

## Reference Design

### 1 kW DC/DC Converter, 48 V<sub>DC</sub> to 12 V<sub>DC</sub>



#### LINKS TO ADDITIONAL RESOURCES



#### DESCRIPTION

As dual board net systems (vehicles with both a 12 V and 48 V bus) increase in popularity, high power, bidirectional 48 V to 12 V DC/DC converters have become key building blocks in the architecture of today's automobiles. To optimize overall vehicle efficiency, energy must be transferred in either direction between the 12 V and 48 V batteries, depending on the vehicle's electrical demands and the state of the batteries' health, which can be achieved with this converter design.

This 1 kW, 48 V to 12 V buck-boost converter features two modular power stages capable of 500 W each. Symmetrical interleaving of both phases reduces the current ripple, while each phase is equipped with protection MOSFETs that can isolate the phase in case of failure and limit inrush current. The converter can automatically switch between buck and boost operation, while its switching frequency of 185 kHz leads to a compact form factor.

#### FEATURES

- Bidirectional 48 V to 12 V converter
- 2-phase interleaved operation
- Automatic buck and boost selection
- Voltage and current regulation
- Inrush current control
- Overvoltage protection
- Overcurrent protection

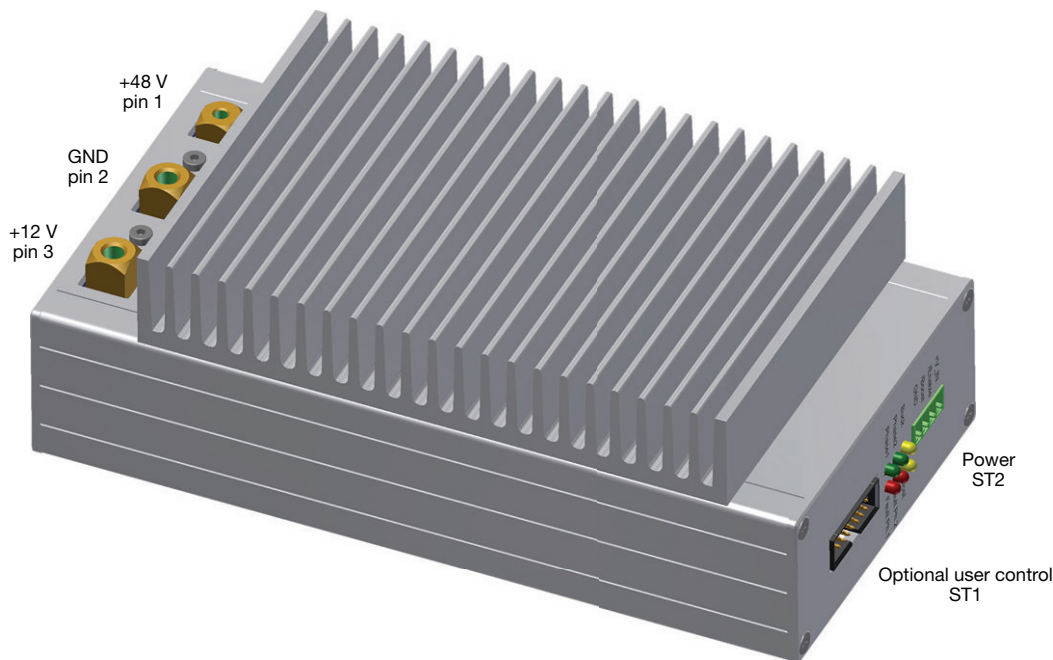
#### KEY COMPONENTS

- [IHDM-1107BB-x0 inductor](#)
- [SQJQ112E MOSFET](#)
- [SQJA90EP MOSFET](#)
- [SQJQ140E MOSFET](#)
- [WSLP2726 shunt](#)
- [IHLP-6767GZ-5A inductor](#)
- [182 CPHZ capacitor](#)
- [T51 vPolyTan™ capacitor](#)

#### APPLICATIONS

- Automotive
- Industrial and server computing
- Networking, telecom, and base station power supplies
- EV test environment

## PIN CONFIGURATION



The DC/DC converter uses three screw terminals to connect the dual bus system and two connectors to supply auxiliary power and communication.

To reduce the stress on the 48 V facing protection MOSFETs while operating in boost mode, it must be ensured that the 48 V load does not force high currents when starting or automatically restarting the converter while the 48 V rail is still below the 12 V rail. To achieve this, the voltage of the electronic load must be set above 20 V, or if a resistive load is used, the resistance must be higher than 2.5  $\Omega$ . These operating conditions are automatically met if using batteries, but need to be taken care of if using electronic loads.

PIN DESCRIPTION			
PIN NUMBER	TERMINAL SIZE	SYMBOL	DESCRIPTION
1	M4	+48 V	Connect to 48 V battery
2	M6	GND	Common ground
3	M6	+12 V	Connect to 12 V battery



## ST1 CONNECTOR

The ST1 connector enables the DC/DC converter to be controlled by an optional controller. The 16-bit I<sup>2</sup>C bus I/O expander (PI4IOE5V6416Q2LEX) is used to control the converter and read its state. In addition, an I<sup>2</sup>C EEPROM (BR24T04NUX-WTR) stores a serial number and configuration used by the user-controlled interface. A 16-bit SPI ADC (ADS8867IDGSR) is connected to an 8-channel multiplexer.

PIN DESCRIPTION		
PIN NUMBER	SYMBOL	DESCRIPTION
1	+5 V	+5 V power supply delivered from the DC/DC converter
2	+5 V	+5 V power supply delivered from the DC/DC converter
3	I <sub>LIM_SW</sub>	If pulled up, the current limit is used from the I <sup>2</sup> C DAC
4	NC	Not connected
5	+3.3 V	+3.3 V must be provided for the EEPROM and ADC
6	NC	Not connected
7	I <sup>2</sup> C_SCL	I <sup>2</sup> C serial clock line
8	I <sup>2</sup> C_SDA	I <sup>2</sup> C serial data line
9	SPI_SCLK	SPI serial clock
10	SPI_/CS	SPI slave select of the ADC (active low)
11	SPI_MISO	SPI master in, slave out
12	SPI_MOSI	SPI master in, slave in
13	GND	Ground; it is internally connected to the GND cable and GND ST2
14	GND	Ground; it is internally connected to the GND cable and GND ST2

(DQG4051EEQ-T1-GE4) can be used to measure input voltage, output voltage, input currents, output currents, and temperatures.

## ST2 LOGIC POWER CONNECTOR

The GND pin on ST1 and ST2 is used as a reference for logic signals and logic power only. Due to the internal connection of all GNDs, an isolated power supply must be connected to ST2. Alternatively, +V\_IN shall be referenced to the GND screw terminal and no connection to GND on ST2 pin 4 shall be made.

PIN DESCRIPTION		
PIN NUMBER	SYMBOL	DESCRIPTION
1	+V_IN	12 V <sub>DC</sub> to 56 V <sub>DC</sub> logic power input
2	/Enable	Connect to GND to enable the converter, leave unconnected to disable
3	/Boost	Connect to GND for boost mode, pull up for buck mode, leave unconnected for auto mode
4	GND	Ground for logic power input; it is internally connected with GND terminal and GND ST1

**RATINGS****Logic Power Connector**

<b>FUNCTIONAL RATINGS</b> ( $T_A = 25\text{ }^{\circ}\text{C}$ , unless otherwise noted)					
PARAMETER	SYMBOL	MIN.	TYP.	MAX.	UNIT
DC logic power	+V_IN	12	15	56	V
Converter ON	/Enable	0	-	2	V
Converter OFF (internal pull-up 5 V)	/Enable	4.5	-	56	V
Forced buck mode	/Boost	8	15	56	V
Forced boost mode	/Boost	0	-	0.5	V

**Buck Mode**

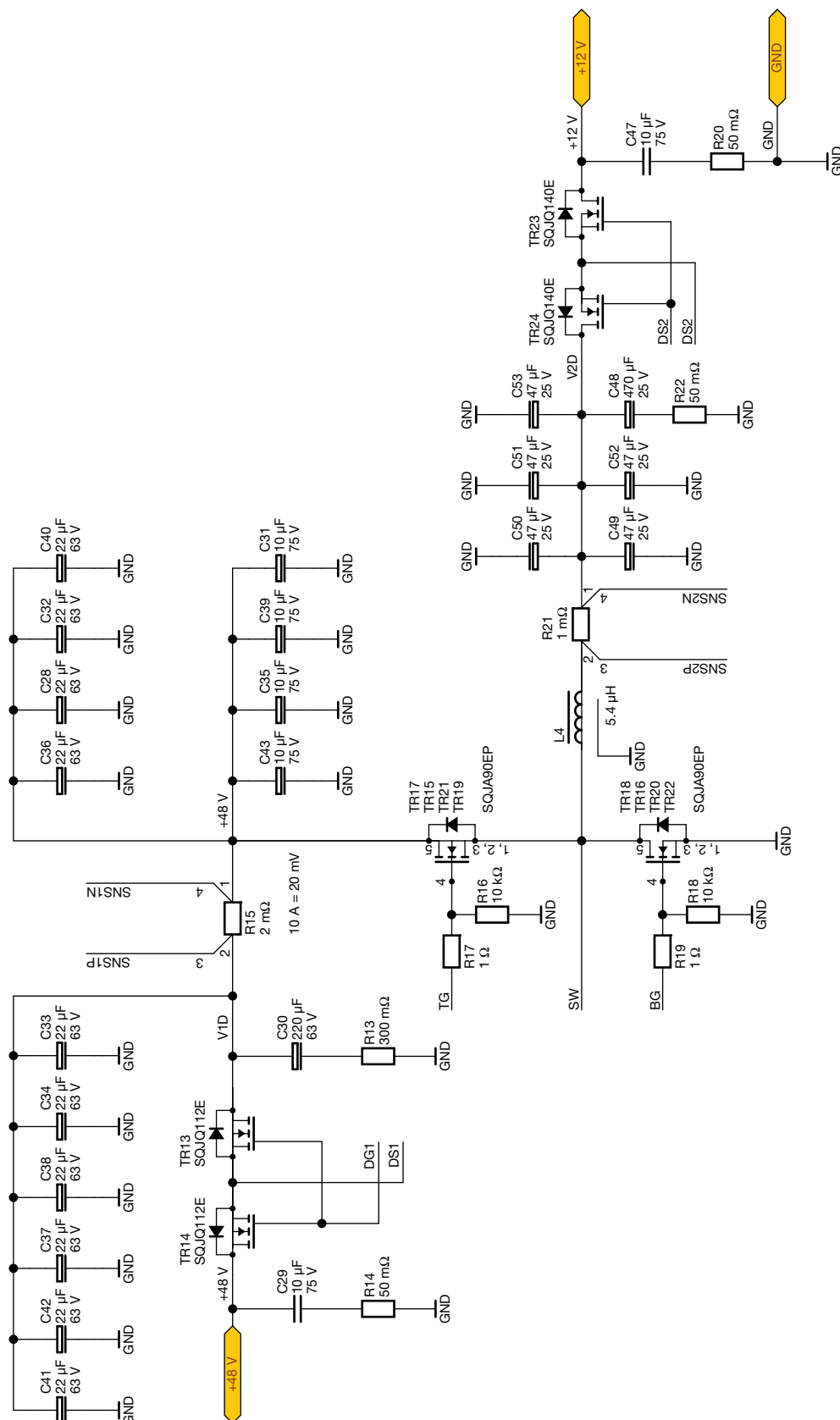
<b>FUNCTIONAL RATINGS</b> ( $T_A = 25\text{ }^{\circ}\text{C}$ , unless otherwise noted)					
PARAMETER	SYMBOL	MIN.	TYP.	MAX.	UNIT
48 V supply range	+48 V	36	48	56	V
48 V undervoltage detection	+48 V	35	36	37	V
12 V output voltage	+12 V	10	12	13	V
Output current limit	+12 V	79	83	85	A
Input current limit	+48 V	26	29	32	A

**Boost Mode**

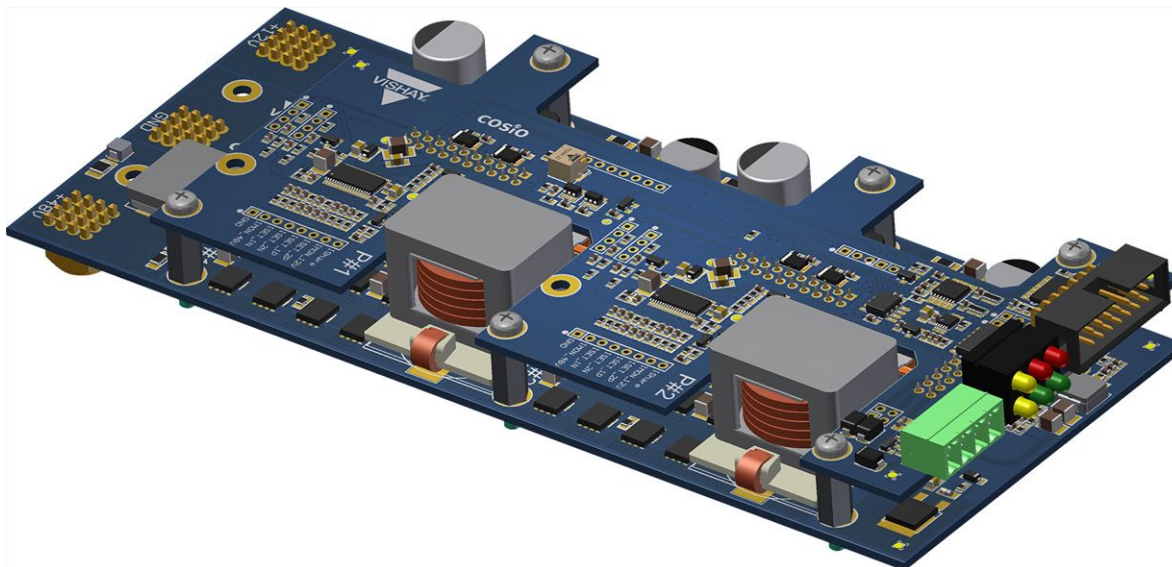
<b>FUNCTIONAL RATINGS</b> ( $T_A = 25\text{ }^{\circ}\text{C}$ , unless otherwise noted)					
PARAMETER	SYMBOL	MIN.	TYP.	MAX.	UNIT
12 V supply range	+12 V	9	12	15	V
12 V undervoltage detection	+12 V	8	9	10	V
48 V output voltage	+48 V	46	48	51	V
Output current limit	+48 V	18	21	23	A
Input current limit	+12 V	89	92	95	A

<b>ABSOLUTE MAXIMUM RATINGS</b> ( $T_A = 25\text{ }^{\circ}\text{C}$ , unless otherwise noted)		
ELECTRICAL PARAMETER	LIMITS	UNIT
+48 V	0 to 56	V
+12 V	0 to 16	V
Logic power voltage +V_IN (pin 1 ST2)	0 to 56	V
/Enable voltage (pin 2 ST2)	0 to 56	V
/Boost voltage (pin 2 ST2)	0 to 56	V
Maximal allowed load in buck mode (minimal allowed resistance value)	0.15	$\Omega$
Minimal output voltage in buck mode (electronic load CV mode)	8	V
Maximal allowed load in boost mode (minimal allowed resistance value)	2.5	$\Omega$
Minimal output voltage in boost mode (electronic load CV mode)	35	V
Ambient temperature	-25 to +40	$^{\circ}\text{C}$
Heatsink temperature (active cooling might be required depending on use case)	-25 to +60	$^{\circ}\text{C}$
Storage temperature	-25 to +80	$^{\circ}\text{C}$
Power dissipation	70	W

### PRINCIPLE DIAGRAM



## OPERATIONAL DESCRIPTION



The 1 kW, 48 V<sub>DC</sub> to 12 V<sub>DC</sub> converter is a synchronous two-phase buck / boost converter. The two power stages are located on the bottom PCB. This PCB is a FR4 with six layers of 2 oz copper thickness, while the top PCB is four layers and 1 oz. For good thermal connection and electric isolation, the bottom PCB is interfaced to the housing using thermal interface material.

The converter uses two interleaved phases to reduce overall ripple. Each phase is controlled by one LT8228 that is driven by clock signals derived off of an MIC1557 oscillator. To further reduce the ripple on the 48 V side, a 4.7  $\mu$ H IHLP-6767 inductor is placed between the +48 V terminal and the two phases. A 2.2  $\mu$ H IHLP-1212 inductor with a 100 m $\Omega$  resistor in series is added in parallel to the IHLP-6767 to shape the transfer function.

Each phase has a pair of protection MOSFETs on each side to isolate the phase in the event of a fault condition. These are also used to limit the inrush current to the DC-Link capacitors. A continuous current of over 40 A per phase can occur on the 12 V side, so a low R<sub>DS(on)</sub> is essential to minimize losses. For this purpose, the SQJQ140E with a typical R<sub>DS(on)</sub> of 0.44 m $\Omega$  is selected. On the 48 V side the currents are lower and the R<sub>DS(on)</sub> is less important. Instead, the inrush current to the DC-Link capacitors must be considered, and the wide safe operating area makes the SQJQ112E a good choice.

A small Miller capacitance is important for the switching MOSFETs in the half bridge in order to reduce the switch-on and switch-off losses. To achieve this, four SQJA90EPs are placed in parallel to reduce the conduction losses.

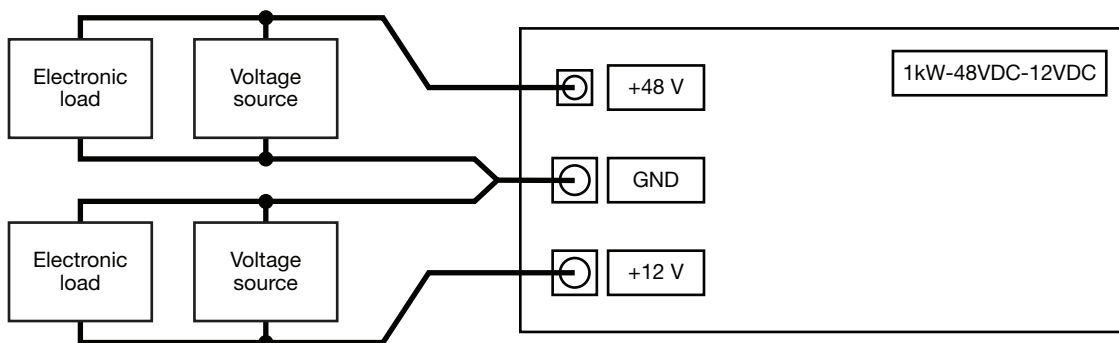
To compensate the high ripple currents on the 48 V side, the DC-Link consists of 10 22  $\mu$ F, 63 V MAL218297802E3 capacitors. This hybrid conductive polymer aluminum capacitor has a very low ESR of 80 m $\Omega$  and is rated for a ripple current of 1.5 A<sub>RMS</sub> with a small footprint of 6.3 mm x 6.3 mm. In addition, there are four 10  $\mu$ F MLCCs placed near the MOSFETs. The 220  $\mu$ F MAL214699808E3 with a 300 m $\Omega$  resistor in series is used for damping. On the 12 V side, five 47  $\mu$ F, 25 V, 60 m $\Omega$ , 2.7 A<sub>RMS</sub> T51D476M025C0060 vPolyTan polymer capacitors and one 470  $\mu$ F aluminum electrolytic capacitor are used for the DC-Link.

The main inductor of the converter is the 5.4  $\mu$ H inductor from the IHDM-1107BB series.

A 2 m $\Omega$  WSLP2726 Power Metal Strip<sup>®</sup> resistor is used for the current measurement on the 48 V side and a 1 m $\Omega$  one on the 12 V side.

**FRONT PANEL**


LED DESCRIPTION		
COLOR	LABEL	DESCRIPTION
Green	Phase1	Phase 1 is enabled
Green	Phase2	Phase 2 is enabled
Yellow	Buck	Buck mode is selected
Yellow	Boost	Boost mode is selected
Red	Fault Ph.1	Fault status on phase 1
Red	Fault Ph.2	Fault status on phase 2

**QUICK START GUIDE**


Use cables of at least 16 mm<sup>2</sup> for the 12 V connection and 4 mm<sup>2</sup> for the 48 V connection. Connect the ground cables of both the 12 V and 48 V rails near or on the GND terminal of the converter to ensure that large current changes on the 12 V side do not cause voltage changes on the 48 V side due to resistance or inductance of the ground cable.

Ensure that the power supplies are protected against reverse current and can handle the full voltage range.

Ensure enough airflow over the heatsink to keep the temperature below 60 °C at all times.

Under light load conditions, the converter can switch to discontinuous operation mode or cycle between buck and boost modes if in automatic mode. This can trigger the fault LEDs due to a light rise in output voltage, but will not affect the operation of the converter.



**BUCK MODE START GUIDE**

1. Connect the +V\_IN pin on ST2 to a voltage source between 12 V and 56 V
2. Connect the /Boost pin on ST2 to a voltage source between 8 V and 56 V to force the buck mode
3. Connect the +48 V terminal to a power supply with a voltage between 35 V and 56 V that can deliver at least 26 A
4. Connect the +12 V terminal to an electric load; set the voltage to at least 8 V and the current to 1 A
5. Enable first the load and then the power supply
6. Connect /Enable pin on ST2 to GND to switch the converter on
7. Now the current in the load can be increased

When the converter reaches its current limits, the controller switches from constant voltage to constant current mode. In this mode the output voltage can fall to the 8 V CV voltage set in the load.

**BOOST MODE START GUIDE**

1. Connect the +V\_IN pin on ST2 to a voltage source between 12 V and 56 V
2. Connect the /Boost pin on ST2 to GND to force the boost mode
3. Connect the +12 V terminal to a power supply with a voltage between 8 V and 15 V that can deliver at least 90 A
4. Connect the +48 V terminal to an electric load; set the voltage to at least 35 V and the current to 1 A
5. Enable first the load and then the power supply
6. Connect /enable pin on ST2 to GND to switch the converter on
7. Now the current in the load can be increased

When the converter reaches its current limits, the controller switches from constant voltage to constant current mode. In this mode the output voltage can fall to the constant voltage level (36 V) set on the load.





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