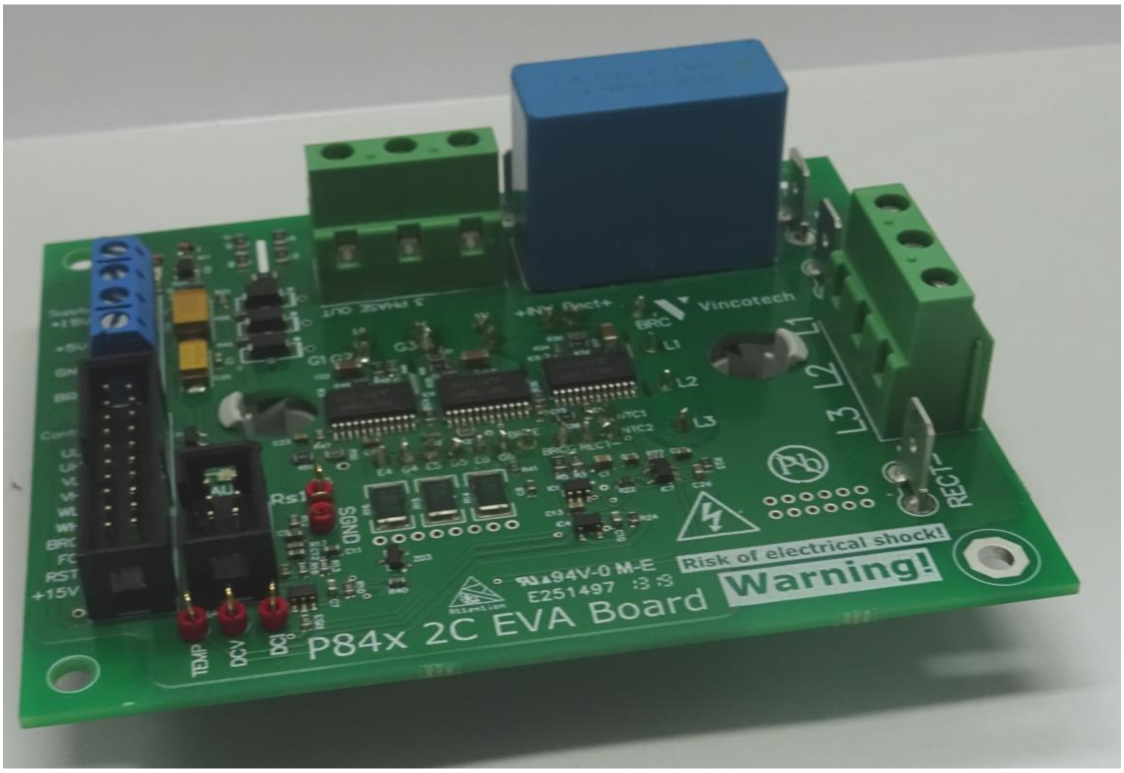
Vincotech

Application Note



Evaluation Board for P84x & P54x modules

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Revision history:

Date	Revision Level	Description	Page number(s)
May. 2013	1	First release	n.a.
Jun. 2020	2	New layout for 2Clips housing	

Safety Information

The board described is an evaluation board (EVA board) dedicated for laboratory environment only. It operates at high voltages. This board must be operated by qualified and skilled personnel familiar with all applicable safety standards.
This EVA board can endanger life by exposure to rotating machinery and high voltages. The ground potential of the EVA board is not floating it is biased to the negative DC-Link voltage potential. In order to be able to measure by non-floating instrument (oscilloscope) use isolation transformer at the AC input.
Allow at least 2 minutes for the DC-Link capacitor to discharge to safe voltage levels (< 50 V).

Failure to follow these guidelines result personal injury or death and/or equipment damage.

1 Abstract

This application note describes an Evaluation Driver Board designed for the P84x line of modules. To learn more about Vincotech modules, please visit www.vincotech.com. This board is a plug-and-play solution that serves to identify this line of modules' switching behavior and efficiency. The PCB has all components on board needed to test the P84x module, for example, half-bridge drivers and over-voltage, over-current and over-temperature protection circuits. It also provides measurement circuits for monitoring the DC link voltage, DC link current and the module's temperature.

2 Features

The following section describes the board's main features, basic electrical parameters, pin assignments and dimensions.

2.1 Main features

- Suitable for the P84x line (600 V to 1200 V / 4 A to 15 A modules)
- Suitable for Mitsubishi M7 and Infineon IGBT4 technology
- Mitsubishi half-bridge driver M81738FP 1200 V IGBT gate driver for each leg
- Active Miller clamp circuit for each IGBT
- Bootstrap circuit for supplying upper IGBT drivers
- Under-voltage lockout
- 5 V TTL compatible inputs
- FO pin (input and output) for a latched fault signal (active low)
- FO_RST pin for resetting the latch
- Onboard comparator to limit over-voltage, over-current and over-temperature
- DCV DC link voltage, DCI DC link current amplified analog outputs
- TEMP heatsink temperature amplified analog output (sensed via an integrated thermistor)
- ±1 A gate drive currents

2.2 Electrical parameters

The electrical characteristics shown here indicate a warranted value range for supply voltages, load, and junction temperature. These are typical median values under normal operating conditions. Unless otherwise noted, all voltages are given with respect to ground (GND).

$V_S=V_{15VDC}=15V$, $V_{BS}=V_B-V_S=14$ V

CL = 1 nF, T_a = 25 °C. Positive currents are assumed to be flowing into pins.

Table 1 Electrical Characteristics

Symbol	Parameter	Min.	Typ.	Max	Unit	Conditions
$U_{CE(600)}$	U_{CEmax} for 600 V modules	-	-	600	V	
$U_{CE(1200)}$	U_{CEmax} for 1200 V modules	-	-	1200	V	
I_C	RMS current through PCB	-	-	20	A	T_{amb} = 60°C T_{rise} = 50°C
U_{15VDC}	Supply voltage for gate drivers	13.5	15	20	V	
U_{5VDC}	Supply voltage for logic and analog	4.9	5	5.3	V	
V_{INH}	High-level input threshold voltage	2.2	3	4	V	HIN, LIN, FO_RST
V_{INL}	Low-level input threshold voltage	0.5	1.5	2.1	V	HIN, LIN, FO_RST
V_{OLFO}	Low-level FO output voltage	-	-	0.95	V	I_{FO}=0.5mA
V_{IHFO}	High-level FO input threshold voltage	2.2	3	4	V	
V_{ILFO}	Low-level FO input threshold voltage	0.6	1.5	2.1	V	
A_{DCI}	DCI current output gain	-	R_{SW} * 4	-	S	see R_{SW} values in Table 2 and Table 3
A_{DCV}	DCV voltage output gain for 1200V modules	-	2.5	-	V/750V	set by R_1, R_2, R_4, R_6, R_7
A_{DCV}	DCV voltage output gain for 600V modules	-	2.5	-	V/450V	set by R_1, R_2, R_4, R_6, R_7
I_{SCP}	Over-Current protection	-	$\frac{1}{2 * R_{SW}}$	-	A	set by R_{SW} shunt
U_{OVP}	Over Voltage protection 1200/600	-	750/450	-	V	set by R_1, R_2, R_4, R_6, R_7
T_{OTP}	Over Temperature protection	-	100	-	°C	set by R_{22}, R_{23}
f_{sw}	switching frequency	2	8	16	kHz	set by PWM controller
$R_{th(j-a)}$	Junction-ambient air R_{th}	-	-	90	K/W	
T_{VJmax}	Junction temperature	-40	-	125	°C	
T_{ST}	Storage temperature	-40	-	150	°C	
	For more details, see the Mitsubishi Electric M81738FP datasheet.					

The following tables shows the various P84x modules and provides information about the recommended switching frequency and passive components.

Table 2 P84x modules with Infineon chipset

Module	P840	P849	P848	P540	P549	P543	P544
Current [A]	15	8	4	15	8	10	15
Voltage [V]	1200	1200	1200	1200	1200	600	600
Shunt	3x100mΩ	2x100mΩ	1x100mΩ	3x100mΩ	2x100mΩ	2x100mΩ	3x100mΩ
R_1, R_2, R_4, R_6, R_7 [kΩ]	300	300	300	300	300	180	180
R_{GON} [Ω]	16	32	64	64	64	32	16
R_{GOFF}[Ω]	8.2	16	32	32	32	16	8.2

Table 3 P84x modules with Mitsubishi M7 chipset

Module	P840	P849	P848
Current [A]	15	10	5
Voltage [V]	1200	1200	1200
Shunt	3x100mΩ	2x100mΩ	1x100mΩ
R_1, R_2, R_4, R_6, R_7 [kΩ]	300	300	300
R_{GON} [Ω]	32	32	64
R_{GOFF}[Ω]	32	32	64

Note: Other modules with the same pinout (like P54x family) can also be driven as long as the maximum RMS current is not exceeded.

2.3 Pin assignments

The driver board has two connectors, one for the digital control signals (Control) and one for the measured analog signals (Analog).

Figure 1 Pin The IDC board connector's pin assignments

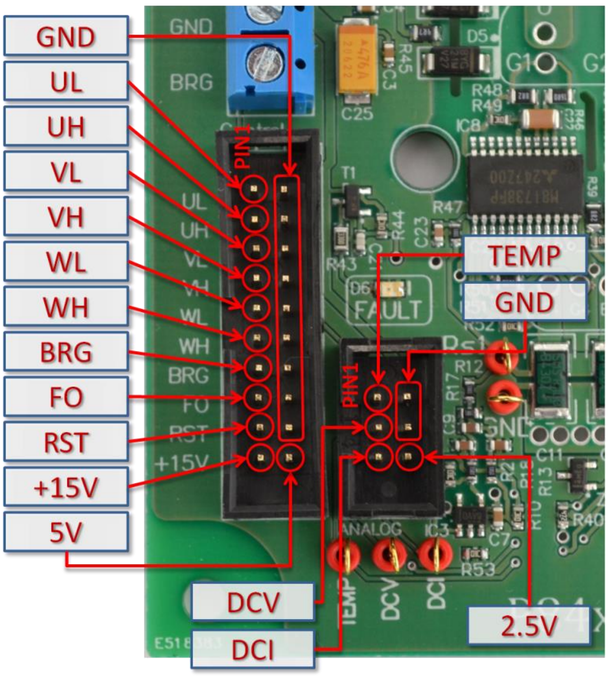


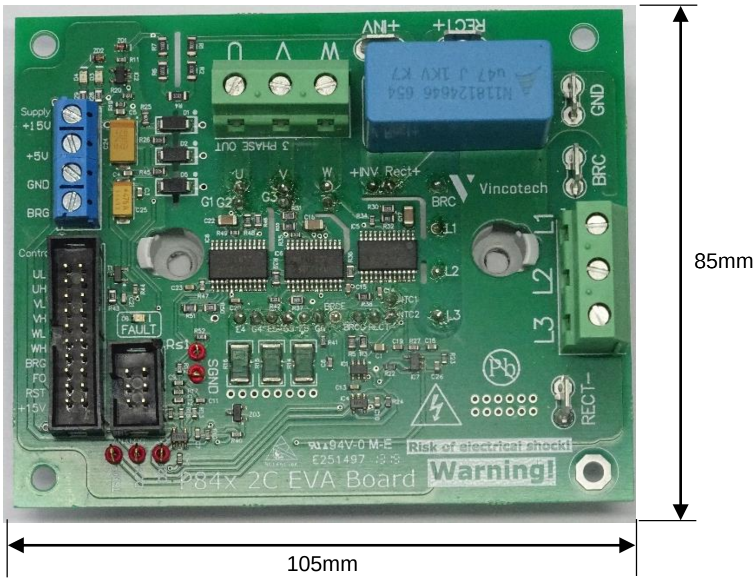
Table 4 Board connectors' pin assignments

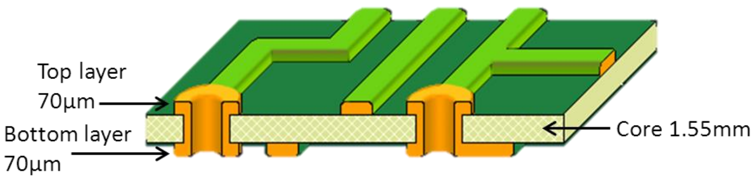
Control connector		
Pin number	Name	Function
1	UL	Phase U low side PWM signal input
2	GND	Ground
3	UH	Phase U high side PWM signal input
4	GND	Ground
5	VL	Phase V low side PWM signal input
6	GND	Ground
7	VH	Phase V high side PWM signal input
8	GND	Ground
9	WL	Phase W low side PWM signal input
10	GND	Ground
11	WH	Phase W high side PWM signal input
12	GND	Ground
13	BRG	Brake signal input
14	GND	Ground
15	FO	Fault signal input/output
16	GND	Ground
17	FO_RST	Fault latch reset input
18	GND	Ground
19	+15V	+15V from supply connector
20	+5V	+5V from supply connector

Analog connector		
Pin number	Name	Function
1	TEMP	Temperature measurement output
2	GND	Ground
3	DCV	DC link voltage measurement output
4	GND	Ground
5	DCI	DC link current measurement output
6	2.5V	2.5V offset of the DCI amplifier

2.4 Dimensions

Figure 2 The board's dimensions





The board is based on a 2-layer FR4 PCB. Each layer is 70 µm thick and the insulation (FR-4) is at least 1.55 mm thick..

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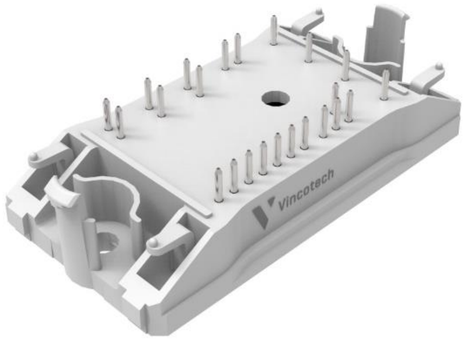
3 Electrical circuits

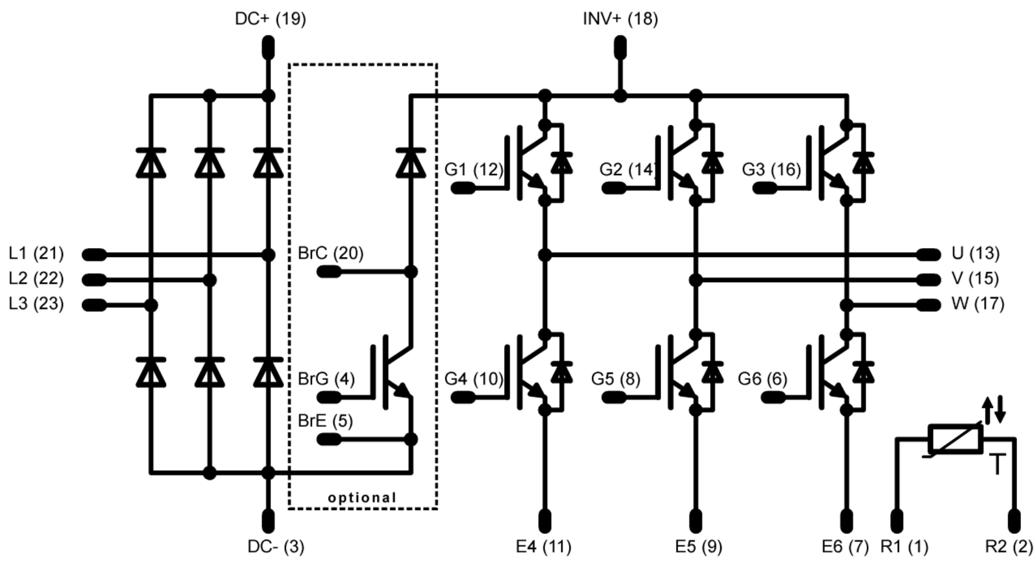
This section describes the various input, output and driver circuits to afford the reader insight into how the board works. It also provides a few tips on adjusting the given IGBT module's switching speed and performance.

3.1 Power module

This line of modules uses a 3~ rectifier to convert the voltage from AC to DC. P84x modules are available with and without a brake chopper. Six IGBTs with freewheeling diodes have been implemented for converting DC to AC. The IGBTs and freewheeling diodes share the same current rating, so modules can be used for 100% braking. An NTC is installed to measure temperature. Note that the isolation of this NTC is purely functional.

Figure 3 The P84x line's housing and topology





3.2 Required power supply

A 15 V power feed for the gate drivers and 5 V feed for the analog circuits must be connected to the supply terminal block for the evaluation board to operate properly.

3.3 Input and output signals

Six PWM signals are required to control the IGBT inverter’s switching. The PWM voltage level is 4.0 V to 5.5 V. DCV, DCI and TEMP analog output signals are provided for measuring the DC link voltage, DC link current and heatsink temperature. These signals are generated by operational amplifiers.

3.4 FO fault input/output pin

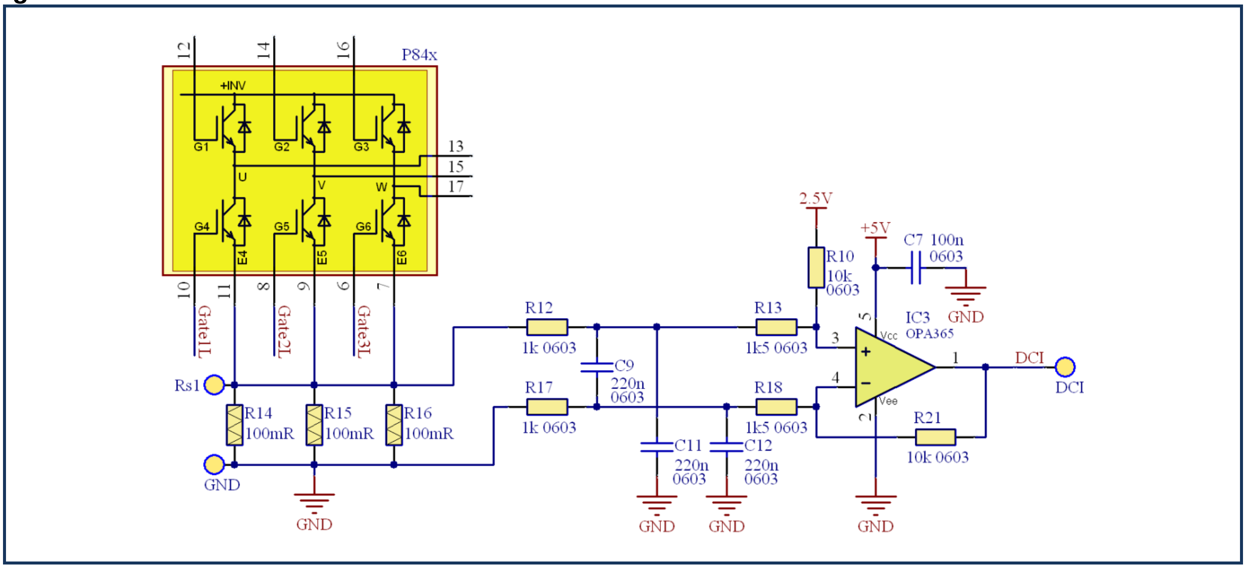
The Control connector’s FO pin can serve as an input and output. If one of the gate driver ICs detects a fault condition, it shuts down and pulls down the FO line with its internal transistor. The other gate driver ICs also shut down as soon as they sense this low level on the FO line. Faults are indicated by the board’s red Fault LED.

4 Schematics

4.1 DC link current measurement and over-current protection

The IC3 operational amplifier handles the DC link current measurement on the low side emitter shunts (R14, R15, and R16). A differential amplifier measures the current on the shunts. The amplifier has a gain of 4 and a 400 Hz upper corner frequency to filter out the high frequencies from the voltages measured on the shunts.

Figure 4 DC link current measurement



Every M81738FP driver IC features an internal comparator with 0.5 V trip voltage for over-current protection. Each comparator serves to protect the PIM module from over-current, over-voltage and over temperature, respectively.

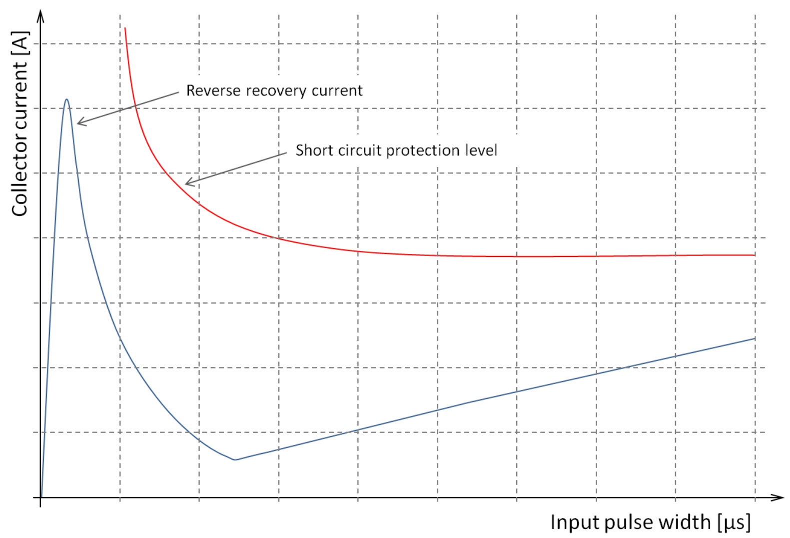
The IC8's internal comparator provides over-current protection. It activates short-circuit protection and shuts down the outputs when the voltage on the shunts rises above 0.5 V. The M81738FP features a fault latch, so the outputs remain disabled until a reset signal arrives at the FO_RST pin (active high).

The internal open-drain MOSFET pulls down the FO line when the internal comparator activates short-circuit protection. The other ICs sense the common FO line's logic level. When it is pulled down, the remaining ICs (on the other phases) activate their protection circuits and shut down as well. As the example in Figure 4 shows, over-current protection is activate when the voltage on the 33 mΩ shunt is equal to or higher than the internal 500 mV reference, so the over-current protection limit is:

$$I_{trip} = \frac{500mV}{33m\Omega} = 15A$$

An RC filter network is connected to the CIN input to prevent inadvertent short-circuit detection triggered by the reverse recovery current. The freewheeling diode's reverse recovery current will briefly flow through the IGBT when it is turned on in a half-bridge application. Without the RC filter, this current spike (Figure 5) can trigger over-current protection. The blanking time in this application is 1 µs.

Figure 5 Over-current protection timing



The short circuit protection of the IC is only active when the low side is being pulsed. Therefore this protection is not suitable for detecting short current, nor can it detect an over current in only one phase of the connected motor. The same applies to the over voltage and over temperature protection. To have all protection features operate correctly please apply such modulation having pulsing all IGBT's at all times.

4.1.1 Over-current protection test

The IGBT must be turned off as quickly as possible in the event of a short circuit. Maximum short-circuit withstand time depends on the semiconductor. It is limited by the IGBT's ability to withstand short-circuit current. For the withstand time of semiconductors in Vincotech's P84x module please check the module datasheet.

A three-phase motor provides a load with high speed-up rate (5 Hz to 40 Hz sudden frequency step) for the over-current protection test. A comparator in the IC8 gate driver monitors the DC link current on the low-side shunt resistor. A P840 module with a nominal chip current of 15 A is used during this test with a 33 mΩ shunt resistor. A shunt resistor with this rating sets the over-current protection to 15 A as indicated in equation 1.

Figure 6 depicts the over-current test. The current rises slowly owing to motor inductance. The protection is activated at 16 A DC link current and the IC8 gate driver pulls down its FO input/output.

Figure 6 Over-current protection test

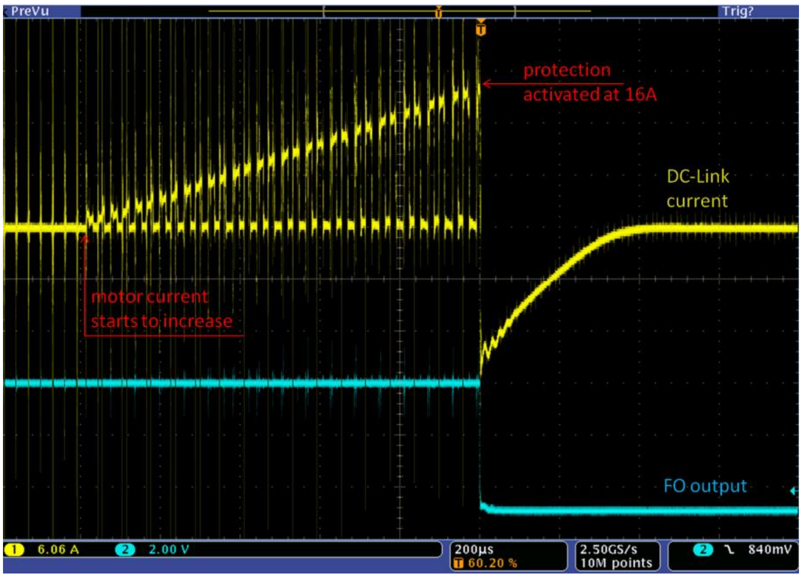
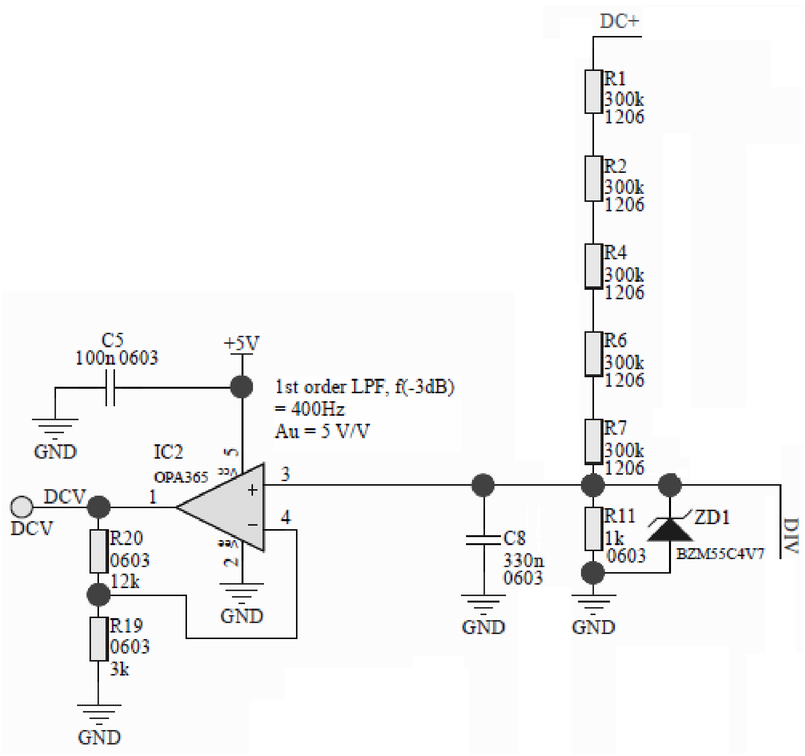


Figure 6 shows the results of the short-circuit test. Two output phases are shorted by one relay. The slope of the current is very high because of the relatively low inductance, but the IGBT characteristic causes it to de-saturate at 45 A. The current is switched off after 2.5 µs. Switch-off time can be extended by increasing the RC filter time constant using an R47 resistor or C23 capacitor.

4.2 Over-voltage protection and DC link voltage measurement

The IC2 operational amplifier handles DC link voltage measurement. The R1, R2, R4, R6 and R7 resistors divide the DC link voltage for the over-voltage comparator. The comparator trip voltage is set to 0.5 V and the divider gain is 1/1500, so the over-voltage protection is $0.5V * 1500 = 750V$. The operational amplifier's gain is 5 V/V, so the overall gain from the DC link voltage to the DCV pin is $1/300\frac{V}{V}$. With the addition of the C8 capacitor, the voltage measurement and over-voltage protection circuit's corner frequency is 400 Hz lower.

Figure 7 DC link voltage measurement

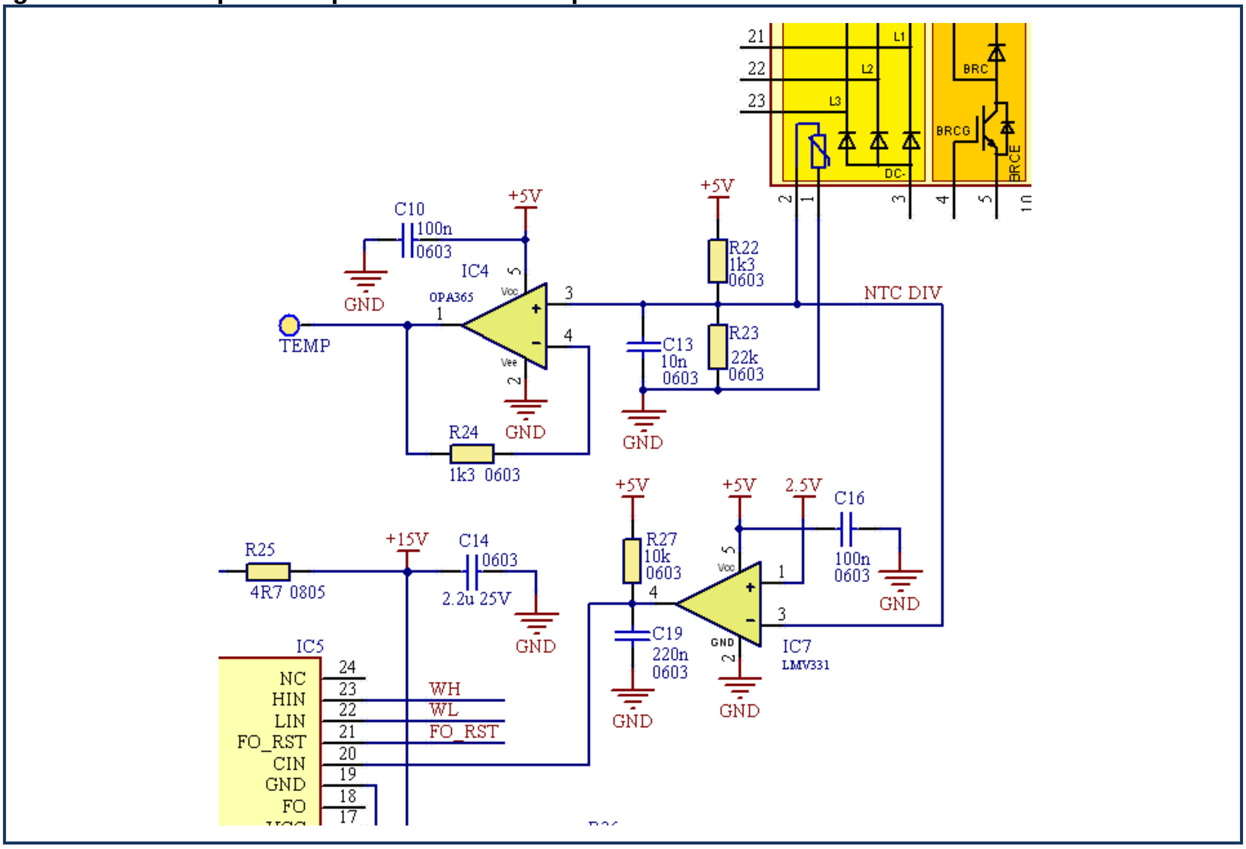


The IC6 gate driver's internal comparator is responsible for over-voltage protection. The comparator activates the protection and shuts down the output when the voltage on the DC link voltage divider output (DIV) exceeds 0.5 V. The fault latch ensures the outputs remain disabled until a reset signal is applied to the FO_RST pin (active high).

4.3 Over-temperature protection and temperature measurement

The IC4 operational amplifier and built-in NTC handle temperature measurement. The module's temperature may be monitored via the TEMP output. Figure 8 shows the TEMP analog output characteristic.

Figure 8 Over-temperature protection and temperature measurement



The IC4 operational amplifier in Figure 8 drives the analog TEMP output signal. The IC7 comparator and IC4 gate driver are responsible for over-temperature protection. The NTC's resistance drops when the module's temperature rises, so the NTC DIV point's voltage decreases with increasing temperature. The IC7 comparator releases the IC5 gate driver's CIN pin when the NTC DIV point's voltage dips below 2.5 V. At this moment, the CIN pin voltage rises, this driver's internal comparator activates its internal protection circuit, and the outputs shut down.

Figure 9 TEMP output characteristic and over-temperature limiting

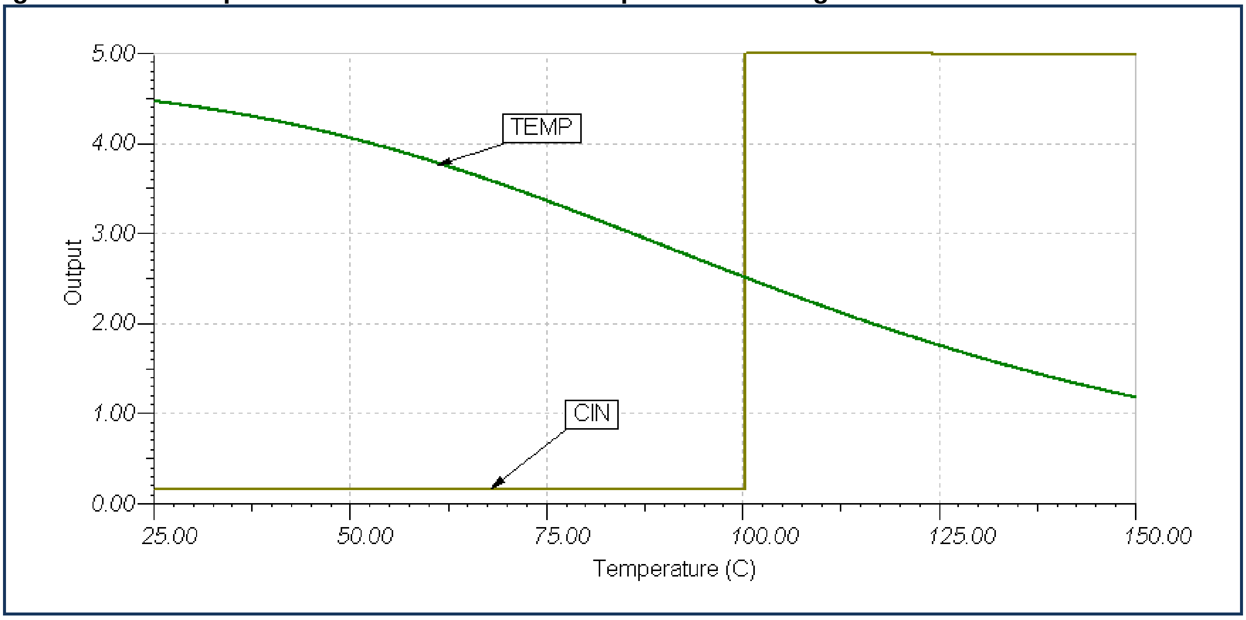


Figure 9 show that over-temperature protection activates at 100 °C. A fault latch circuit ensures the outputs remain disabled until a reset signal arrives at the FO_RST pin (active high).
The built-in NTC's resistance is 22 kΩ @ 25 °C and the $B_{(25/100)}$ value is 4000K. The following equation expresses the relationship between the NTC's resistance and temperature NTC, whereby T stands for temperature:

$$R_{NTC} = R_{25} * e^{B\left(\frac{1}{T} - \frac{1}{298K}\right)}$$

The relationship between the voltage on the TEMP pin and the temperature (see Figure 9) is given as:

$$U_{TEMP} = 5V * \frac{\frac{R_{NTC} * R_{23}}{R_{NTC} + R_{23}}}{\frac{R_{NTC} * R_{23}}{R_{NTC} + R_{23}} + R_{22}}$$

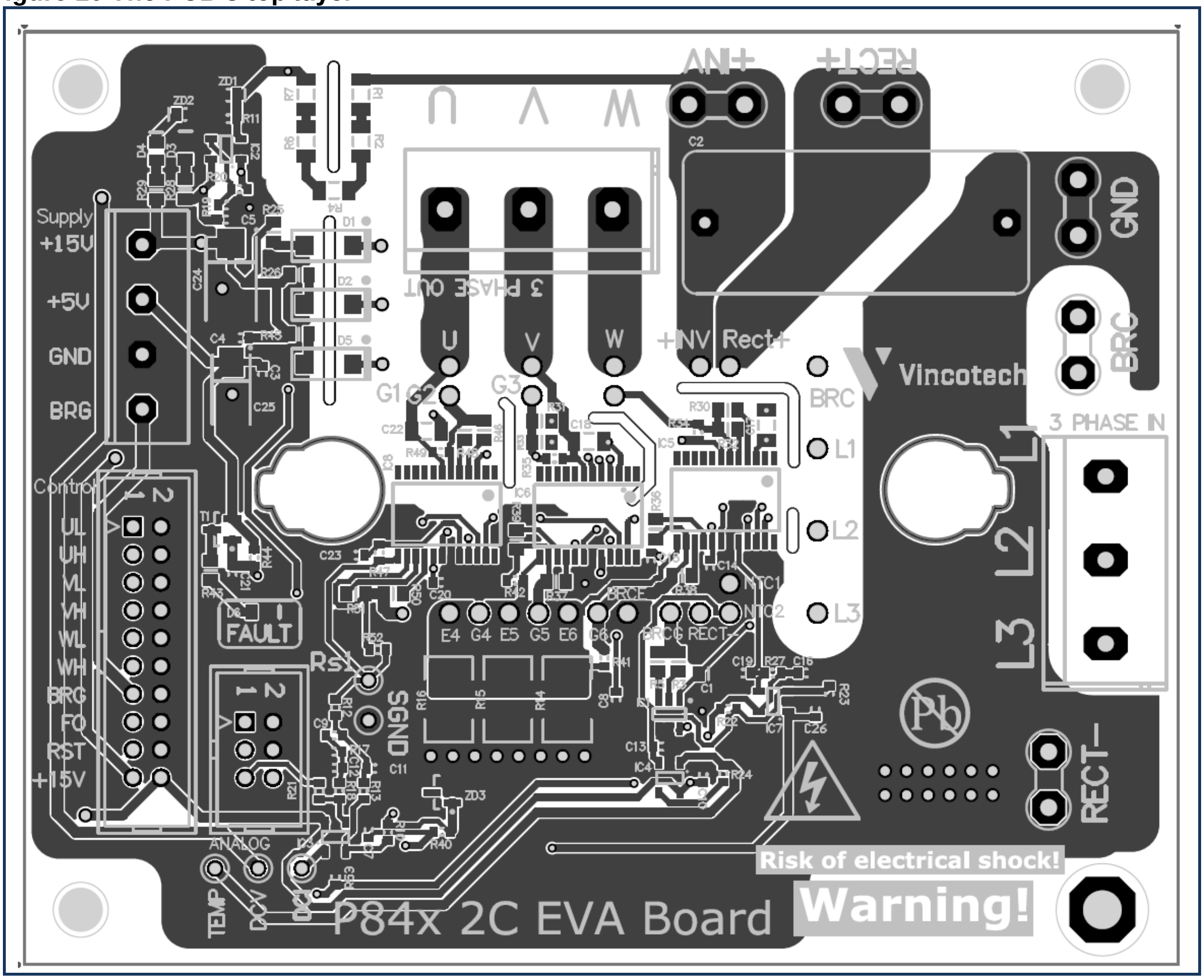
Note that R_{23} = 22 kΩ and R_{22} = 1.3 kΩ (refer to Figure 8).

5 PCB design

5.1 TOP layer design

The top layer contains almost all components except the P84x power module. Switching off the IGBT triggers an over-voltage spike in parasitic inductances, so this design was developed to provide low inductance connections. Components with higher voltage ratings are required to handle this voltage spike.

Figure 10 The PCB's top layer



5.2 BOTTOM layer design

The only component on the bottom layer is the P84x power module. This bottom layer is designed to establish the connection between the gate driver ICs and the Control connector and the power traces between the P84x module and three-phase input terminals, DC link capacitor and brake resistor.

6 Layout

Figure 11 TOP assembly drawing

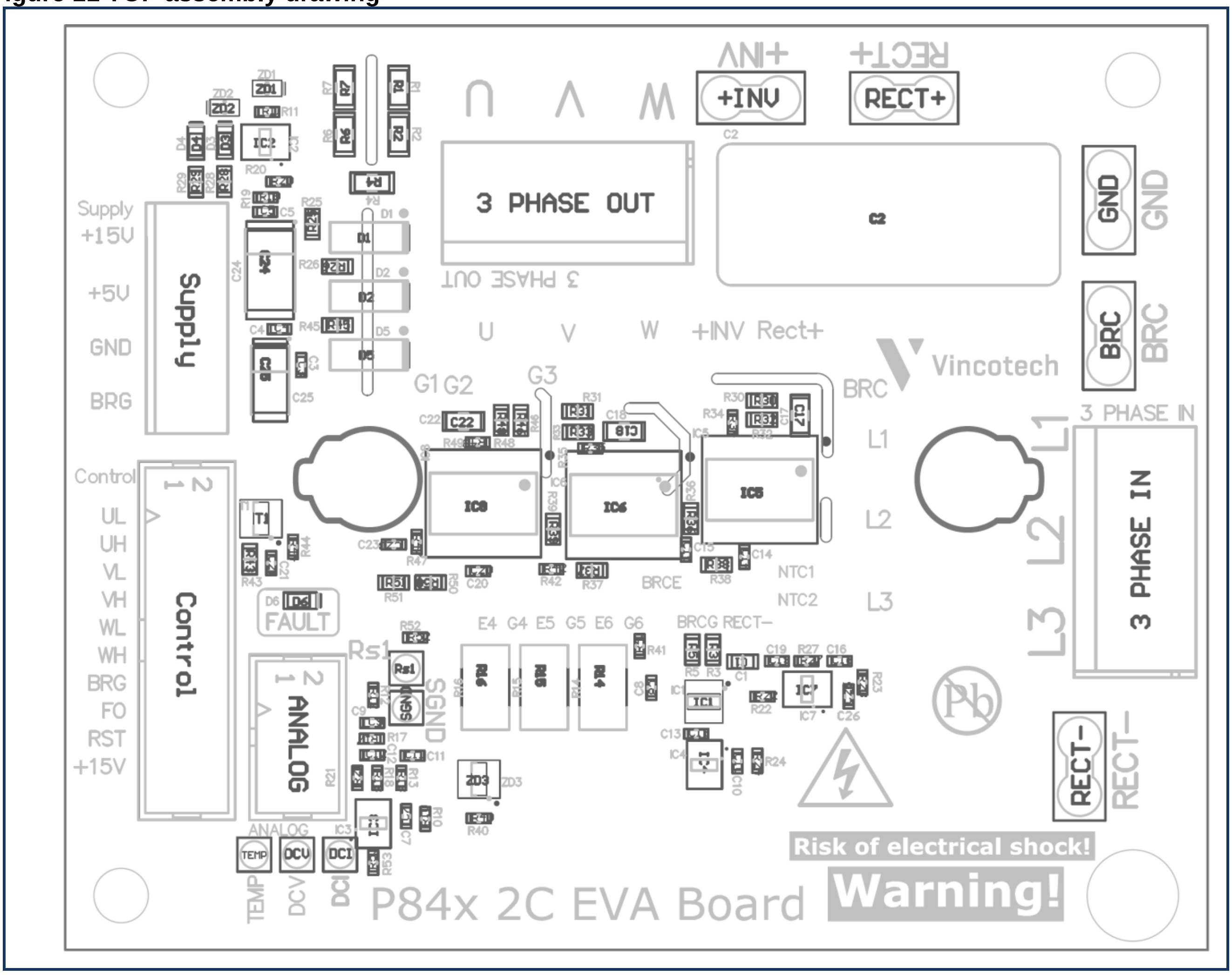


Figure 12 TOP layer

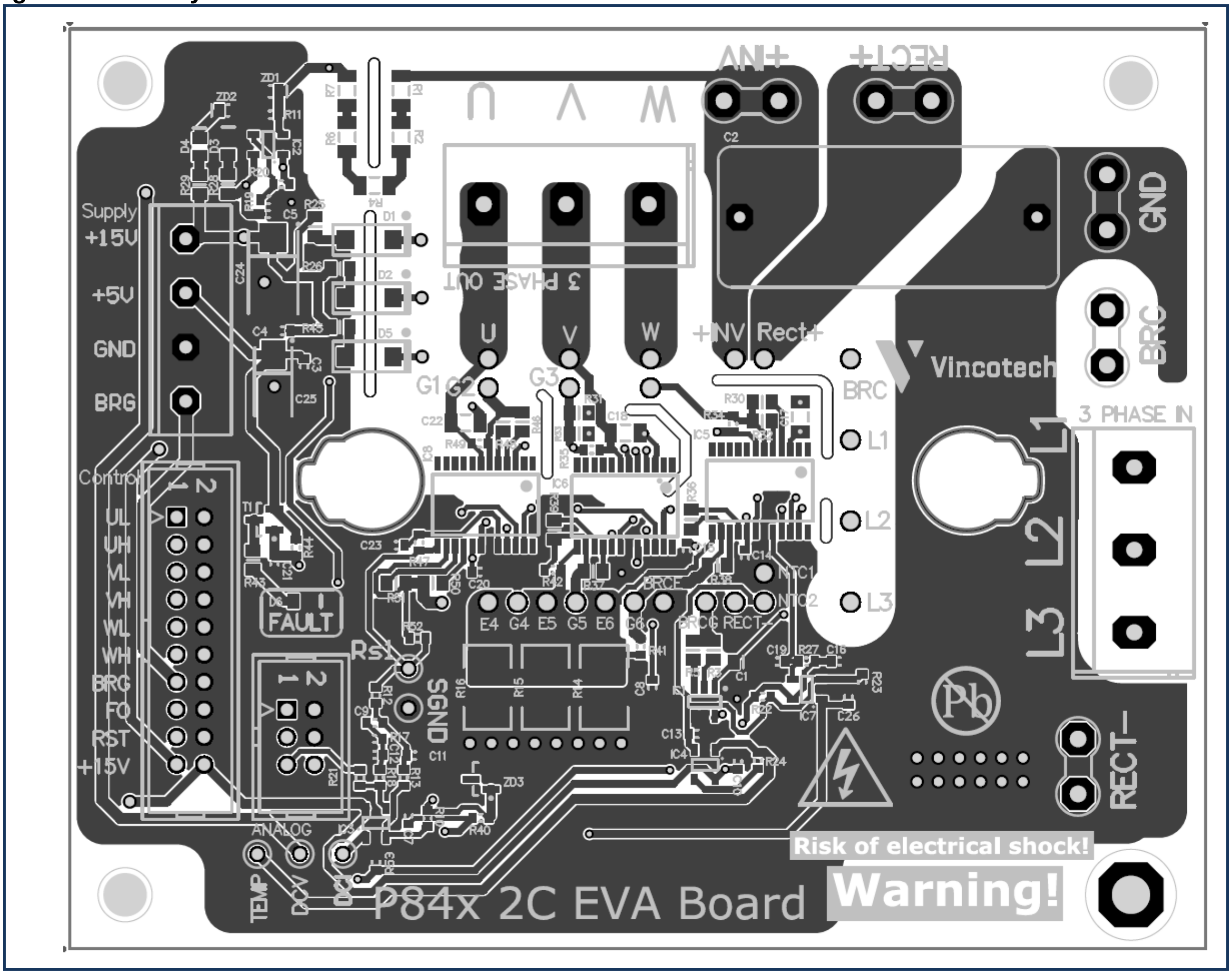
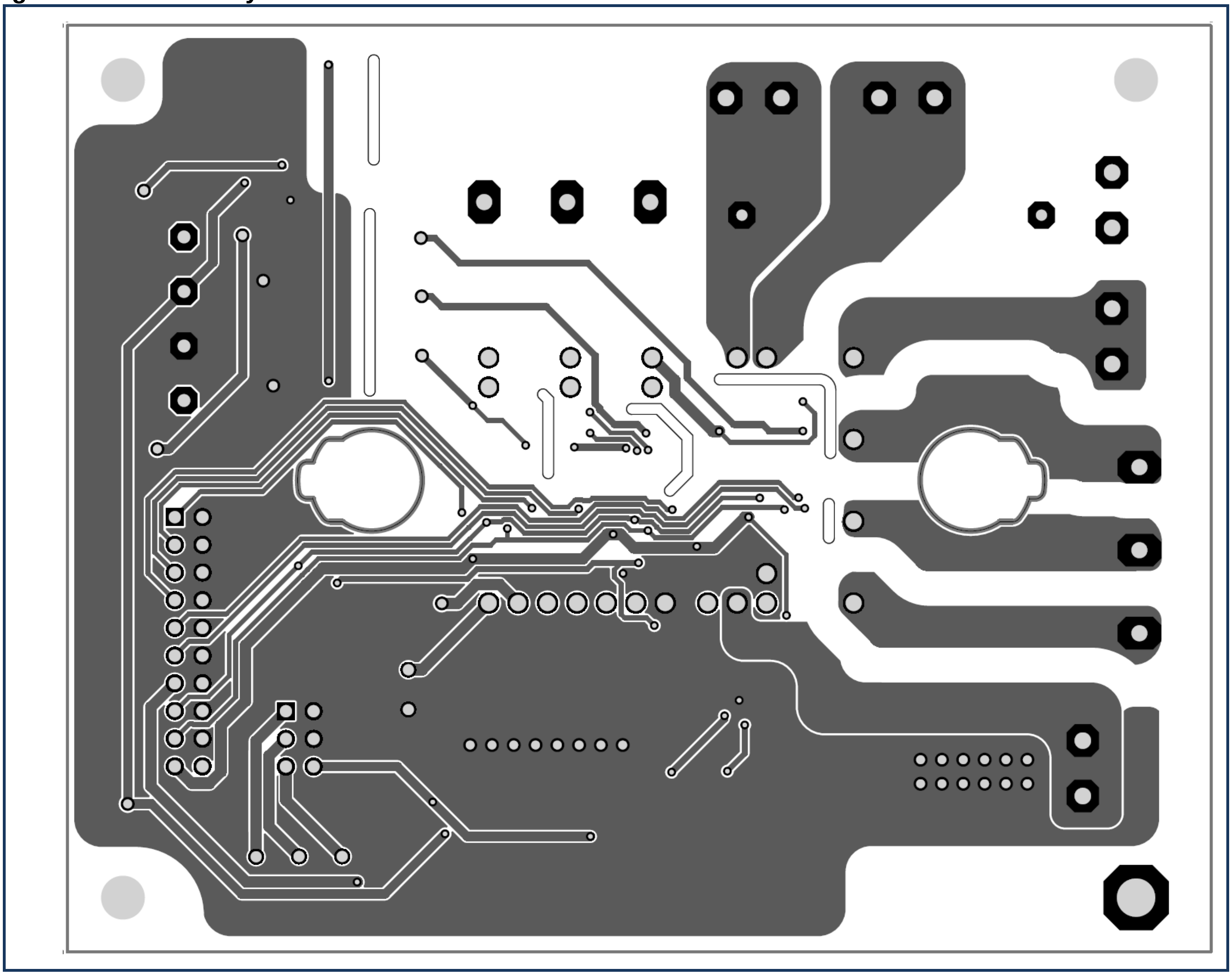
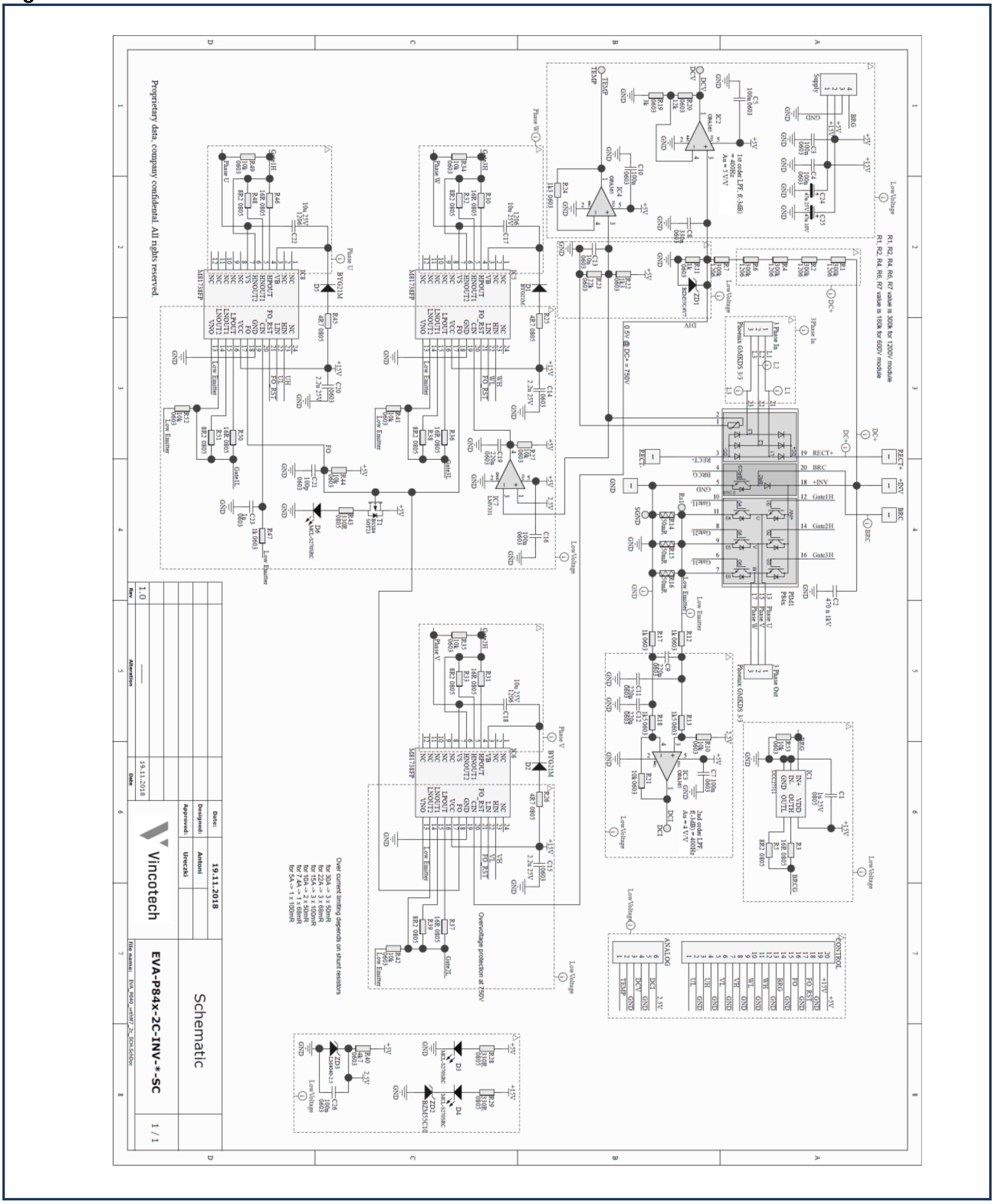


Figure 13 BOTTOM layer



7 Schematic

Figure 14 Schematic



8 Bill of material

Table 5 BOM list

Part No.	Value	Designator
Test-1(R)	Test Pin (Multicomp)	GND, DCI, DCV, Rs1, TEMP
T821-1-06-S1	IDC connector 6 PIN (Amphenol)	ANALOG
GRM21BR71E105KA99L	Ceramic Capacitor 1u 25V X7R 0805 (Murata)	C1
B32654A6105K	1u 630V MKP Capacitor RM 27.5mm (Epcos)	C2
C1608X7R1H104K	Ceramic Capacitor 100n 50V X7R 0603 10% (TDK)	C3, C4, C5, C7, C10, C16
C1608X7R1H334K	Ceramic Capacitor 330n 50V X7R 0603 10% (TDK)	C8
C1608X7R1H224K	Ceramic Capacitor 220n 50V X7R 0603 10% (TDK)	C9, C11, C12, C19
C1608X7R1H103K	Ceramic Capacitor 10n 50V X7R 0603 10% (TDK)	C13
C1206C106K3RAC TU	Ceramic Capacitor 10u 25V X7R 1206 (KEMET)	C17, C18, C22
C1608X7R1H101K	Ceramic Capacitor 100p 50V X7R 0603 10% (TDK)	C21
C1608X7R1H102K	Ceramic Capacitor 1n 50V X7R 0603 10% (TDK)	C23
GRM188R61E225KA12D	Ceramic Capacitor 2.2u 25V X5R 0603 10% (MURATA)	C14, C15, C20
T821-1-20-S1	IDC connector 20 PIN (Amphenol)	CONTROL
BYG21M	Diode 1000V (Vishay)	D1, D2, D5
MCL-S270SRC	Super Red LED 0805 (Multicomp)	D6
MCL-S270GC	Green LED 0805 (Multicomp)	D3, D4
UCC27511	Gate Driver SOT23-6 (Texas Instruments)	IC1
OPA365	Low offset RRIO OPAMP SOT23-5 (Texas Instruments)	IC2, IC3, IC4
M81738FP	Gate driver (Mitsubishi Electric)	IC5, IC6, IC8
LMV331	Low Voltage Comparator SOT23-5 (Texas Instruments)	IC7
CRCW060310K0FKEA	Resistor 10k 0603 1% (Vishay)	R10, R21, R27, R34, R35, R41, R42, R44, R49, R52, R53
CRCW06031K00FKEA	Resistor 1k 0603 1% (Vishay)	R11, R12, R17, R47
CRCW06031K50FKEA	Resistor 1k5 0603 1% (Vishay)	R13, R18
CRCW06033K00FKEA	Resistor 3k 0603 1% (Vishay)	R19
CRCW060312K0FKEA	Resistor 12k 0603 1% (Vishay)	R20
CRCW06031K30FKEA	Resistor 1k3 0603 1% (Vishay)	R22, R24
CRCW060322K0FKEA	Resistor 22k 0603 1% (Vishay)	R23
CRCW08054R70JNEA	Resistor 4R7 0805 5% (Vishay)	R25, R26, R45
CRCW0805330RJNEA	Resistor 330R 0805 5% (Vishay)	R28, R29, R43
CRCW06034K70JNEA	Resistor 4k7 0603 5% (Vishay)	R40
AK100/4DS-5.0-V-GREY-BL	PCB Terminal Block 4 Pole (PTR Messtechnik)	Supply
BSS84	P-Ch. MOSFET 50V SOT23 (NXP)	T1
BZM55C4V7	Zener Diode 4.7V MicroMELF (Vishay)	ZD1
BZM55C10	Zener Diode 10V MicroMELF (Vishay)	ZD2
LM4040D25	Shunt Reference 2.5V 1% SOT23 (Texas Instruments)	ZD3
TPSC476K010R0350	Tantalum Capacitor 47u 10V size 3212 (size C) (AVX)	C25

T491X476K025AT	Tantalum Capacitor 47u 25V size 7343 (size E) (KEMET)	C24
GMKDS 3/3	PCB Terminal Block 3 Position (Phoenix Contact) RM 7.5mm	3 PHASE IN, 3 PHASE OUT
63824-1	PCB Tab (TE Connectivity)	REST-, RECT+, BRC, +INV, GND
CRCW1206300KFKEA	Resistor 300k 1206 1% (Vishay)	R1, R2, R4, R6, R7
SMS-R100-1.0	Resistor Shunt 0.1R SMS series 3W (Isabellenhütte)	R14, R15, R16