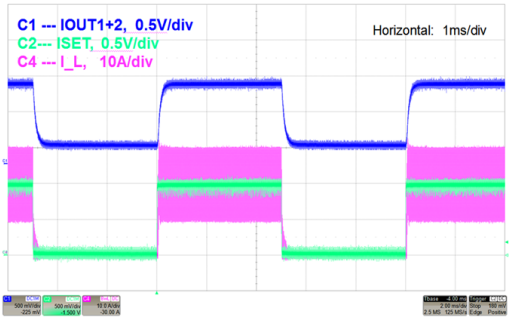


Figure 16. Inductor Current Tracking: Buck Mode

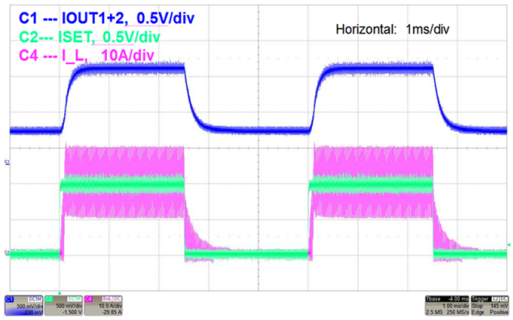


Figure 17. Inductor Current Tracking: Boost Mode

4.7 Diode Emulation Preventing Negative Currents

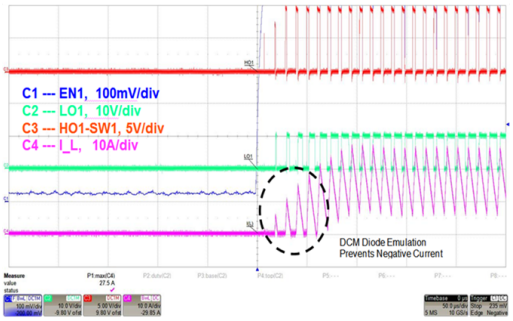


Figure 18. Diode Emulation During Start-Up

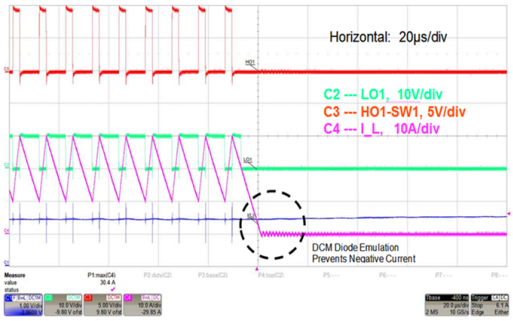


Figure 19. Diode Emulation During Shutdown

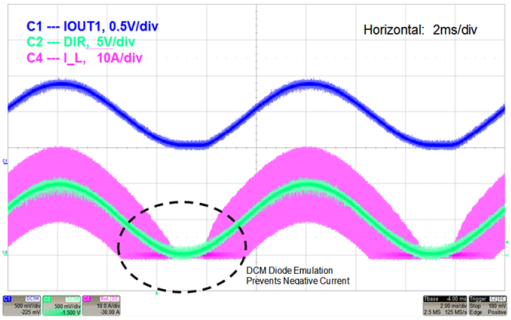


Figure 20. Diode Emulation in DCM

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4.8 Dynamic DIR Change

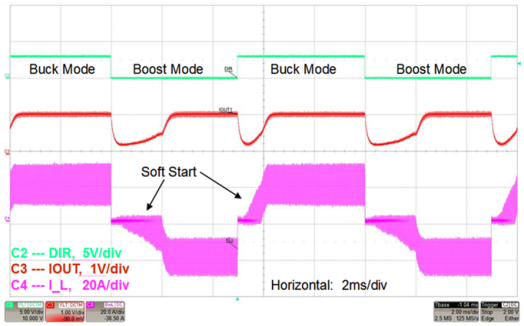


Figure 21. Response to Dynamic DIR Change

4.9 Step Load Response

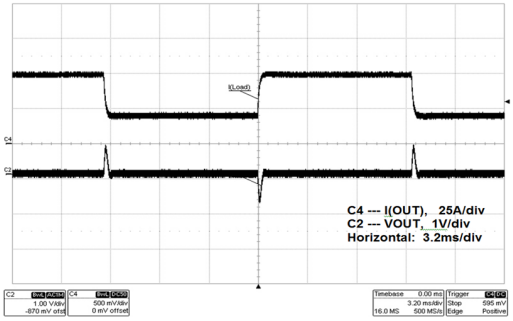


Figure 22. Step Load Response: Buck Mode; 20-A to 50-A Load Step 1A/µs

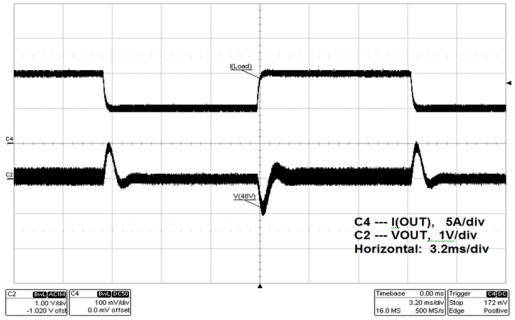


Figure 23. Step Load Response: Boost Mode, 5-A to 10-A Load Step 1A/µs

4.10 OVP

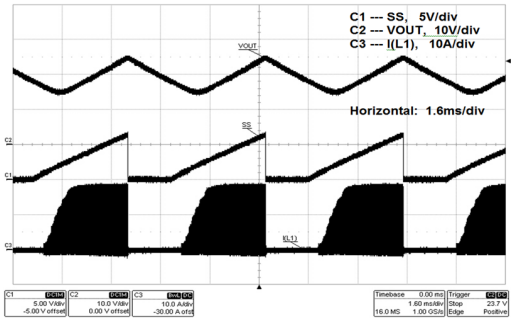


Figure 24. OVP in Buck Mode

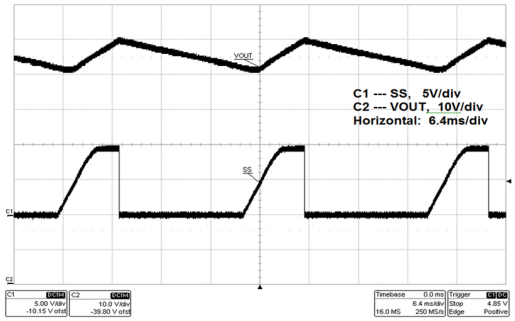


Figure 25. OVP in Boost Mode

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4.11 Output Short Circuit

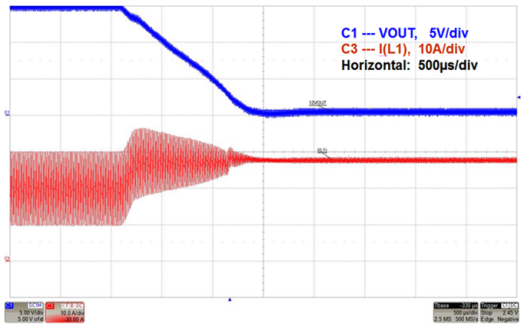


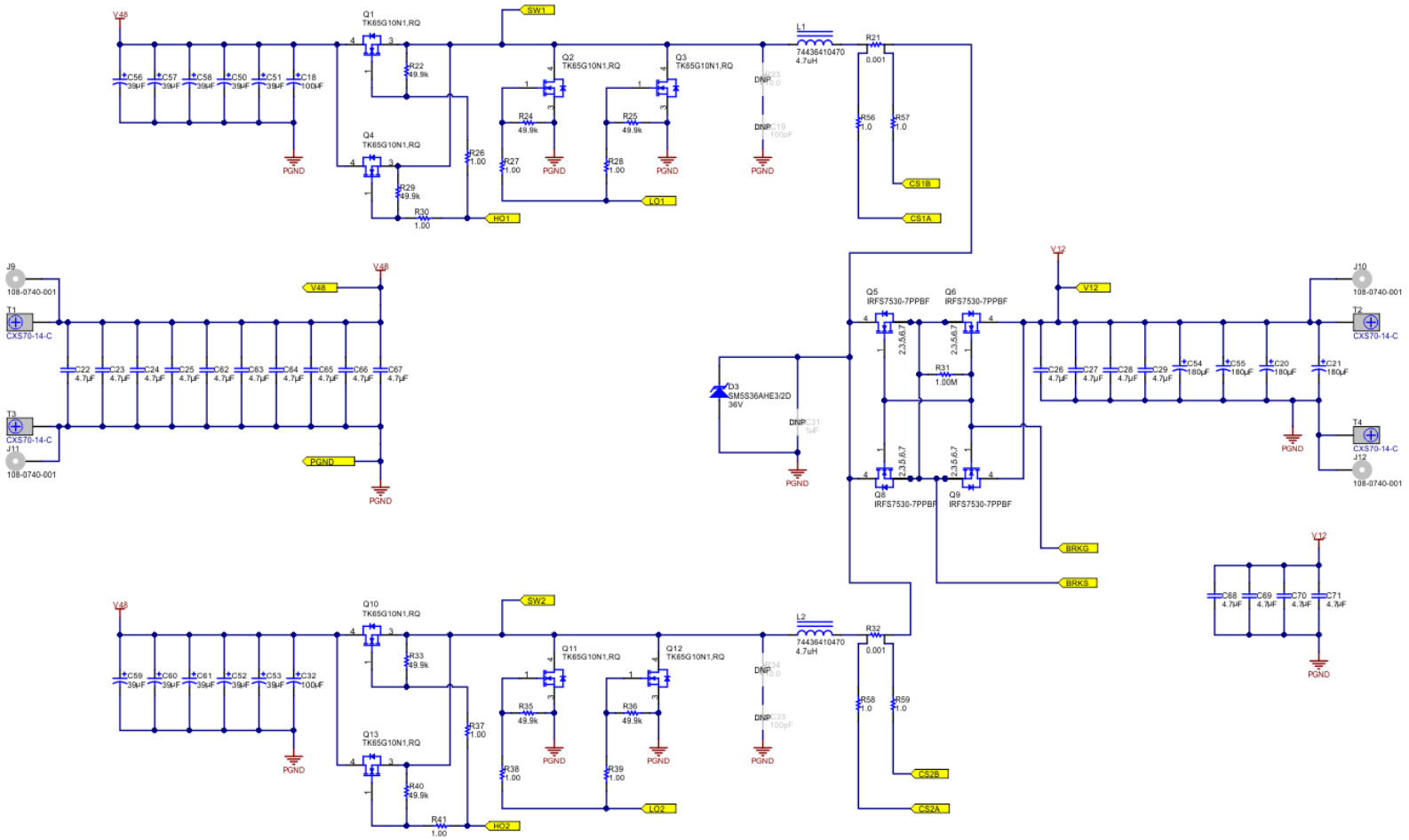
Figure 26. Output Short Circuit: Buck Mode

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5 Design Files

5.1 Schematics

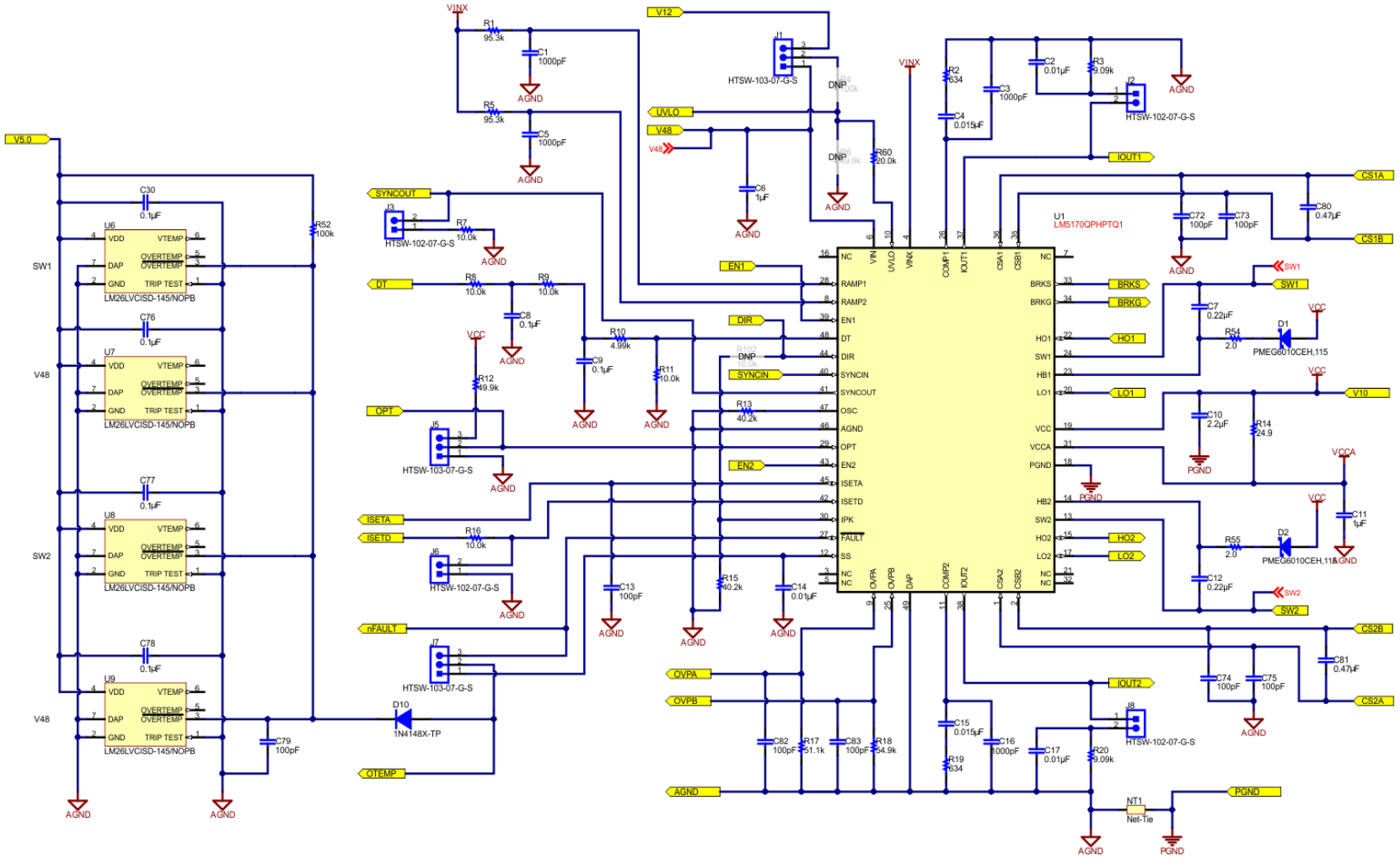
To download the Schematics for the EVM board, see the design files at www.ti.com/tool.



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Figure 27. EVM Schematic Part 1: Power Circuit

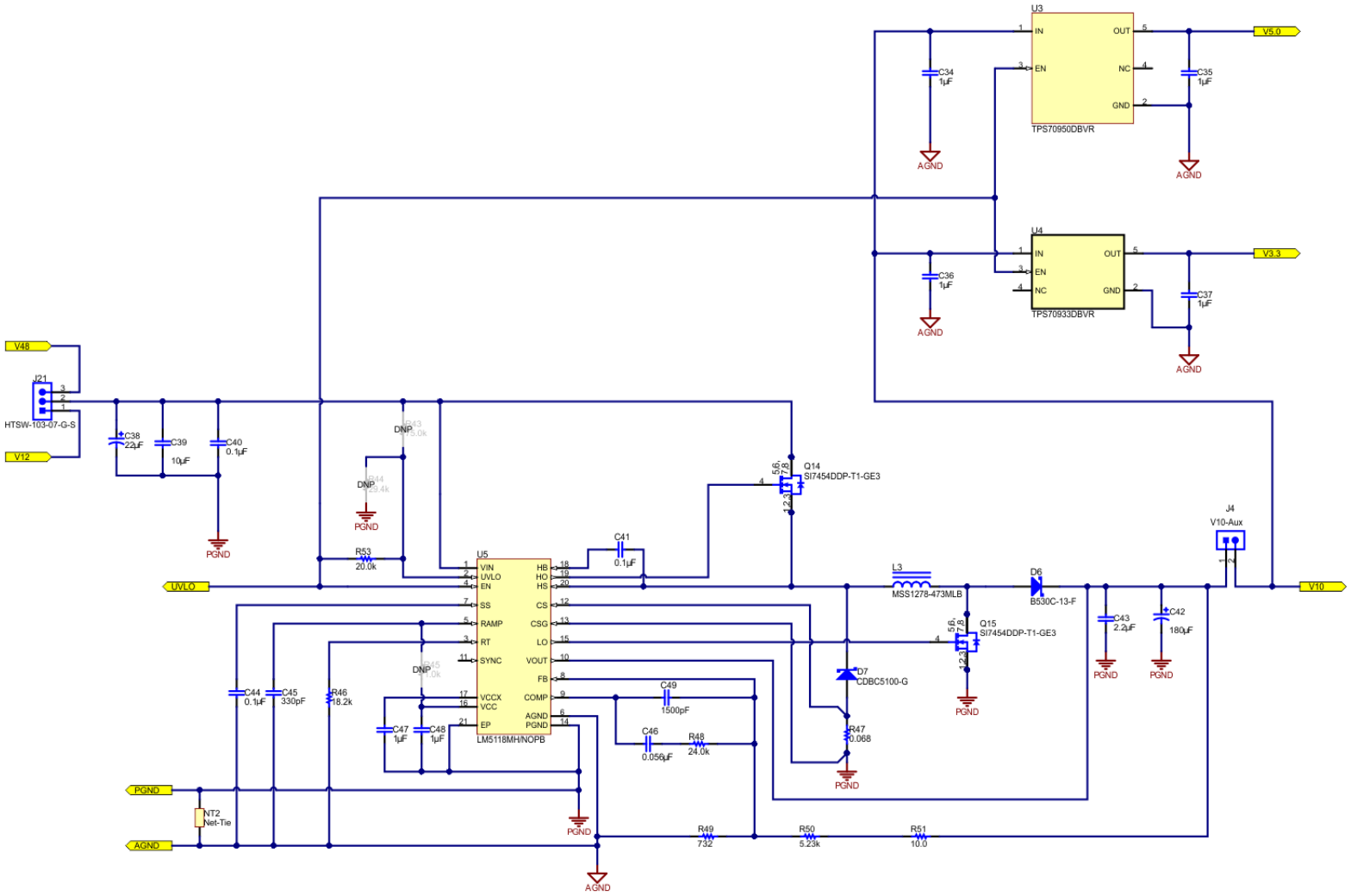
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Figure 28. EVM Schematic Part 2: Control Circuit

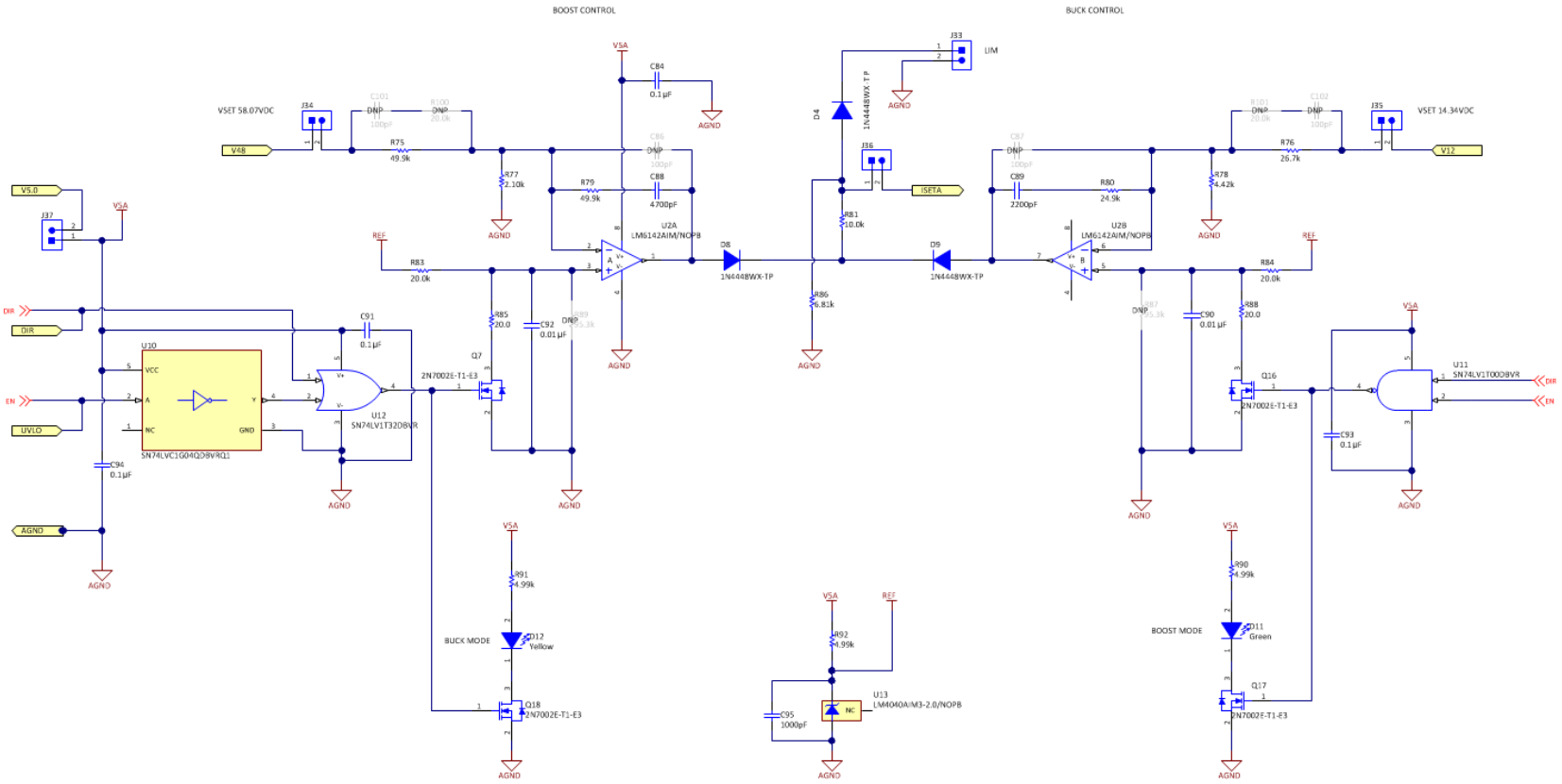
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Figure 29. EVM Schematic Part 3: Bias Supplies

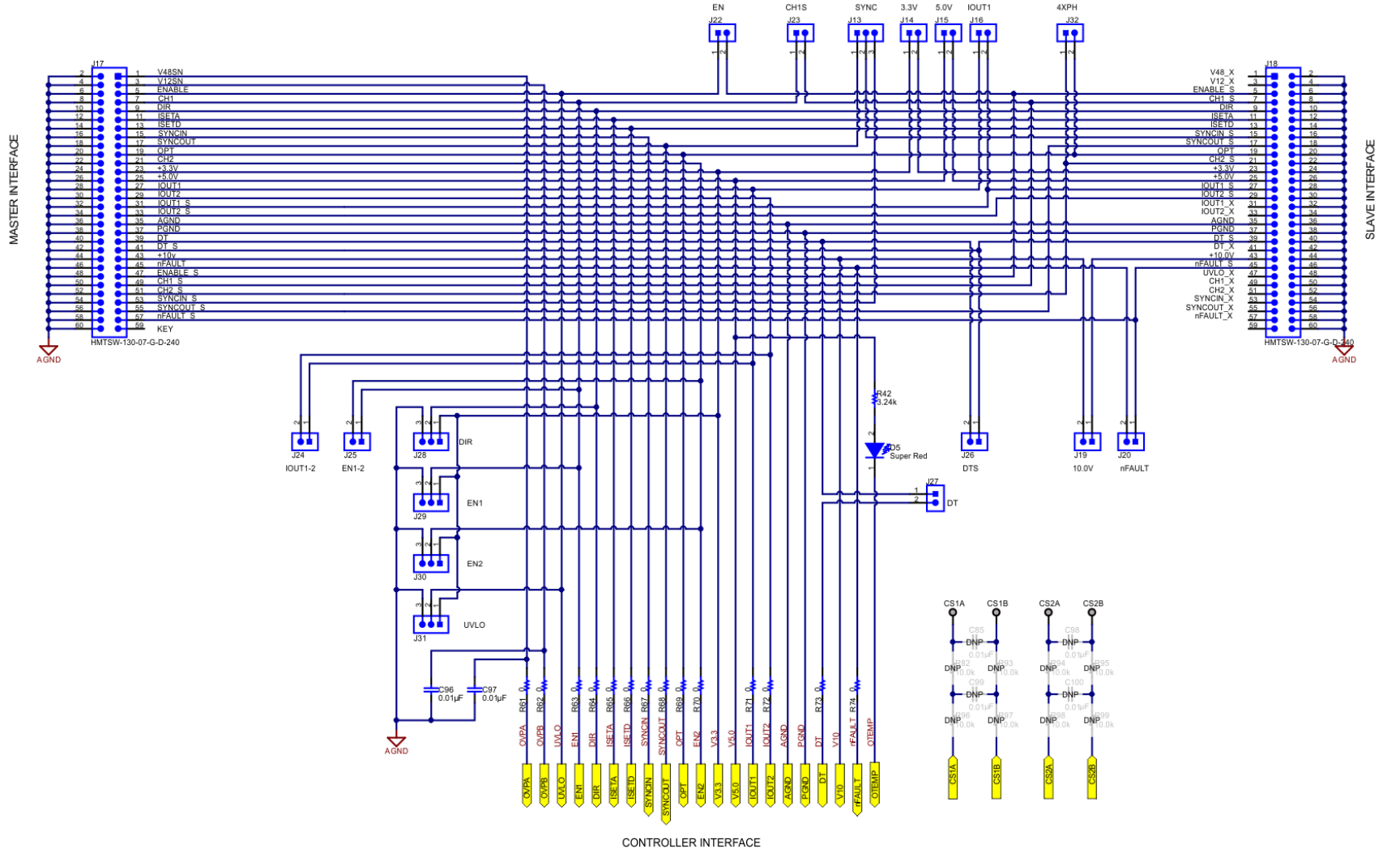
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Figure 30. EVM Schematic Part 4: Optional Outer Voltage Loop Control Circuit

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Figure 31. EVM Schematic Part 5: Interface Connectors and Configuration Headers

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5.2 Bill of Materials

Table 6. Bill of Materials

COUNT	DESIGNATOR	DESCRIPTION	PART NUMBER	MANUFACTURER
5	C1, C3, C5, C16, C95	CAP, CERM, 1000 pF, 100 V, ±5%, C0G/NP0, 0603	C1608C0G2A102J080AA	TDK
7	C2, C14, C17, C90, C92, C96, C97	CAP, CERM, 0.01 µF, 100 V, X7R, 0603	06031C103KAT2A	AVX
2	C4, C15	CAP, CERM, 0.015 µF, 25 V, X7R, 0603	GRM188R71E153KA01D	MuRata
5	C6, C34, C35, C36, C37	CAP, CERM, 1 µF, 100 VX7S, 0805	C2012X7S2A105K125AB	TDK
2	C7, C12	CAP, CERM, 0.22 µF, 50 V, X7R, 0603	C1608X7R1H224K080AB	TDK
12	C8, C9, C30, C41, C44, C76, C77, C78, C84, C91, C93, C94	CAP, CERM, 0.1 µF, 100 V, X7R, 0603	GRM188R72A104KA35D	MuRata
2	C10, C43	CAP, CERM, 2.2 µF, 16 V, X7R, 0805	C2012X7R1C225K125AB	TDK
3	C11, C47, C48	CAP, CERM, 1 µF, 25 V, X7R, 0603	GRM188R71E105KA12D	MuRata
8	C13, C72, C73, C74, C75, C79, C82, C83	CAP, CERM, 100 pF, 50 V, ±5%, C0G/NP0, 0603	C0603C101J5GACTU	Kemet
2	C18, C32	CAP, AL, 100 µF, 100 V, SMD	EMVH101GDA101MLH0S	Chemi-Con
4	C20, C21, C54, C55	CAP, AL, 180 µF, 50 V, SMD	PCR1H181MCL1GS	Nichicon
18	C22, C23, C24, C25, C26, C27, C28, C29, C62, C63, C64, C65, C66, C67, C68, C69, C70, C71	CAP, CERM, 4.7 µF, 100 V, X7R, 2220	C5750X7R2A475M230KA	TDK
1	C38	CAP, AL, 22 µF, 100 V, ±20%, SMD	EMVH101ADA220MJA0G	Chemi-Con
1	C39	CAP, CERM, 10 µF, 100 V, X7S,	C5750X7S2A106M230KB	TDK
1	C40	CAP, CERM, 0.1 µF, 100 V, X7R, 0805	C2012X7R2A104K125AA	TDK
1	C40	CAP, CERM, 0.1 µF, 100 V, X7R, 0805	C2012X7R2A104K125AA	TDK
1	C45	CAP, CERM, 330 pF, 100 V, ±5%, C0G/NP0, 0603	C1608C0G2A331J080AA	TDK
1	C46	CAP, CERM, 0.056 µF, 50 V, X7R, 0603	GRM188R71H563KA93D	MuRata
1	C49	CAP, CERM, 1500 pF, 100 V, ±5%, C0G/NP0, 0603	GRM1885C2A152JA01D	MuRata
10	C50, C51, C52, C53, C56, C57, C58, C59, C60, C61	CAP, Aluminum Polymer, 39 µF, 80 V, AEC-Q200 Grade 1, D10xL10 mm SMD	HHXA800ARA390MJA0G	Chemi-Con
2	C80, C81	CAP, CERM, 0.47 µF, 16 V, X7R, 0603	GRM188R71C474KA88D	MuRata
1	C88	CAP, CERM, 4700 pF, 50 V, X7R, 0603	C0603C472K5RACTU	Kemet
1	C89	CAP, CERM, 2200 pF, 50 V, X7R, 0603	GRM188R71H222KA01D	MuRata
2	D1, D2	Diode, Schottky, 60 V, 1 A, SOD-123F	PMEG6010CEH,115	NXP Semiconductor
1	D3	Diode, TVS, Uni, 36 V, 3600 W, DO-218	SM5S36AHE3/2D	Vishay-Semiconductor
3	D4, D8, D9	Diode, Switching, 75 V, 0.25 A, SOD-323	1N4448WX-TP	Micro Commercial Components

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Table 6. Bill of Materials (continued)

COUNT	DESIGNATOR	DESCRIPTION	PART NUMBER	MANUFACTURER
1	D5	LED, Super Red, SMD	150060SS75000	Wurth Elektronik
1	D6	Diode, Schottky, 30 V, 5 A, SMC	B530C-13-F	Diodes Inc.
1	D7	Diode, Schottky, 100 V, 5 A, SMC	CDBC5100-G	Comchip Technology
1	D10	Diode, Switching, 75 V, 0.3 A, SOD-523	1N4148X-TP	Micro Commercial Components
1	D11	LED, Green, SMD	150060VS75000	Wurth Elektronik
1	D12	LED, Yellow, SMD	150060YS75000	Wurth Elektronik
4	H1, H2, H3, H4	Machine Screw, Round, #4-40 x 1/4, Nylon, Philips panhead	NY PMS 440 0025 PH	B&F Fastener Supply
4	H5, H6, H7, H8	Standoff, Hex, 1"L #4-40 Aluminum	2205	Keystone
9	J1, J5, J7, J13, J21, J28, J29, J30, J31	Header, 100mil, 3x1, Gold, TH	HTSW-103-07-G-S	Samtec
22	J2, J3, J4, J6, J8, J14, J15, J16, J19, J20, J22, J23, J24, J25, J26, J27, J32, J33, J34, J35, J36, J37	Header, 100mil, 2x1, Gold, TH	HTSW-102-07-G-S	Samtec
4	J9, J10, J11, J12	Standard Banana Jack, Uninsulated, 15 A	108-0740-001	Emerson Network Power
2	J17, J18	Header, 100 mil, 30x2, Gold, TH	HMTSW-130-07-G-D-240	Samtec
2	L1, L2	Inductor, 4.7 µH,	SMT 74436410470	Wurth
1	L3	Inductor, 47 µH, 2.9 A, 0.07 Ω, SMD	MSS1278-473MLB	Coilcraft
		Inductor, 47 µH, SMD (Substitue)	784770470	Wurth
8	Q1, Q2, Q3, Q4, Q10, Q11, Q12, Q13	MOSFET N CH 100 V D2PAK	TK65G10N1,RQ	Toshiba Semiconductor and Storage
4	Q5, Q6, Q8, Q9	MOSFET N CH 60 V 240 A D2PAK	IRFS7530-7PPBF	International Rectifier
4	Q7, Q16, Q17, Q18	MOSFET, N-CH, 60 V, 0.24 A, SOT-23	2N7002E-T1-E3	Vishay-Siliconix
2	Q14, Q15	MOSFET, N-CH, 100 V, 21 A, PowerPAK SO-8	SI7454DDP-T1-GE3	Vishay-Siliconix
2	R1, R5	RES, 95.3 k, 1%, 0.1 W, 0603	CRCW060395K3FKEA	Vishay-Dale
2	R2, R19	RES, 634, 1%, 0.1 W, 0603	CRCW0603634RFKEA	Vishay-Dale
2	R3, R20	RES, 9.09 k, 1%, 0.1 W, 0603	CRCW06039K09FKEA	Vishay-Dale
6	R7, R8, R9, R11, R16, R81	RES, 10.0 k, 1%, 0.1 W, 0603	CRCW060310K0FKEA	Vishay-Dale
4	R10, R90, R91, R92	RES, 4.99 k, 1%, 0.1 W, 0603	CRCW06034K99FKEA	Vishay-Dale
3	R12, R75, R79	RES, 49.9 k, 1%, 0.1 W, 0603	CRCW060349K9FKEA	Vishay-Dale
2	R13, R15	RES, 40.2 k, 1%, 0.1 W, 0603	CRCW060340K2FKEA	Vishay-Dale
1	R14	RES, 24.9, 1%, 0.125 W, 0805	CRCW080524R9FKEA	Vishay-Dale
1	R17	RES, 51.1 k, 1%, 0.1 W, 0603	CRCW060351K1FKEA	Vishay-Dale
1	R18	RES, 54.9 k, 1%, 0.1 W, 0603	CRCW060354K9FKEA	Vishay-Dale
2	R21, R32	RES, 0.001, 1%, 3 W, 6.6x3x6.9mm	WSL27261L000FEB	Vishay-Dale
8	R22, R24, R25, R29, R33, R35, R36, R40	RES, 49.9 k, 1%, 0.125 W, 0805	CRCW080549K9FKEA	Vishay-Dale
8	R26, R27, R28, R30, R37, R38, R39, R41	RES, 1.00, 1%, 0.125 W, 0805	CRCW08051R00FKEA	Vishay-Dale
1	R31	RES, 1.00 M, 1%, 0.125 W, 0805	CRCW08051M00FKEA	Vishay-Dale

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Table 6. Bill of Materials (continued)

COUNT	DESIGNATOR	DESCRIPTION	PART NUMBER	MANUFACTURER
1	R42	RES, 3.24 k, 1%, 0.1 W, 0603	CRCW06033K24FKEA	Vishay-Dale
1	R46	RES, 18.2 k, 1%, 0.1 W, 0603	CRCW060318K2FKEA	Vishay-Dale
1	R47	RES, 0.068, 1%, 1 W, 0612	PRL1632-R068-F-T1	Susumu Co Ltd
1	R48	RES, 24.0 k, 1%, 0.1 W, 0603	RC0603FR-0724KL	Yageo America
1	R49	RES, 732, 1%, 0.1 W, 0603	CRCW0603732RFKEA	Vishay-Dale
1	R50	RES, 5.23 k, 1%, 0.1 W, 0603	CRCW06035K23FKEA	Vishay-Dale
1	R51	RES, 10.0, 1%, 0.1 W, 0603	CRCW060310R0FKEA	Vishay-Dale
1	R52	RES, 100 k, 1%, 0.063 W, 0402	CRCW0402100KFKED	Vishay-Dale
4	R53, R60, R83, R84	RES, 20.0 k, 1%, 0.1 W, 0603	CRCW060320K0FKEA	Vishay-Dale
2	R54, R55	RES, 2.0, 5%, 0.125 W, 0805	CRCW08052R00JNEA	Vishay-Dale
4	R56, R57, R58, R59	RES, 1.0, 5%, 0.1 W, 0603	CRCW06031R00JNEA	Vishay-Dale
14	R61, R62, R63, R64, R65, R66, R67, R68, R69, R70, R71, R72, R73, R74	RES, 0, 5%, 0.1 W, 0603	CRCW06030000Z0EA	Vishay-Dale
1	R76	RES, 26.7 k, 1%, 0.1 W, 0603	CRCW060326K7FKEA	Vishay-Dale
1	R77	RES, 2.10 k, 1%, 0.1 W, 0603	CRCW06032K10FKEA	Vishay-Dale
1	R78	RES, 4.42 k, 1%, 0.1 W, 0603	CRCW06034K42FKEA	Vishay-Dale
1	R80	RES, 24.9 k, 1%, 0.1 W, 0603	CRCW060324K9FKEA	Vishay-Dale
2	R85, R88	RES, 20.0, 1%, 0.1 W, 0603	CRCW060320R0FKEA	Vishay-Dale
1	R86	RES, 6.81 k, 1%, 0.1 W, 0603	CRCW06036K81FKEA	Vishay-Dale
4	T1, T2, T3, T4	Terminal 70-A Lug	CXS70-14-C	Panduit
1	U1	Dual Channel 48-V to 12-V Bidirectional Current Controller, PHP0048D	LM5170QPHPTQ1	Texas Instruments
1	U2	17MHz Rail-to-Rail Input and Output Op Amp, D0008A	LM6142AIM/NOPB	Texas Instruments
1	U3	150-mA, 30-V, 1-µA IQ LDO with Enable, DBV0005A (SOT-5)	TPS70950DBVR	Texas Instruments
1	U4	150-mA, 30-V, 1-µA IQ LDO with Enable, DBV0005A (SOT-5)	TPS70933DBVR	Texas Instruments
1	U5	Wide VIN Buck-Boost Controller, 20-pin TSSOP-EP, Pb-Free	LM5118MH/NOPB	Texas Instruments
4	U6, U7, U8, U9	Temperature Switch and Temperature Sensor, 6-pin LLP, Pb-Free	LM26LVCISD-145/NOPB	Texas Instruments
1	U10	Single Inverter Gate, DBV0005A	SN74LVC1G04QDBVRQ1	Texas Instruments
1	U11	Single NAND Gate CMOS Logic Level Shifter, DBV0005A	SN74LV1T00DBVR	Texas Instruments
1	U12	Single OR Gate CMOS Logic Level Shifter, DBV0005A	SN74LV1T32DBVR	Texas Instruments
1	U13	Precision Micropower Shunt Voltage Reference, 3-pin SOT-23, Pb-Free	LM4040AIM3-2.0/NOPB	Texas Instruments

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5.3 Board Layout

The EVM includes various headers for flexible configurations suitable for different applications. Figure 32 through Figure 41 show the EVM PCB artwork.

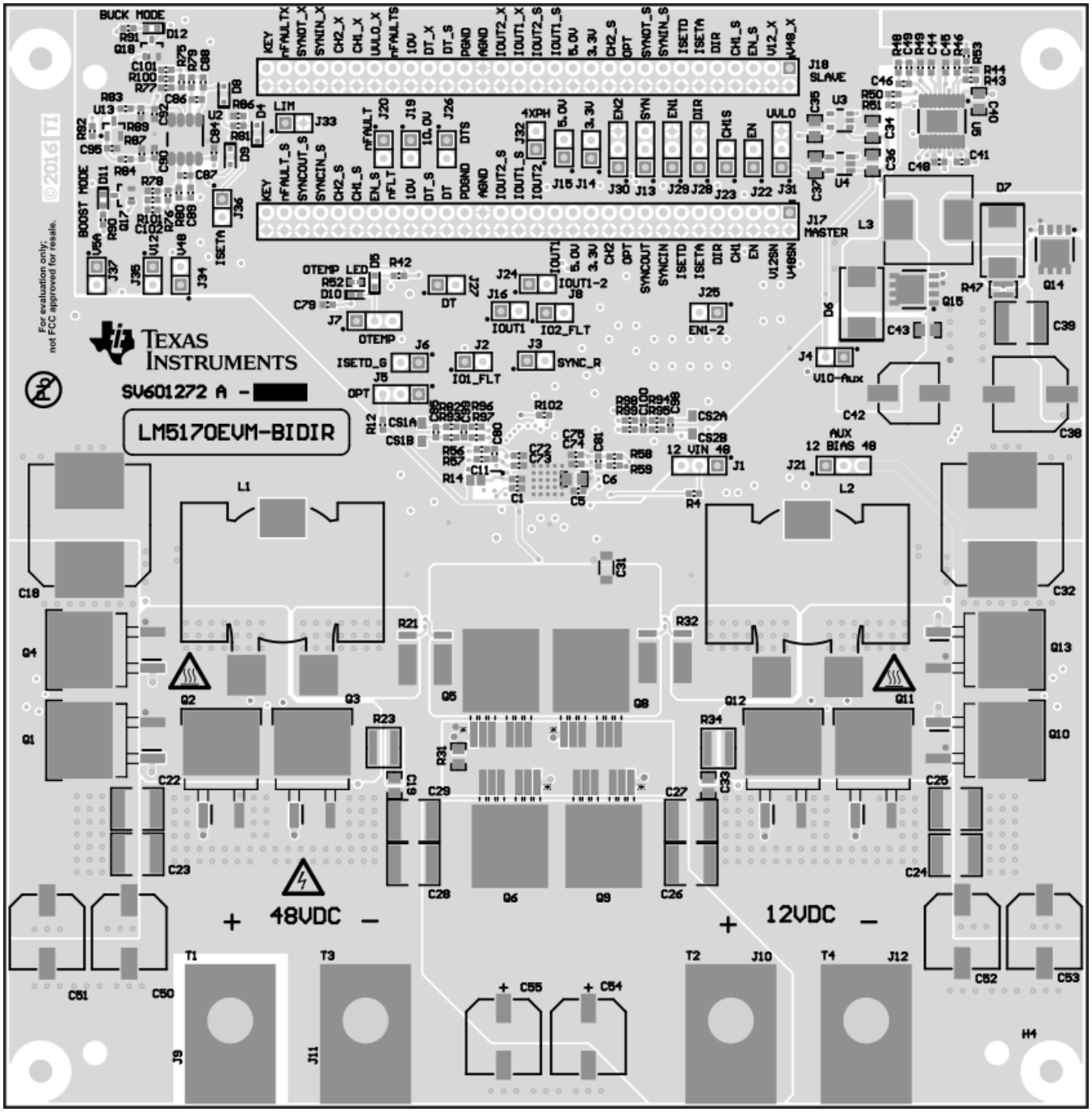


Figure 32. EVM Top Layer Silkscreen

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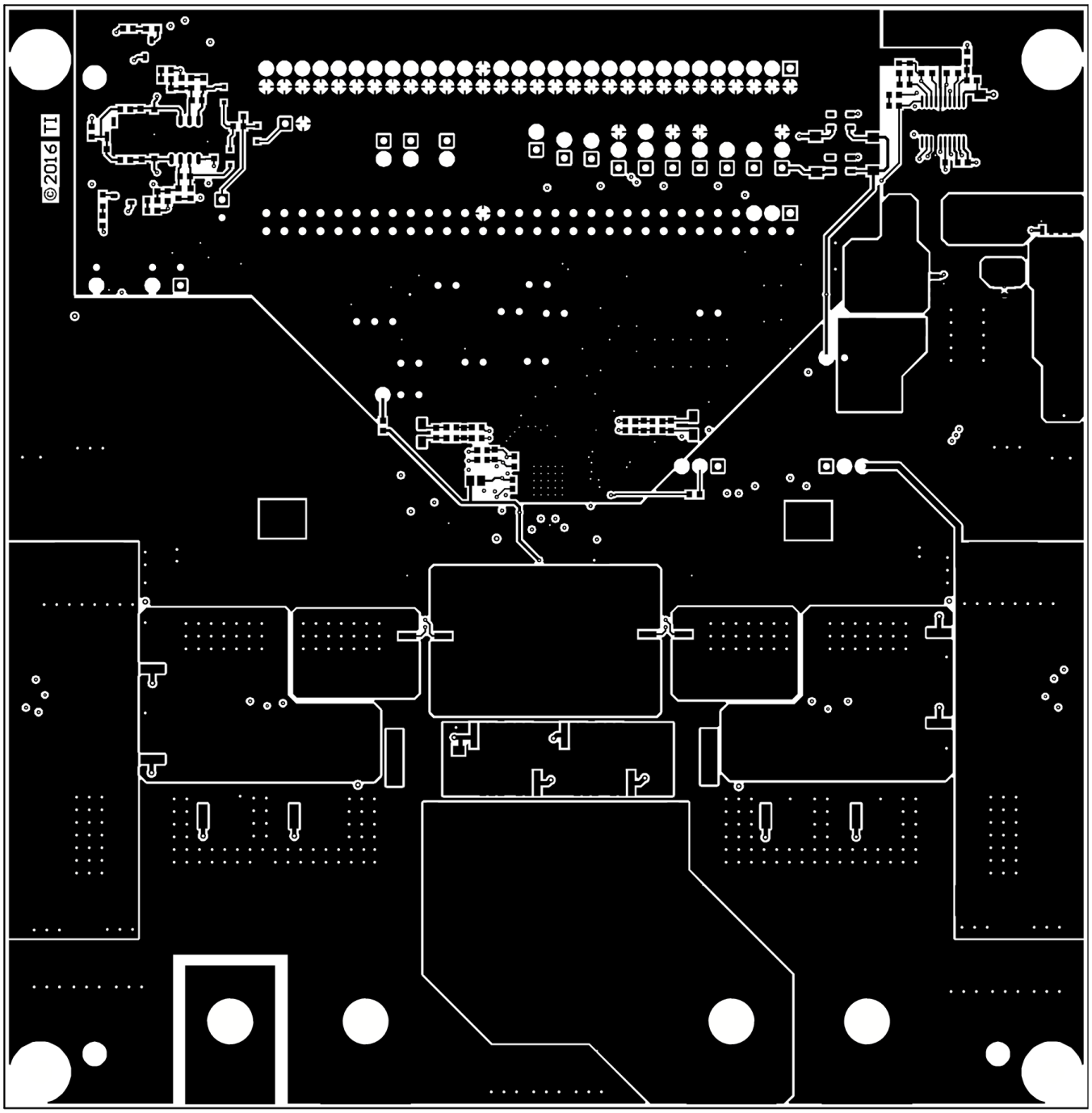


Figure 33. EVM Top Layer Copper

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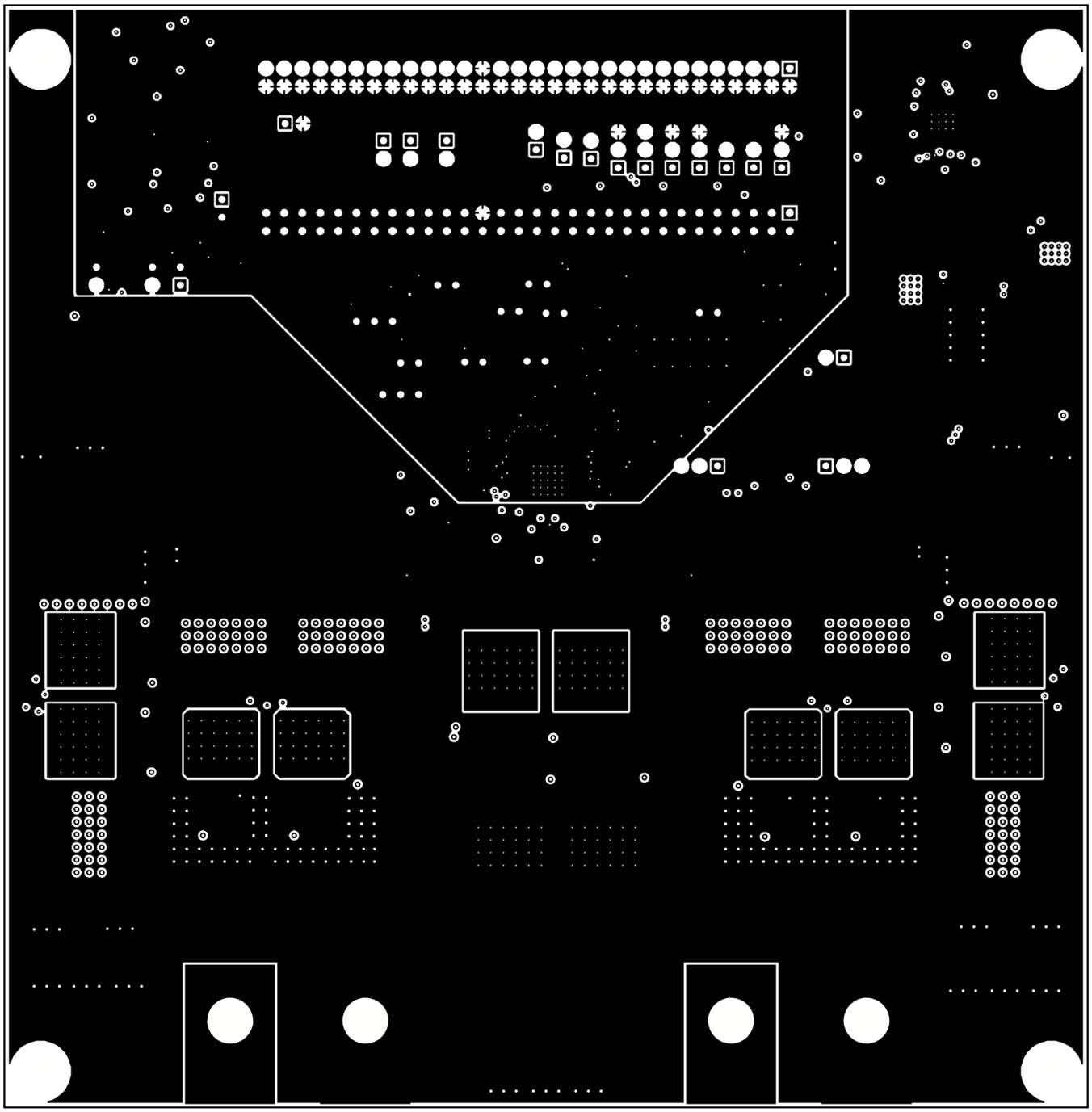


Figure 34. EVM Middle Layer 1

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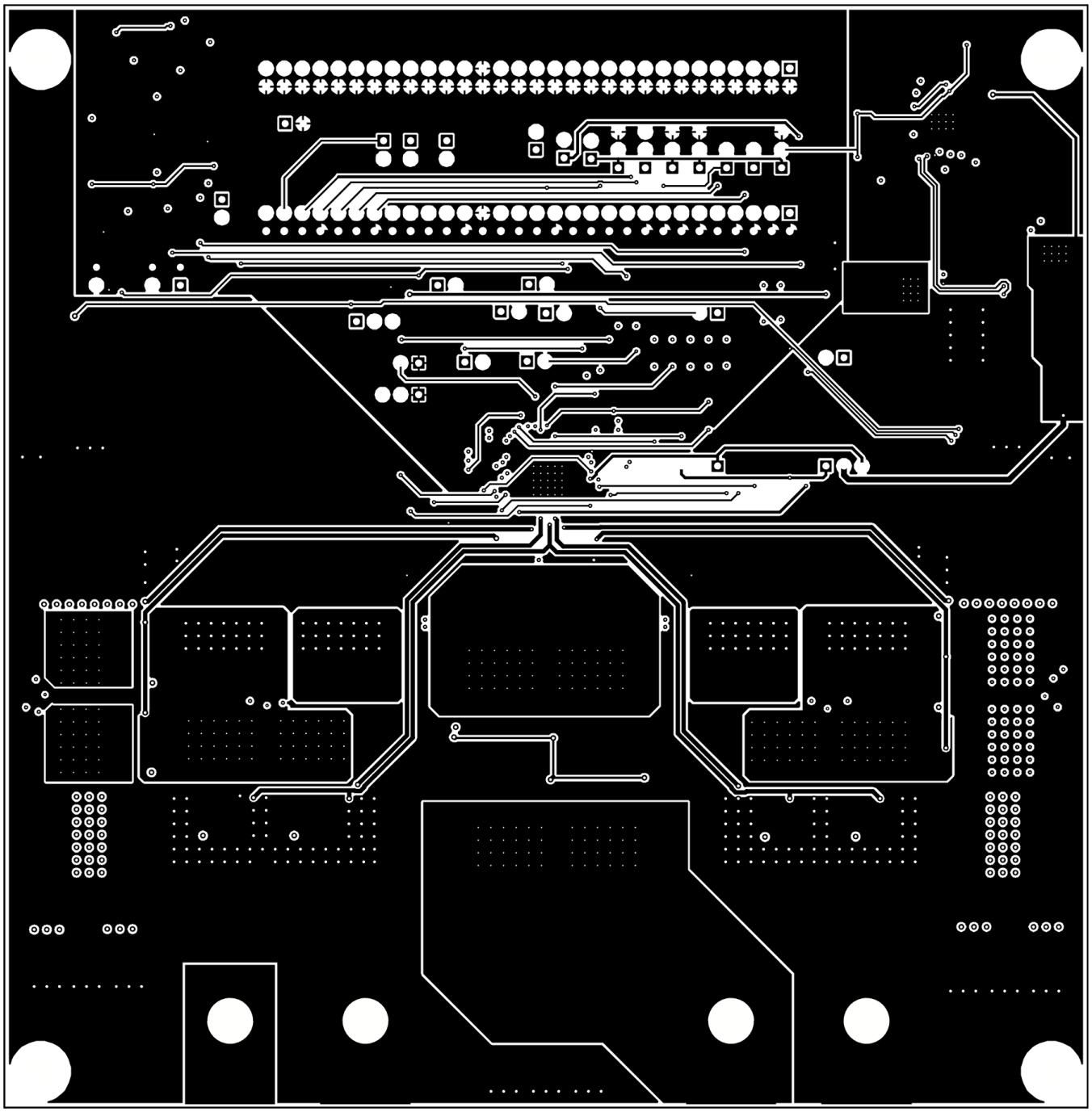


Figure 35. EVM Middle Layer 2

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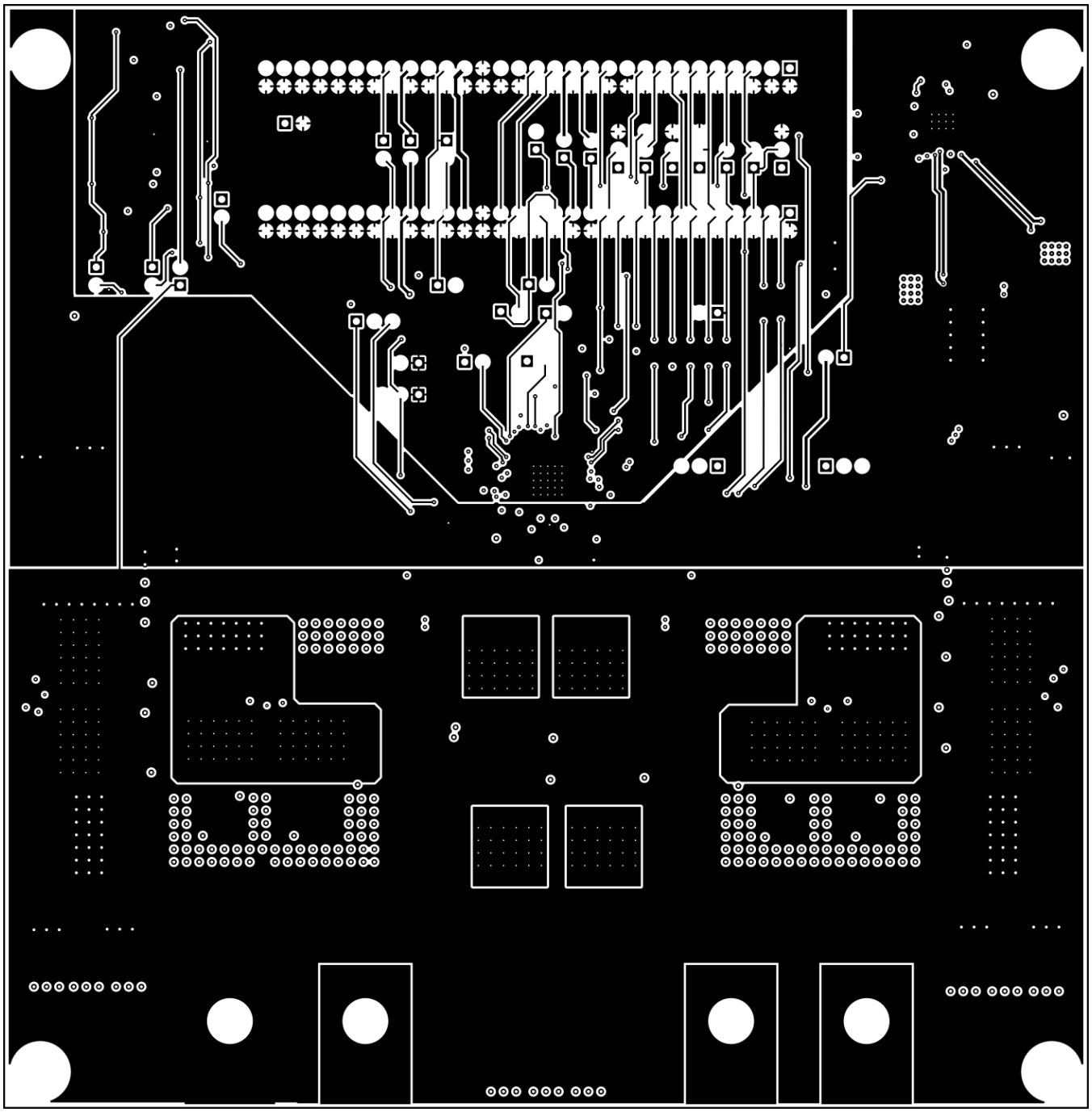


Figure 36. EVM Middle Layer 3

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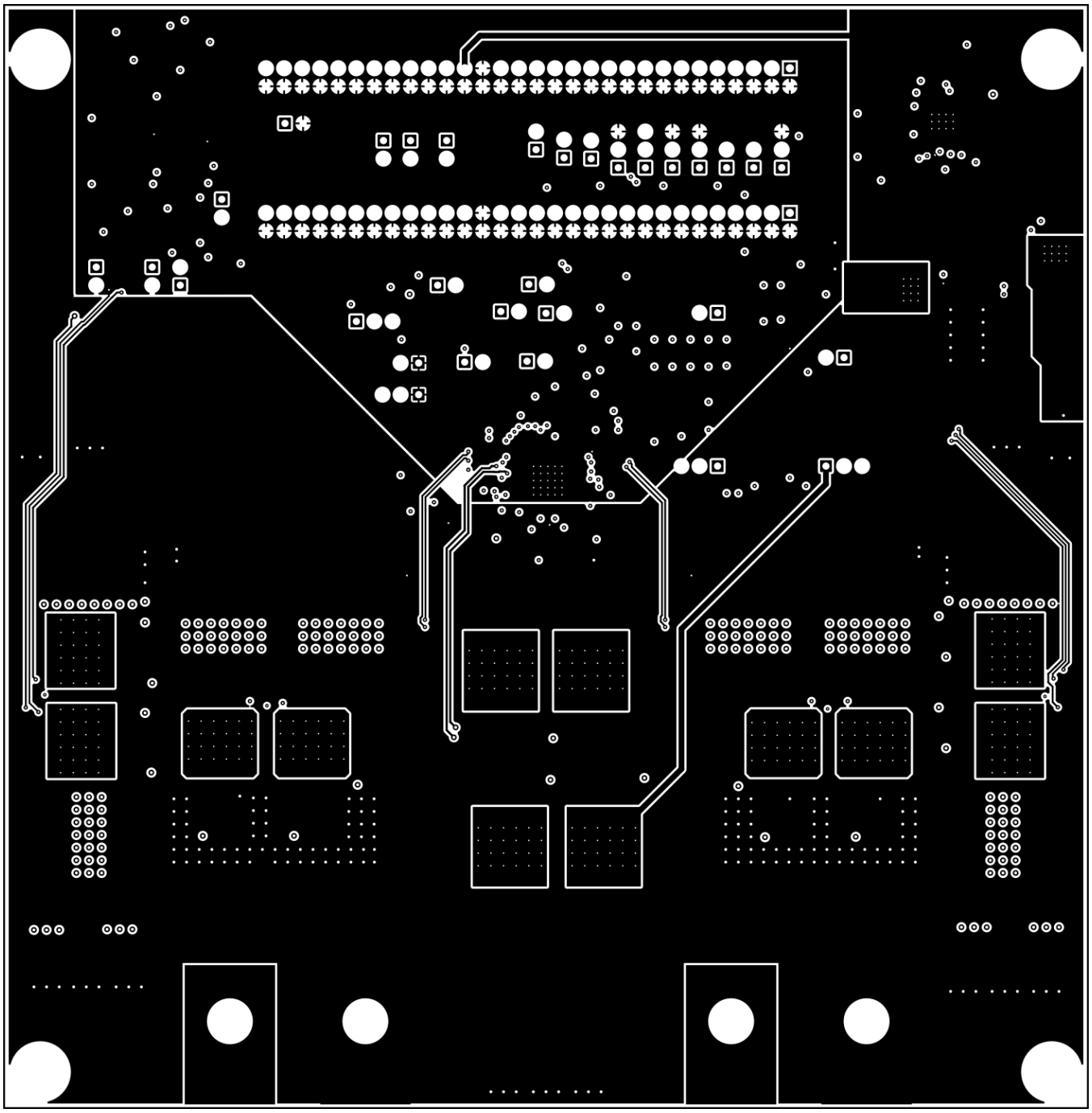


Figure 37. EVM Middle Layer 4

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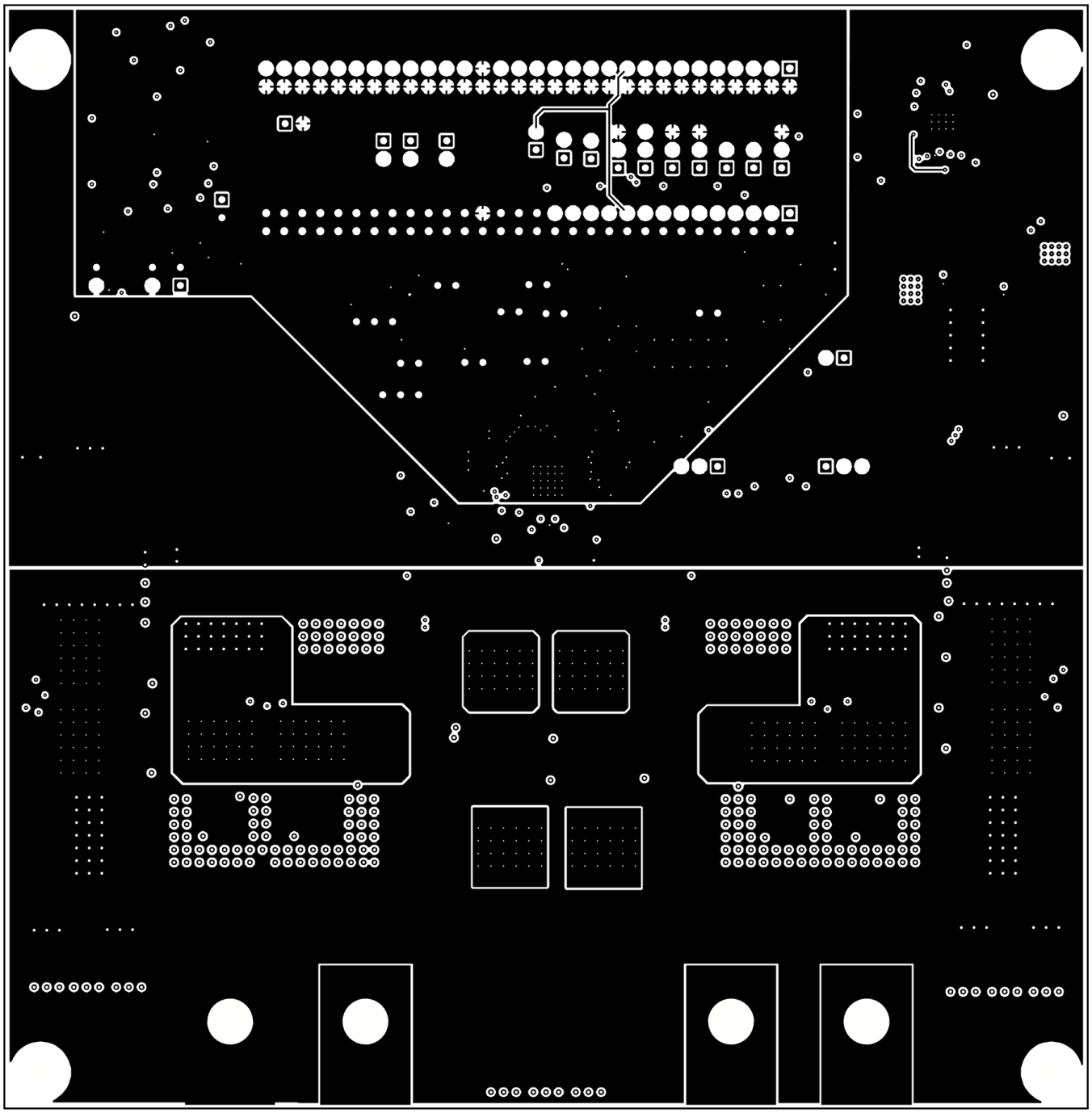


Figure 38. EVM Middle Layer 5

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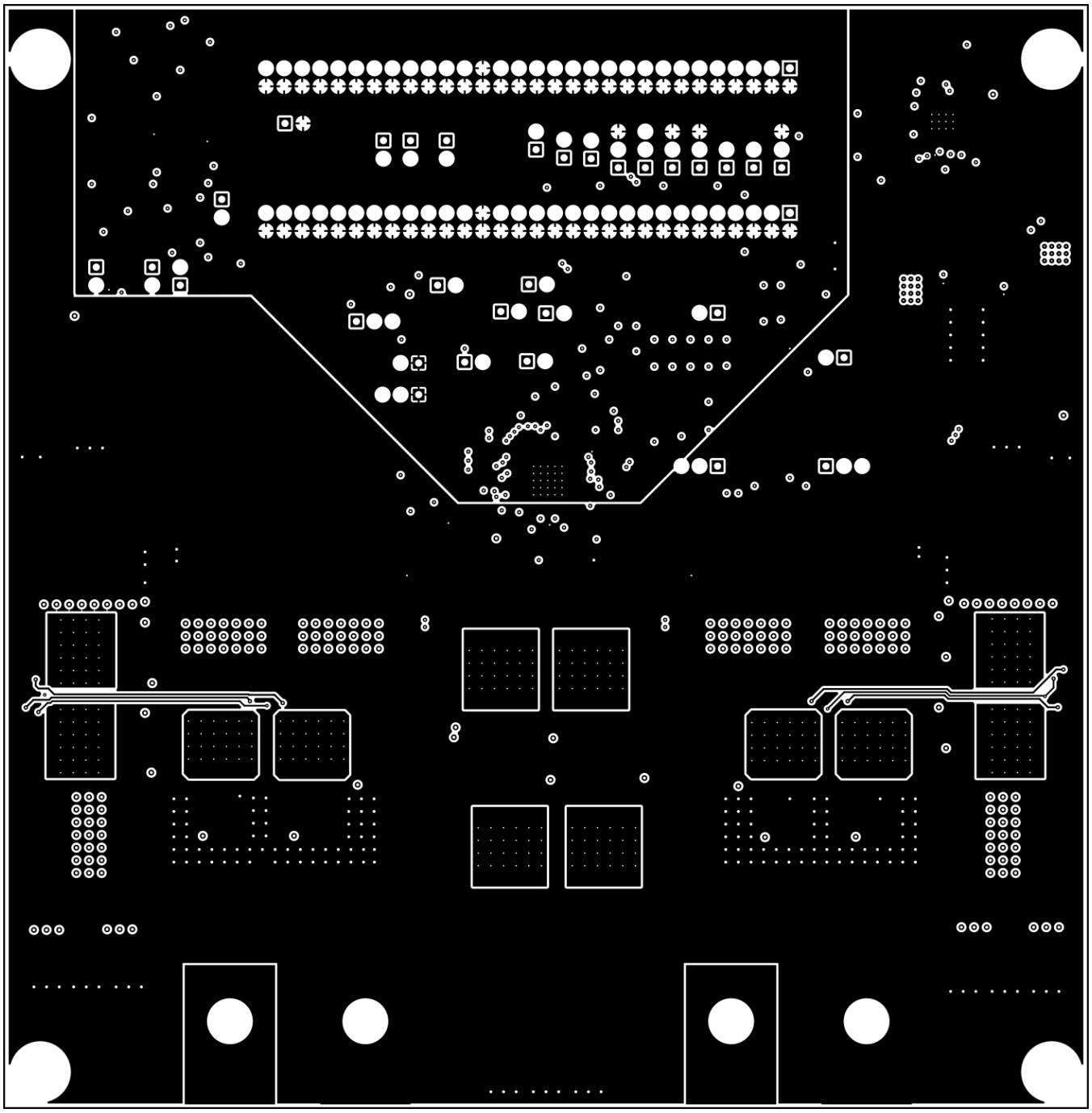


Figure 39. EVM Middle Layer 6

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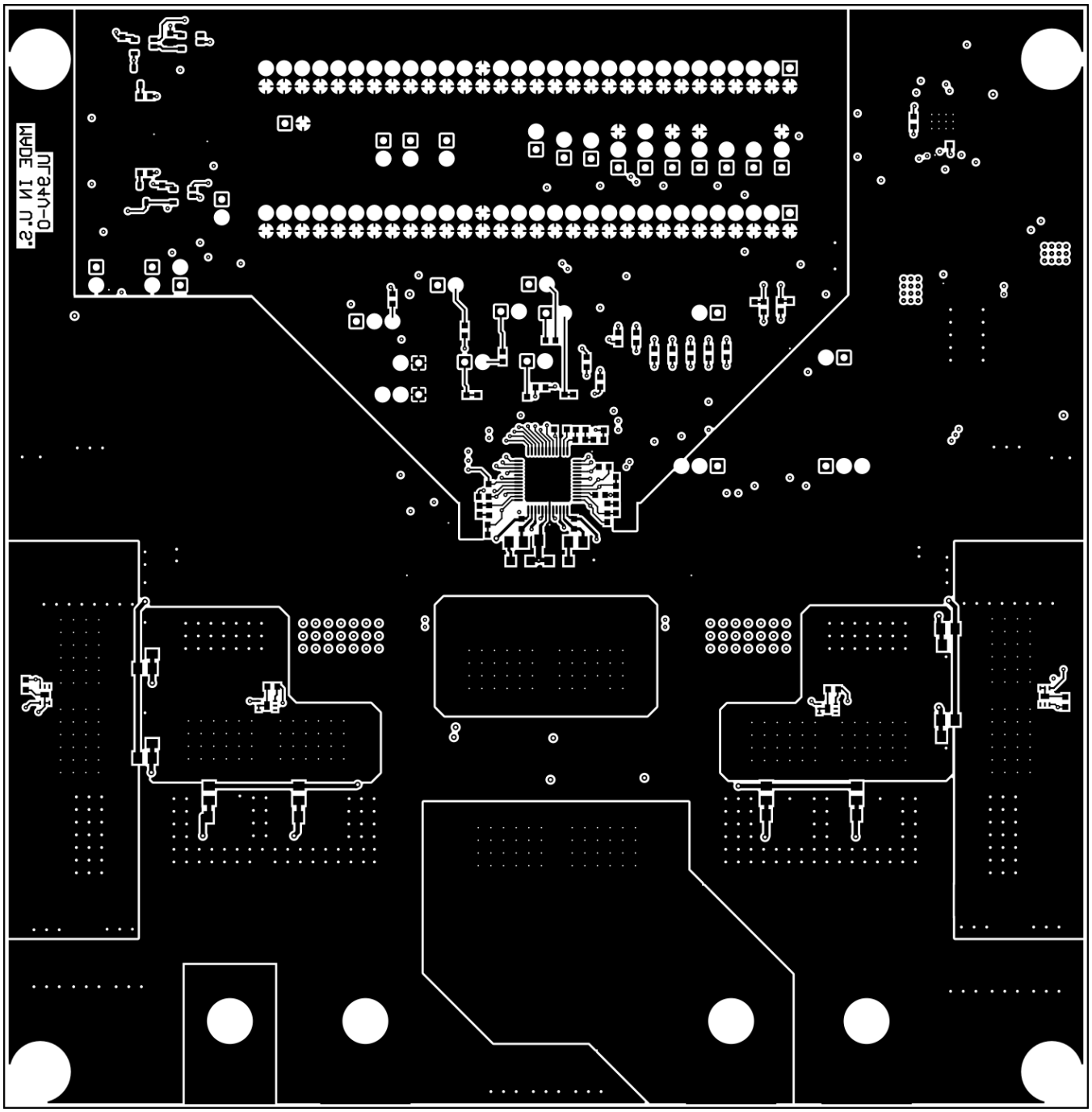


Figure 40. EVM Bottom Layer Copper

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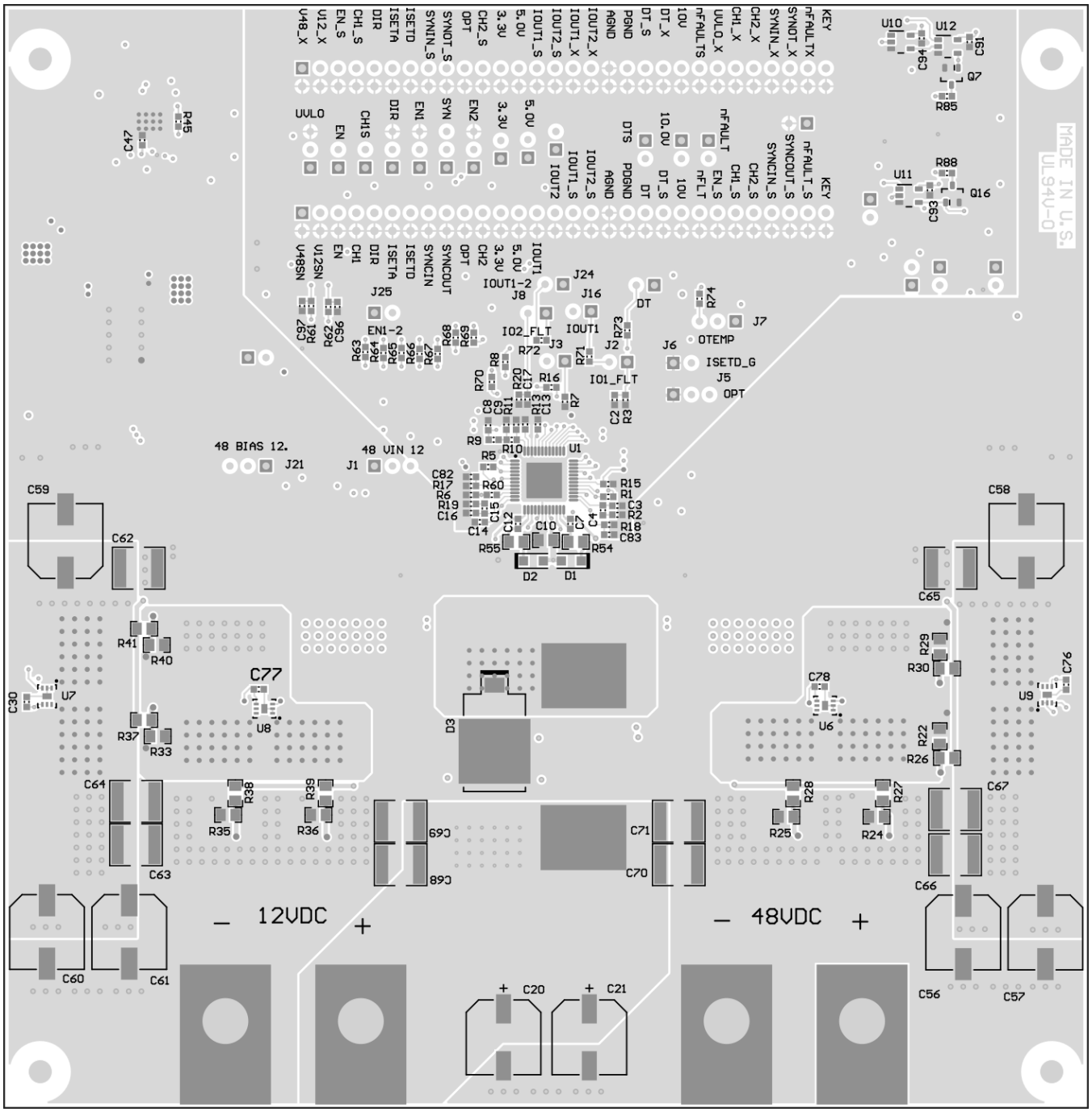


Figure 41. EVM Bottom Layer Silkscreen

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Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Original (November 2016) to A Revision	Page
• Changed the test conditions for 48VDC-Port input parameter from: DIR < 1 V to: DIR > 2 V	4
• Changed the test conditions for 12VDC-Port input parameter from: DIR > 2 V to: DIR < 1 V	4
• Changed the test conditions for 48VDC-Port output parameter from: Buck mode to: Boost mode	4
• Changed the test conditions for 48VDC-Port output parameter from: Boost mode to: Buck mode	4

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