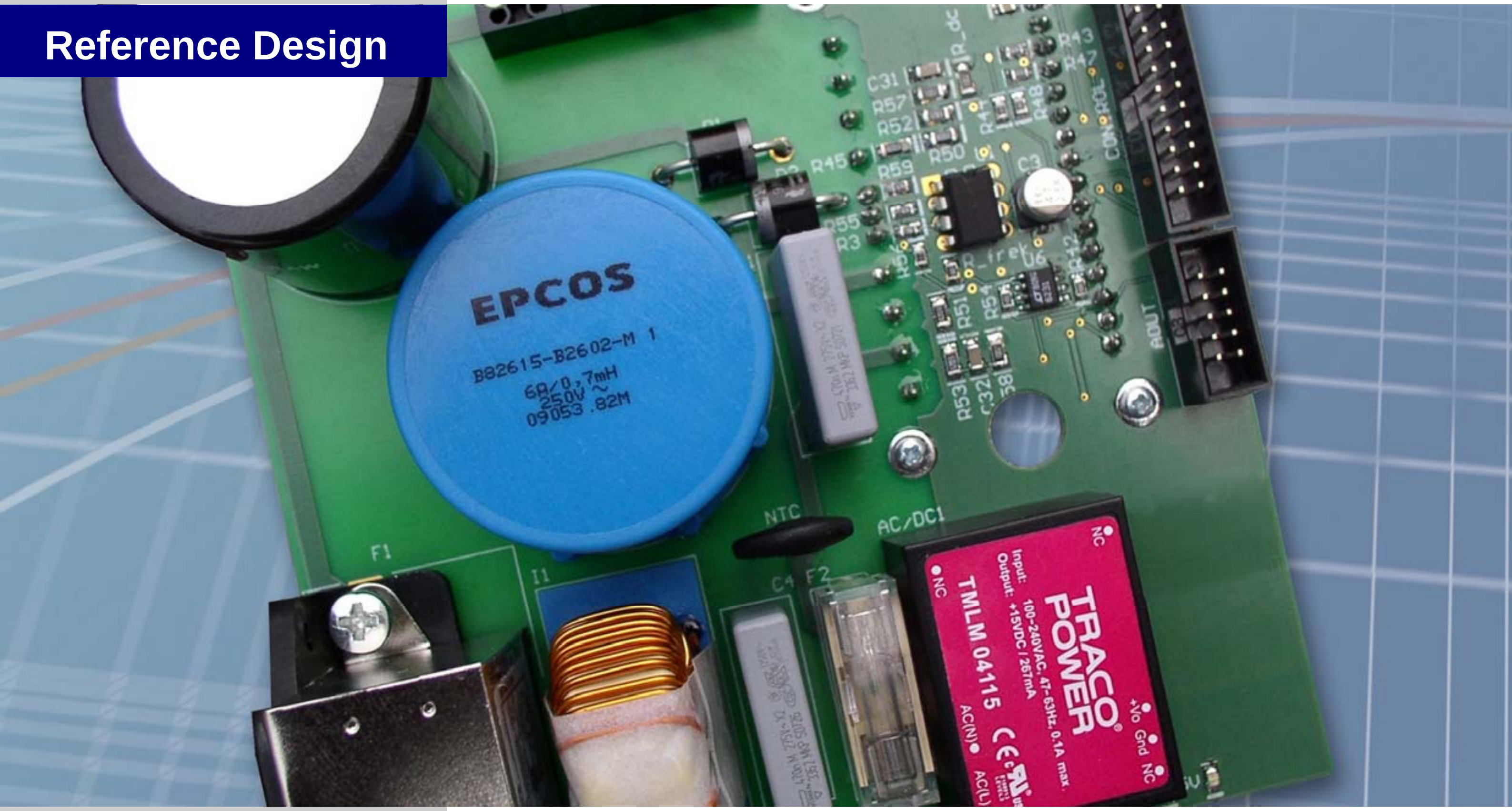
Reference Design



Evaluation Board for

*flow*IPM 1B Power Modules

EVA_P950 for Intelligent Power Modules

Reference Design no.:
RD_2011-01_001-v02

Table of Contents

Revision history:

Date	Revision Level	Description	Page number(s)
Mar. 2011	1	First Release	23

1 Introduction

In this application note the Evaluation Board for the module P950 or in other words the *flow*IPM1B is described. This board gives a plug and play solution to get familiar with the switching behavior and efficiency of the mentioned module.

Ordering number: **EVA_P950**

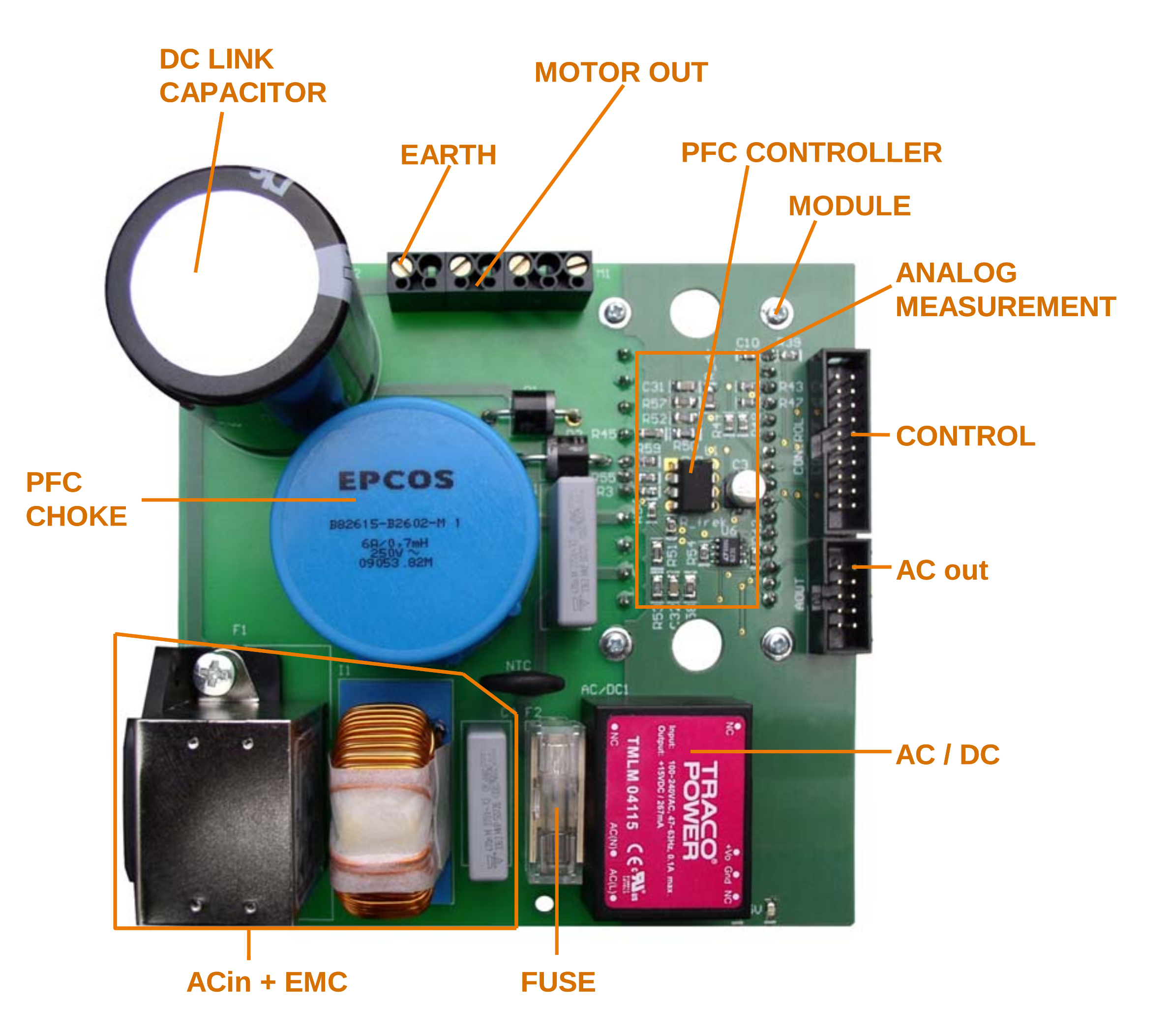


Figure 1: Evaluation board for P950 module

2 Features of the board

The next chapter describes the main features, basic electrical parameters as well as pin assignments and mechanical dimensions.

2.1 Main features

- P950 power module featuring rectifier, PFC, six-pack with driver, and current sensing shunts
- Complete 1 kW PFC circuit with PFC controller (switching frequency settable by resistor)
- 110 VAC – 230 VAC single phase input with 2 stage EMC filter, fuse and NTC inrush protection
- 380 VDC link (settable by resistor)
- phase 230 VAC motor output
- V TTL compatible inverting (active low) PWM inputs for the six-pack
- Dedicated Enable input (active high)
- Fault output signal (open collector)
- AC/DC converter for powering the PFC controller, circuit for measurement and the gate drivers in the module
- PCB is designed to fulfill the requirements of IEC61800-5-1, pollution degree 2, overvoltage category III

2.2 Electrical parameters

<table>
<tr><th colspan="2"></th><th>min.</th><th>typ.</th><th>max.</th><th>Unit</th><th>Remarks</th></tr>
<tr><td colspan="2">AC input voltage</td><td>90</td><td></td><td>250</td><td>VAC</td><td>47-63 Hz</td></tr>
<tr><td colspan="2">AC input current</td><td></td><td></td><td>5</td><td>Arms</td><td></td></tr>
<tr><td colspan="2">DC link voltage</td><td>230</td><td>400</td><td>450</td><td>VDC</td><td></td></tr>
<tr><td colspan="2">AC output voltage</td><td></td><td></td><td>240</td><td>VAC</td><td>@400 VDC link, 3~, SPWM</td></tr>
<tr><td colspan="2">AC output current</td><td></td><td></td><td>3.5</td><td>Arms</td><td></td></tr>
<tr><td colspan="2">MODUL_FAULT_N output</td><td></td><td></td><td>8</td><td>mA</td><td>Open collector</td></tr>
<tr><td rowspan="2">Voltage for logic Inputs</td><td>U_{InH},</td><td>1.7</td><td>2.1</td><td>2.4</td><td rowspan="2">V</td><td rowspan="2">Inverse TTL</td></tr>
<tr><td>U_{InL}</td><td>0.7</td><td>0.9</td><td>1.1</td></tr>
<tr><td>Input current for PWM</td><td></td><td></td><td></td><td>200</td><td>µA</td><td></td></tr>
<tr><td rowspan="5">Analog output</td><td>S_PFC</td><td>0</td><td>U_REF</td><td>5</td><td rowspan="6">V</td><td>0.22 V/A</td></tr>
<tr><td>S_INV</td><td>0</td><td>U_REF</td><td>5</td><td>0.25 V/A</td></tr>
<tr><td>DC2+_M</td><td></td><td>2.26</td><td></td><td>@400 VDC</td></tr>
<tr><td>DC1+_M</td><td></td><td>1.83</td><td></td><td>@324 V_{dcpeak}</td></tr>
<tr><td>NTC2</td><td></td><td>2.7</td><td></td><td>@T_h = 25 °C</td></tr>
<tr><td>Reference input</td><td>U_REF</td><td></td><td>2.5</td><td></td><td>Shunt current measurement</td></tr>
<tr><td colspan="2">f_{sw} PFC – switching frequency</td><td>106</td><td>133</td><td>161</td><td>kHz</td><td>@R4xR_frek= 33 kΩ</td></tr>
<tr><td colspan="2">T_{hmax} – Power Module</td><td></td><td></td><td>100</td><td>°C</td><td></td></tr>
<tr><td colspan="2">T_{OP} – Operation ambient temperature</td><td>-40</td><td></td><td>85</td><td>°C</td><td></td></tr>
<tr><td colspan="2">T_{ST} – Storage temperature</td><td>-40</td><td></td><td>85</td><td>°C</td><td></td></tr>
<tr><td colspan="7">*Table 1: Electric parameters*</td></tr>
</table>

2.3 Pin assignments

Connector		Pin name	Direction	Description
Symbol	Pin			
F1	L	L	Power I	1~ power input
	N	N	Power I	Null potential input
	Earth	Earth	Power I/O	Safety earth
J1	U	U	Power O	3~ output to motor drive
	V	V	Power O	3~ output to motor drive
	W	W	Power O	3~ output to motor drive
	Earth	Earth	Power I/O	Safety earth
AOUT	1	GND	Power O	Power for measure logic
	2	S_PFC	Analog O	Analog signal from PFC shunt measured
	3	NC	Not connected	
	4	S_INV	Analog O	Analog signal from six pack shunt measured
	5	NC	Not connected	
	6	DC2+_M	Analog O	Analog signal from DC2 link
	7	DC1+_M	Analog O	Analog signal from rectifier output
	8	NTC2	Analog O	Analog signal from NTC
	9	U_REF	Analog I	Reference voltage input
	10	15V	Power I	Power for measure logic
Control	1	15V	Power I	Power for control logic
	2, 4-10,12,13	NC	Not connected	
	3	EN	TTL I	Module shut down signal
	11	FAULT_N	O	Open collector fault signal with internal pull up resistor, active low
	14	LIN3_N	TTL I	control signal, active low
	15	HIN3_N	TTL I	control signal, active low
	16	LIN2_N	TTL I	control signal, active low
	17	HIN2_N	TTL I	control signal, active low
	18	LIN1_N	TTL I	control signal, active low
	19	HIN1_N	TTL I	control signal, active low
	20	GND	Power O	Power for control logic

Table 2: Pin description of connectors

2.4 Mechanical dimensions

Mechanical dimensions for width and length: **124** mm x **123** mm

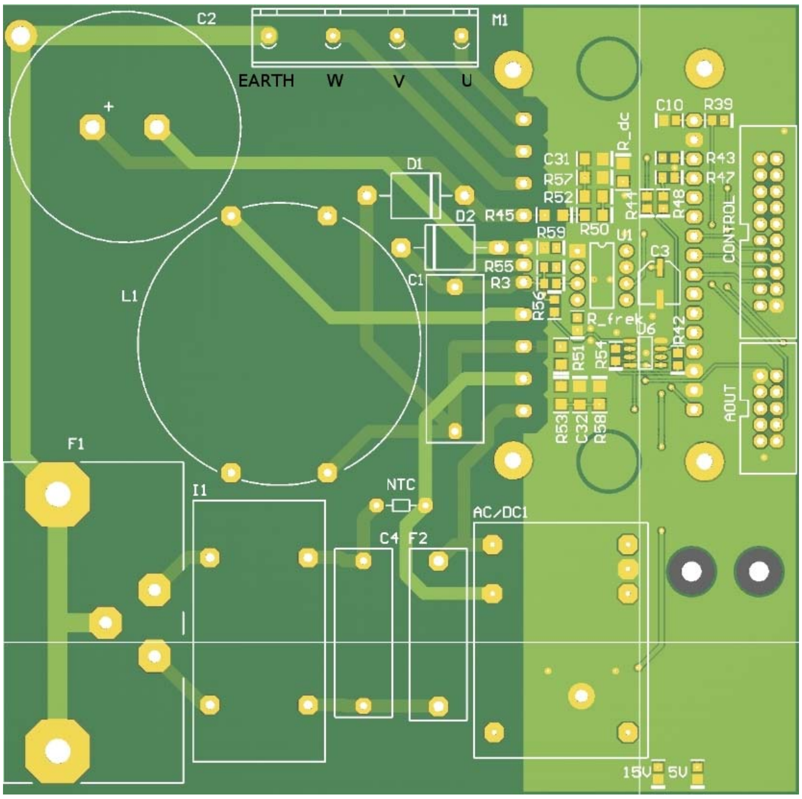


Figure 2: PCB of Evaluation Driver Board

3 Description of electrical parts

This chapter describes the different electrical parts like the input signals, output signals and driver circuit for better understanding how the board works.

In this module a 1~ rectifier is used to convert the voltage from AC to DC. The PFC MOSFET with gate driver makes a Power Factor Correction, so the U_{DC1+} voltage and the rectified current have got same phase shift. Six IGBTs with free-wheeling diodes are implemented for the conversion from DC to AC with variable frequency. There is no braking chopper on the board; therefore the modules can not be used for braking operation.

The power requirement of P950 kit is a very basic, 1~ AC 110 V – 230 V. For the internal power supply for drivers and measure circuit a compact AC/DC converter is implemented.

Please refer to the P950 datasheet for more information about the power module:

http://download.vincotech.com//power/documents/1B06IPA004MF-P953A10-14.pdf

For measurement of the heatsink temperature an NTC is equipped.

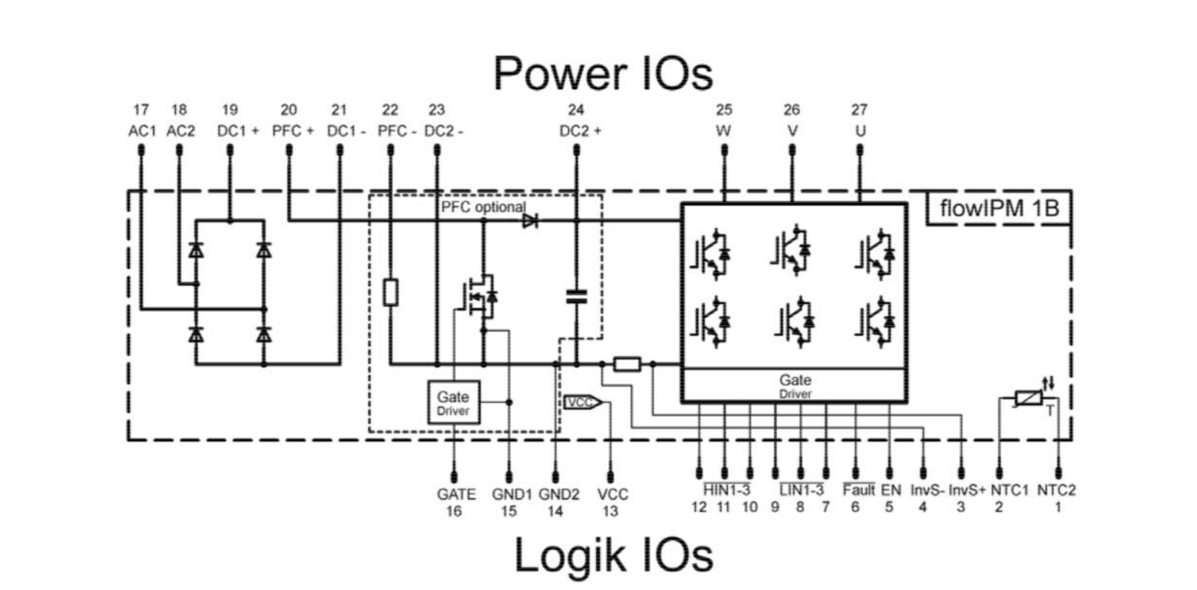


Figure 3: Topology of P950 module family

3.1 Input filter and rectification

The input AC voltage rectification is implemented by bridge. The single phase AC input is connected to *F1* which includes one stage EMC filter and the second stage (*I1*, *C4*) is added on board. An NTC is limiting the inrush current at start up. The fuse protects the whole circuit.

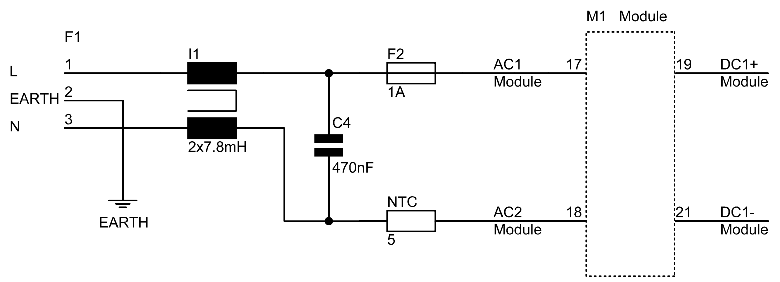


Figure 4: Input filter and rectification

The rectified voltage on pin 19 and pin 21 of the module is DC1 link. These powers up to the PFC circuit which is described in the next chapter.

3.2 PFC

1 kW PFC circuit is included in the board with settable switching frequency and settable DC2 link voltage and with $C2$ capacitor (470 µF/450 VAC). The PFC MOSFET, PFC diode, gate driver and shunt resistor have been integrated in the module. The value of the PFC inductor $L1$ is 0.7 mH. $D1$ and $D2$ are protection diodes for the PFC shunt and PFC diode.

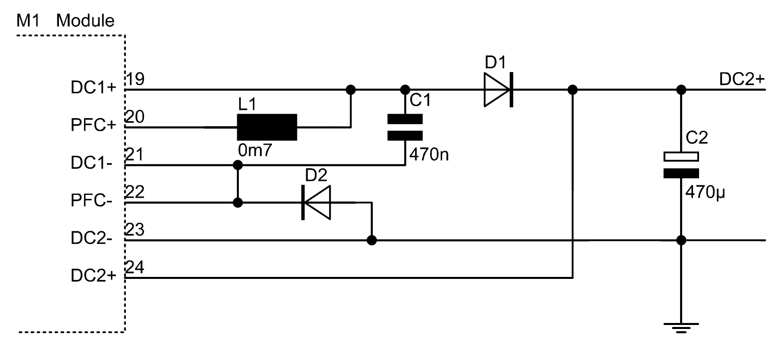


Figure 5: PFC power circuit

The switching signals for the integrated MosFet are generated by the ICE2PCS01 PFC controller. This is powered with an AC/DC converter supplying +15 V. Two resistors connected to pin 4 of the PFC controller adjust the switching frequency. This is set by $R4$ and R_frek to 130 kHz. Changing R_frek change the switching frequency.

$$R_{frec\_set} = \frac{R4 \cdot R\_frek}{R4 + R\_frek}$$

The datasheet of the ICE2PCS01 shows a diagram with the dependency of R_{frec_set} and the switching frequency.

The voltage of $DC2+$ can be modified with the resistor R_dc.

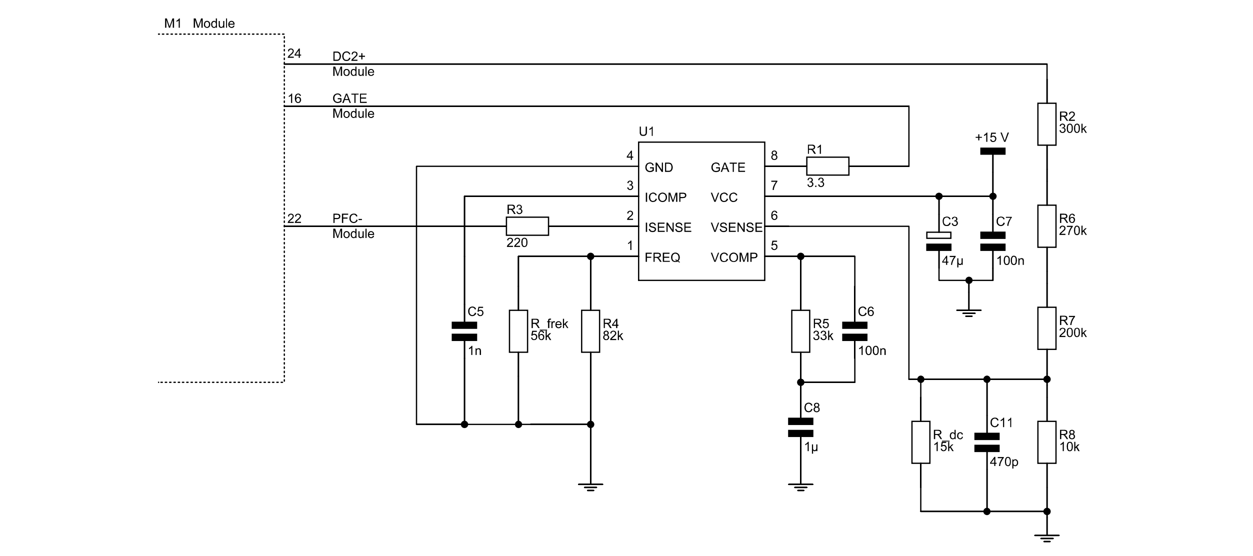


Figure 6: PFC controller circuit

The default voltage is approx. 400 VDC. This is the maximum suggested DC-Link voltage. The following equation shows how to adjust the voltage of the DC-Bus. The internal reference voltage of the PFC controller is 3 V.

$$U_{DC2+} = \frac{3V \cdot \left(\frac{R8 \cdot R\_dc}{R8 + R\_dc} + R2 + R6 + R7 \right)}{\frac{R8 \cdot R\_dc}{R8 + R\_dc}}$$

There has been a 90 mΩ PFC shunt resistor integrated in module. By this shunt the PFC current can be measured. The kit contains dual differential amplifier. One amplifier is used to measure the current through the PFC shunt and the other amplifier is used to measure the DC-Link current which will be explained more in detail in the next chapter. An additional voltage U_REF can be applied to Pin 9 of the AOUT connector to shift the amplified signals of the PFC shunt measurement and the inverter shunt measurement to a level that is suitable for the used microcontroller. This can be e.g. 2.5 V or 3.3 V.
Pin 2 of AOUT connector has U_REF potential when no current is driven through the PFC shunt. If the PFC stage works the S_PFC output signal change according to the current through the shunt. Refer to the following figure.

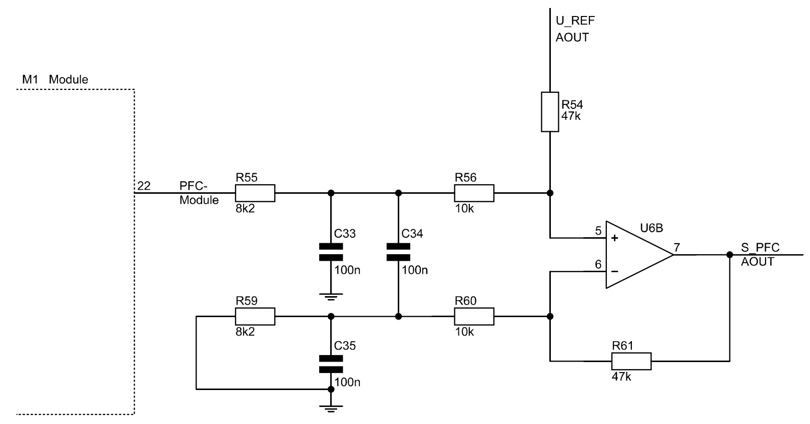


Figure 7: Picture of differential amplifier at PFC shunt resistor

Check the PFC controller under this link:

http://www.infineon.com/cms/en/product/findProductTypeByName.html?q=ice2pcs01

3.3 *Inverter part and shunt measurement*

The inverter switches, contained in the module gets the drive signals from the TTL level PWM input signals. Level shifters and high side bootstrap driver are also included in the module. For the measurement of the motor current a DC link shunt with a value of 100 mΩ is implemented in the module in the common emitter of low side IGBTs. InvS+ and InvS- are connected direct to the inverter shunt and provide a signal through the second differential amplifier to the AOUT connector.

Like for the PFC shunt measurement the output signal is shifted with the U_REF voltage. If the motor is not in operation U_REF is forwarded to pin 4. If the motor is driven, the potential of pin 4 will change according to the current flow through the shunt.

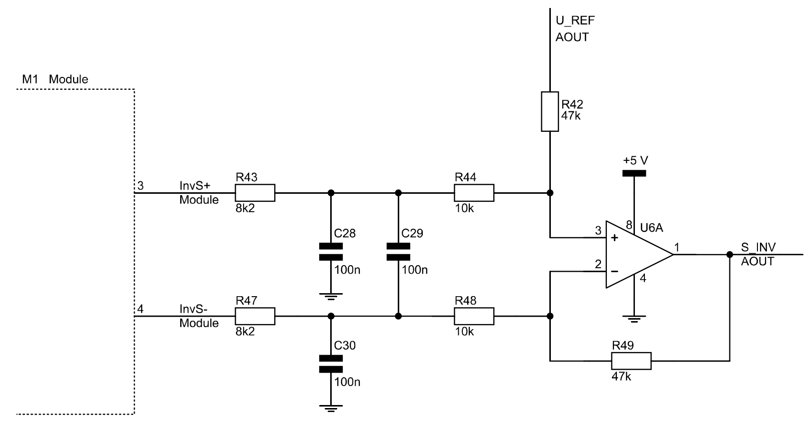


Figure 8: Picture of differential amplifier at six pack shunt resistor

3.4 Voltage measurements

The kit contains two voltage dividers. Through those the voltage after the rectification U_{DC1+} and the voltage after the PFC stage U_{DC2+} can be measured. The output of voltage dividers is 1.83 Vpeak / 324 Vpeak for the U_{DC1+_M} and 2.20 V / 400V DC in case of U_{DC2+_M}. The voltages are provided to the connector AOUT. The following equations show how to calculate:

$$U_{DC1+\_M} = U_{DC1+} \cdot \frac{R58}{R46 + R51 + R53 + R58}$$

$$U_{DC2+\_M} = U_{DC2+} \cdot \frac{R57}{R45 + R50 + R52 + R57}$$

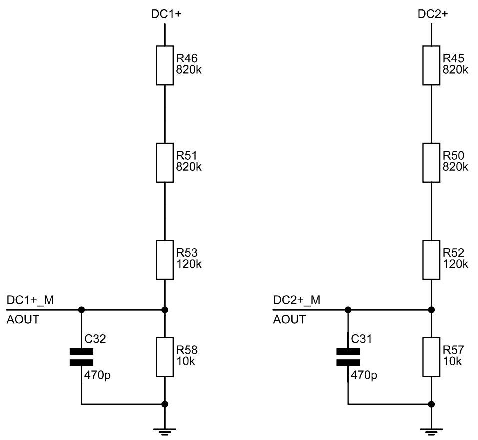


Figure 9: Picture of voltage divider

It is recommended only to change $R57$ or $R58$.

3.5 Temperature measurement

The internal NTC for temperature measurement can be monitored via the AOUT connector.

For calculating heatsink temperature the following circuit can be used, and the NTC characteristics can be read from the module datasheet:

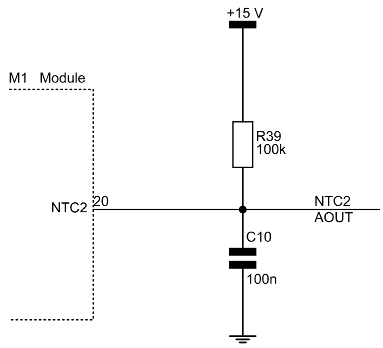


Figure 10: NTC measurement circuit

The thermistor has a resistance of 22 kΩ at 25 °C and a $B_{(25/50)}$-value of 3950 K.

The relation between resistance and temperature of the NTC is expressed as:

$$R_{NTC} = R_{25} \cdot e^{\left[B_{25/50}\left(\frac{1}{T_2} - \frac{1}{298{,}15K}\right)\right]}$$

Where T_2 is the measured NTC temperature.

4 Operation

The module can be activated via an active high signal on the pin 3 of the control connector. By default the module is disabled.

Before the module can handle the PWM signals from the microcontroller if is necessary to wait at least 800 ns after the enable signal is applied.

The following startup sequence should be applied:

- MODUL_ENABLE signal go LOW
- wait for at least 800 ns
- start the PWM
- MODULE_ENABLE signal go HIGH

Fault signal is generated in case of short circuit on the output. In this case set the MODULE_ENABLE signal to disable within 5 µs time, and it must be kept in this state for at least one second. The number of allowed short circuits is limited to 1000.

The recommended switching frequency is 16 kHz.

Check the sixpack driver IC under this link:

http://www.infineon.com/cms/en/product/findProductTypeByName.html?q=6ED003L06-F+

5 Definition of layers

The driver board is based on a 2-Layer PCB. The used material is FR4. Figure 11 depicts a cross section of the layer thickness and for pre-packs.

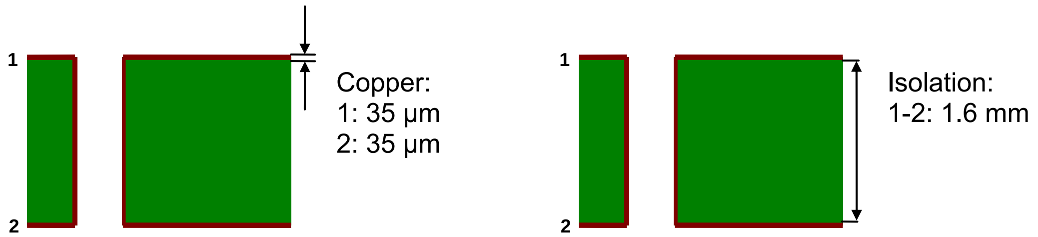


Figure 11: Copper thicknesses and isolation for layers

6 Layout

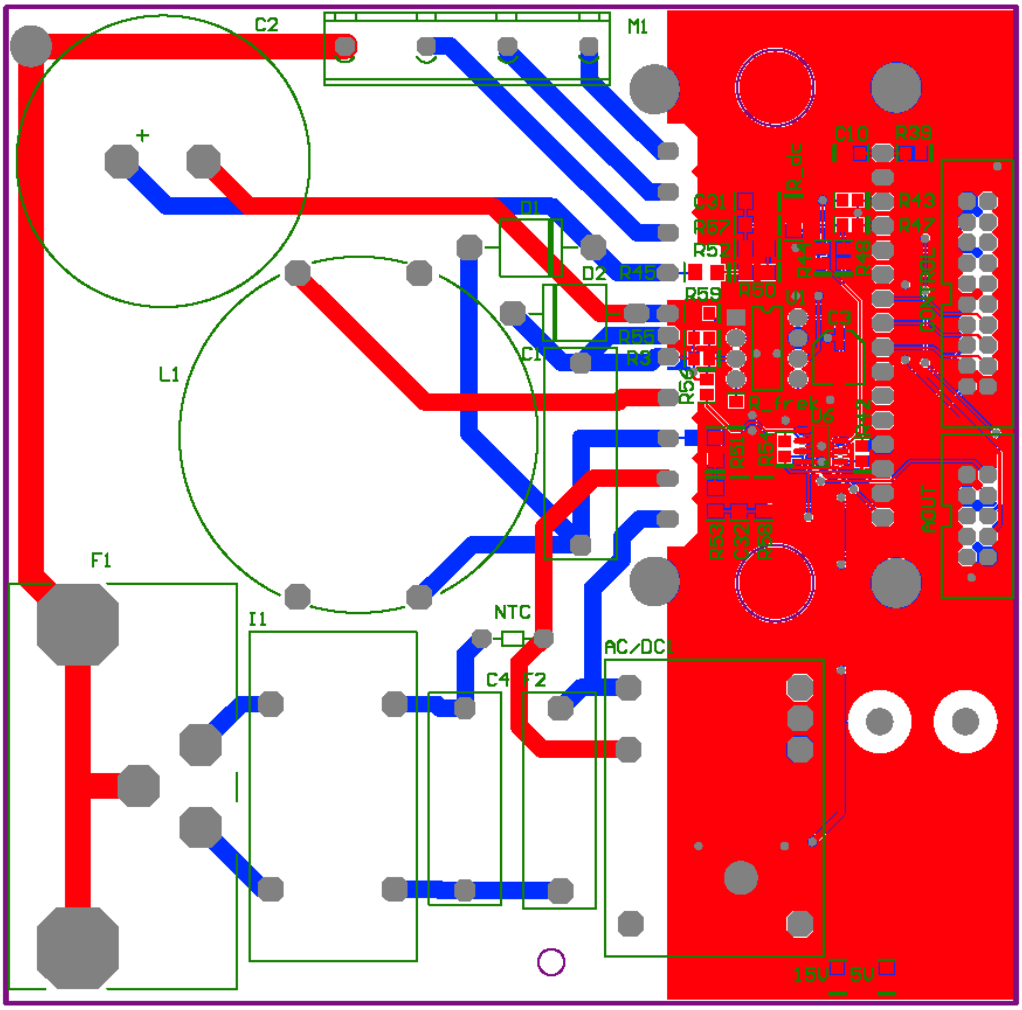


Figure 12: Assembly drawing TOP

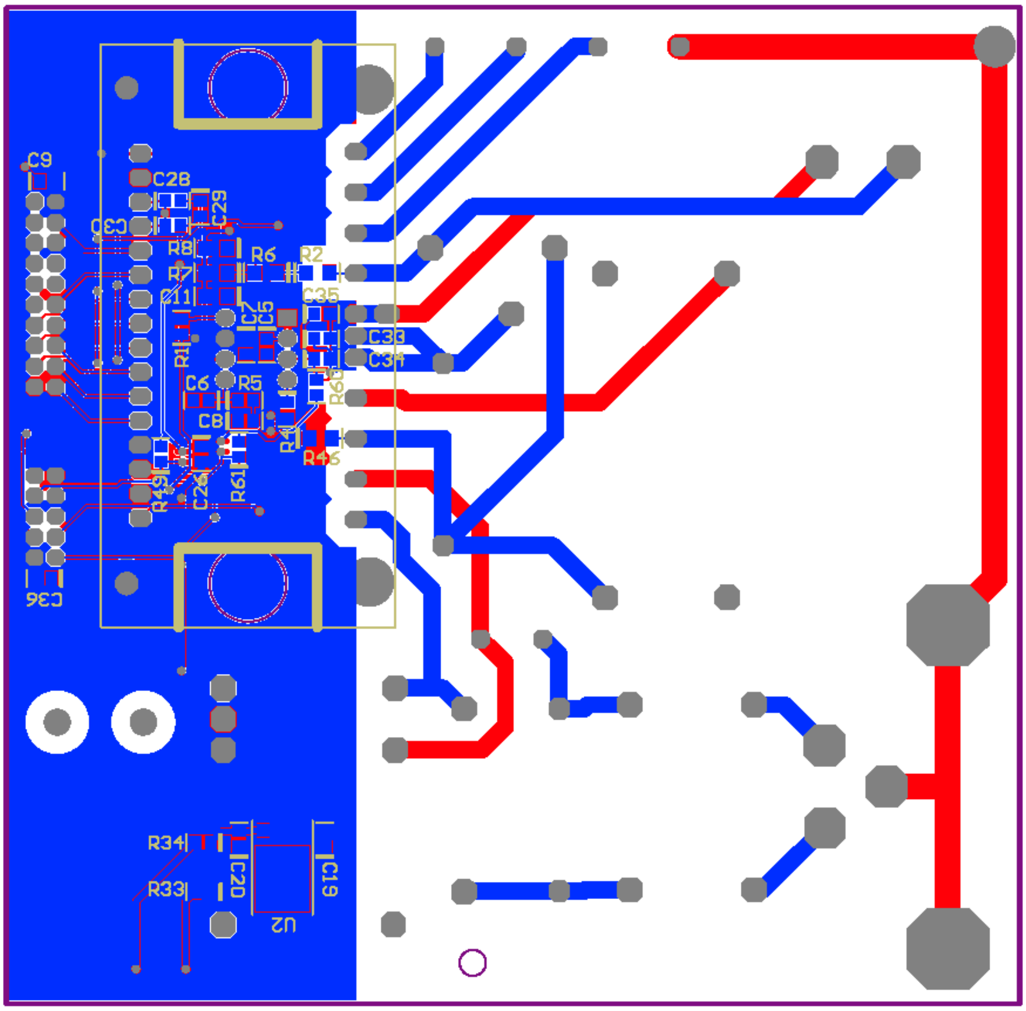


Figure 13: Assembly drawing BOTTOM

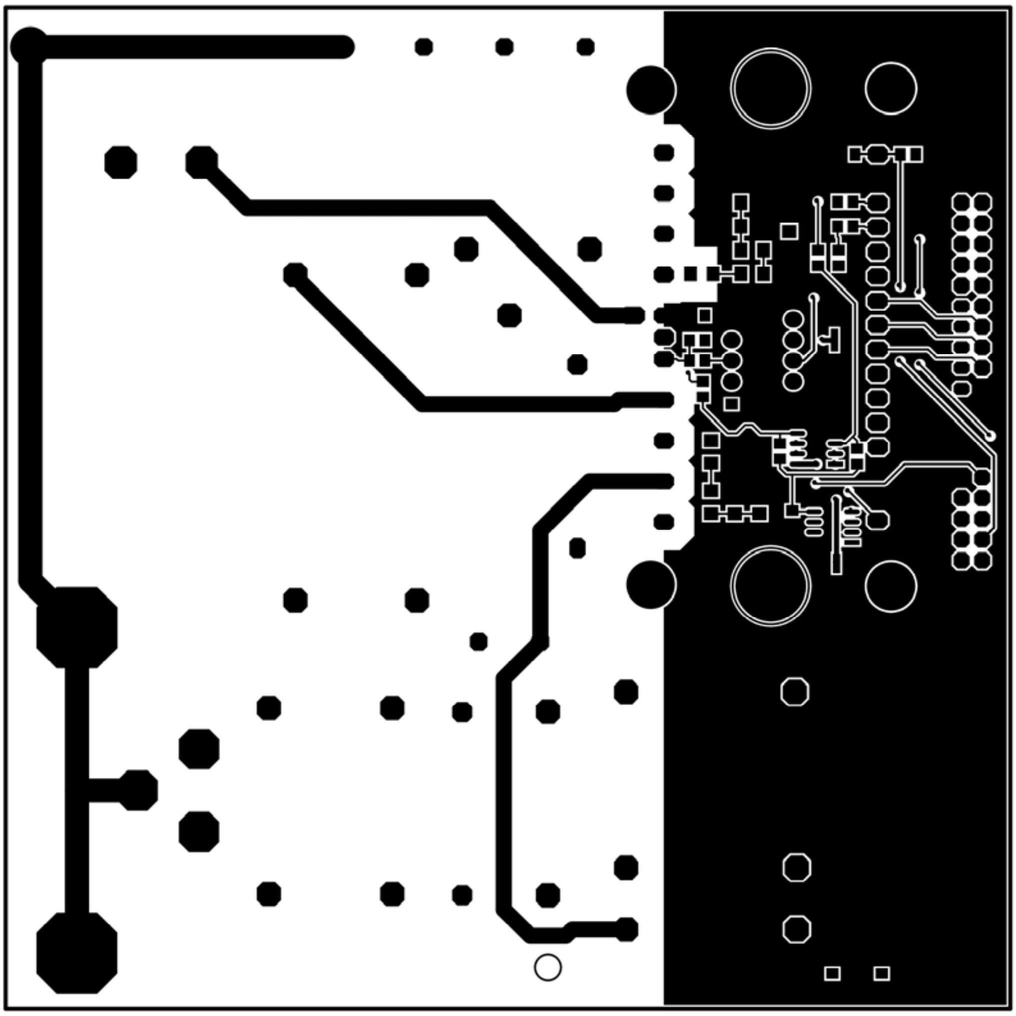


Figure 14: TOP layer

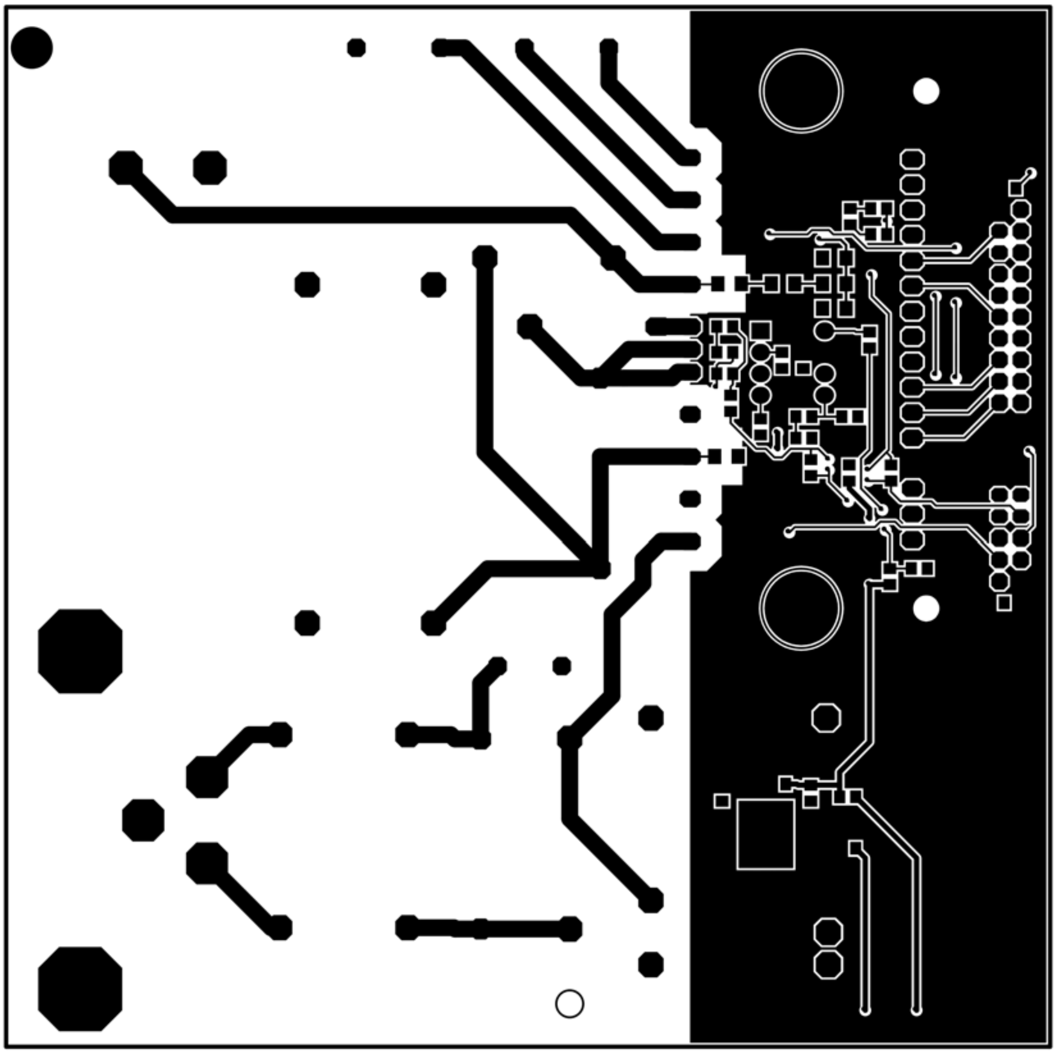


Figure 15: BOTTOM layer

7 Schematics

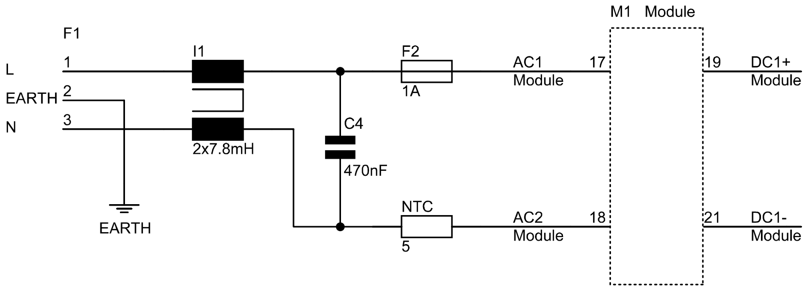


Figure 16: Input circuit

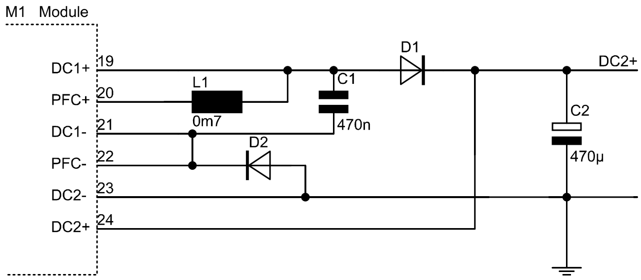


Figure 17: PFC circuit

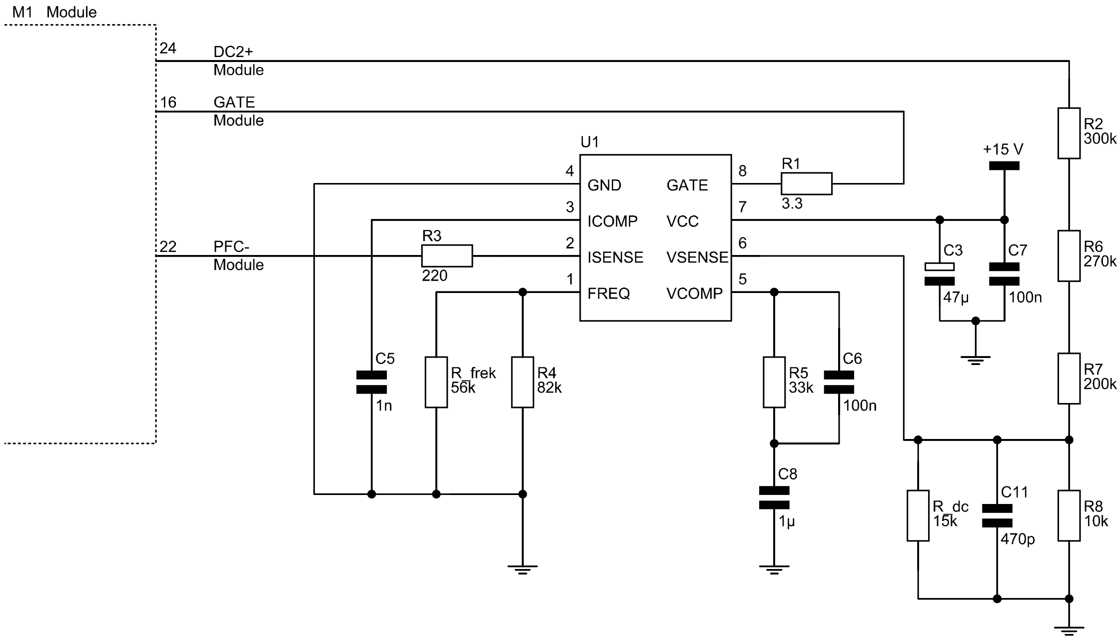


Figure 18: PFC controller circuit

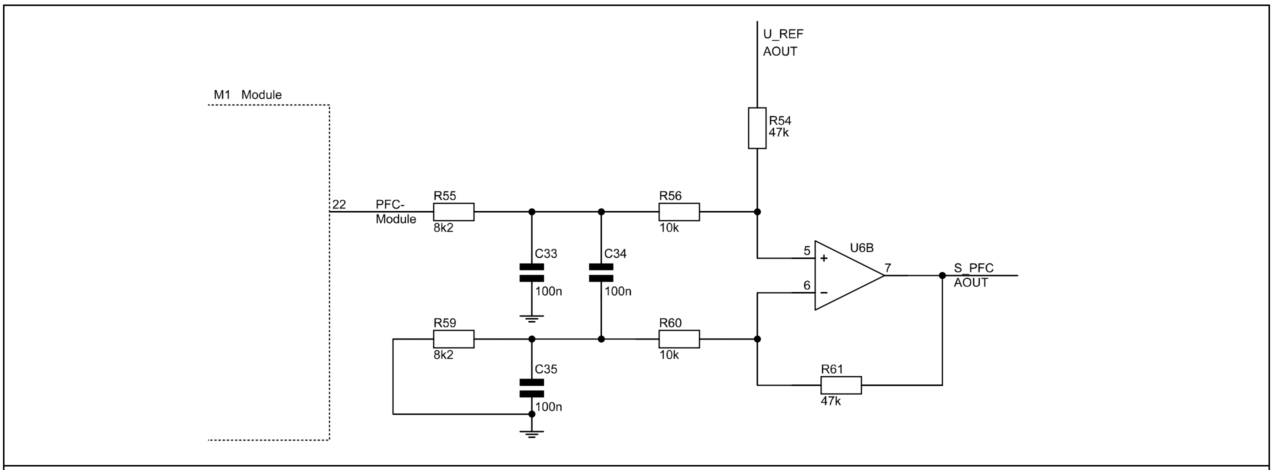


Figure 19: PFC shunt measurement

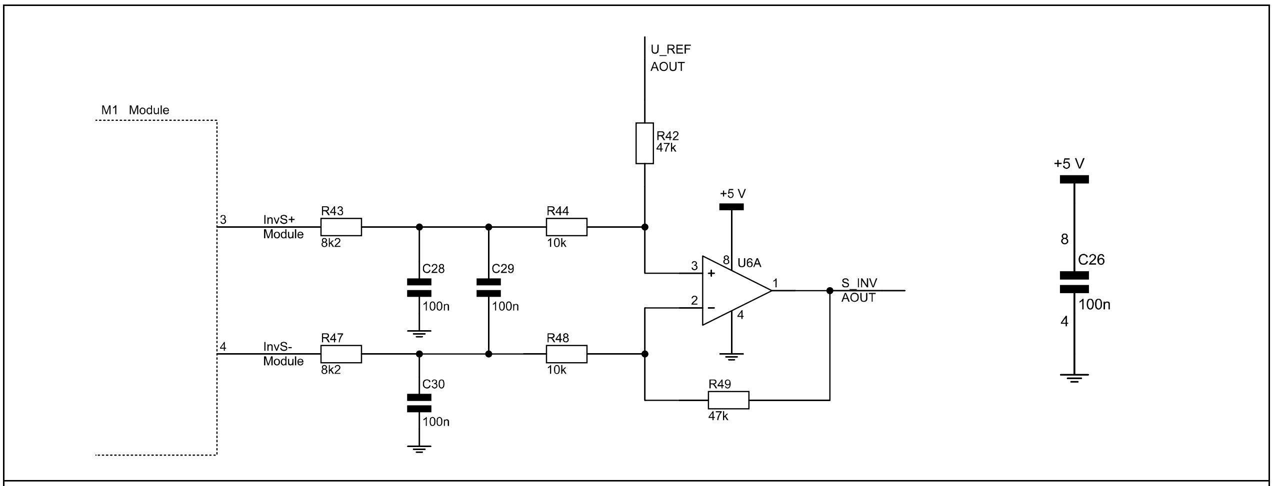


Figure 20: Inverter shunt measurement

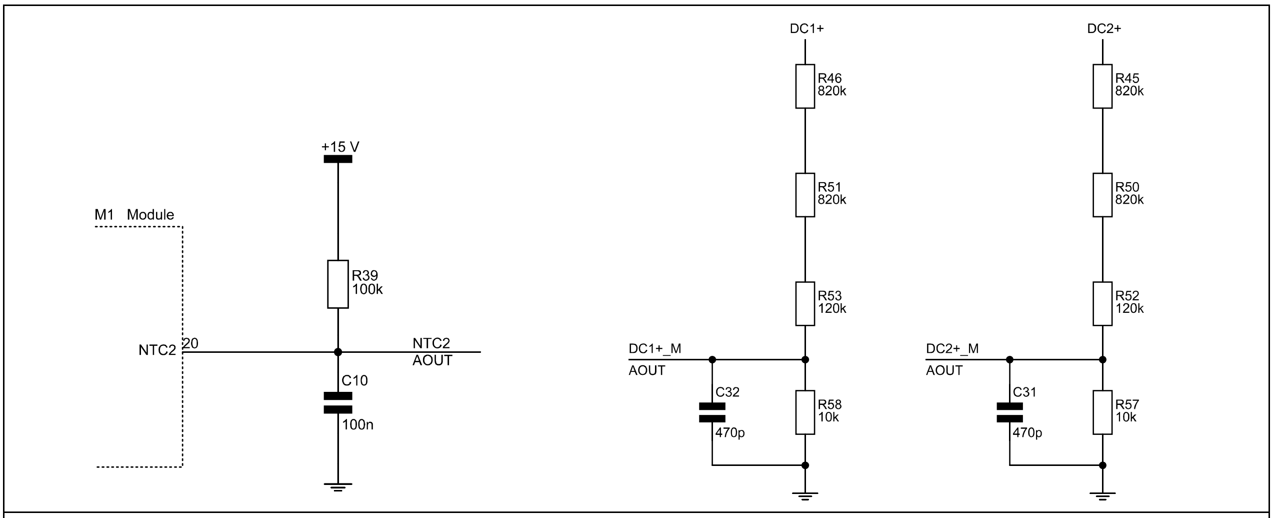


Figure 21: Temperature and voltage measurement

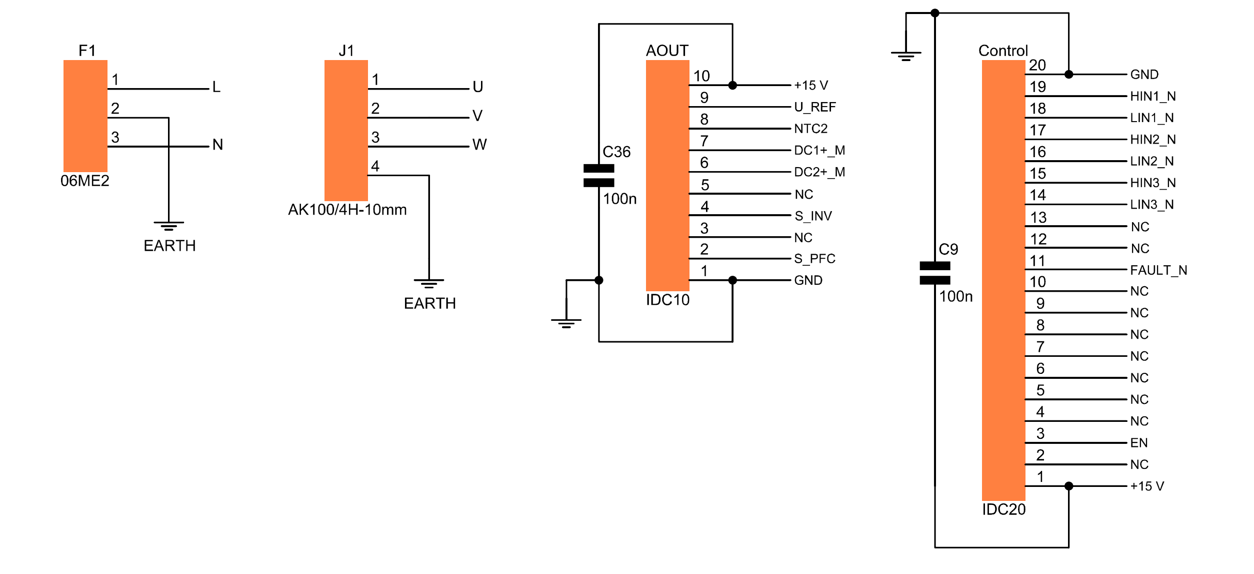


Figure 22: Connectors

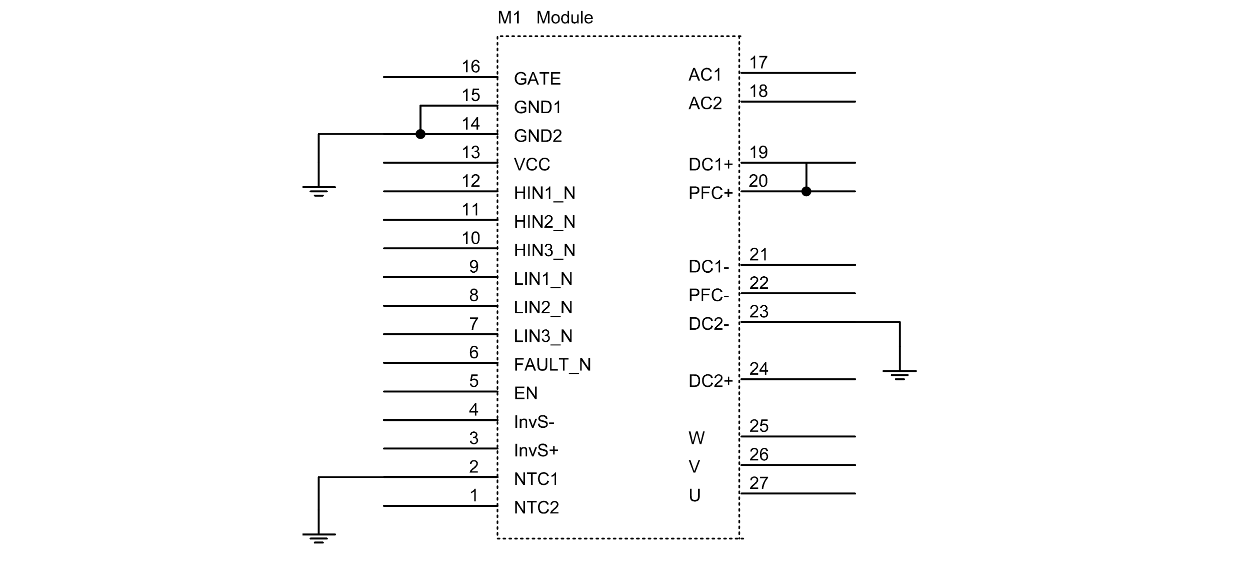


Figure 23: Power module

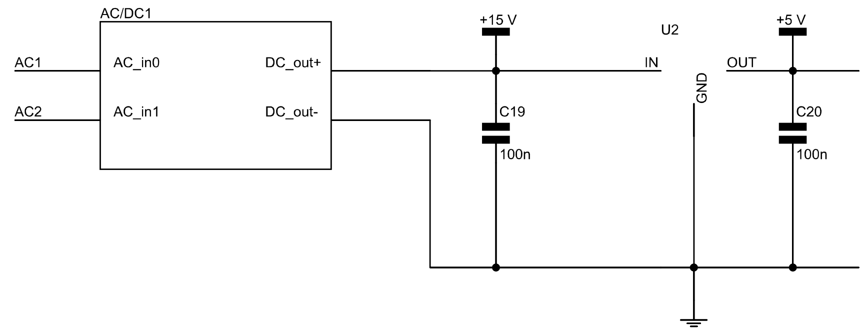


Figure 24: AC/DC power supply

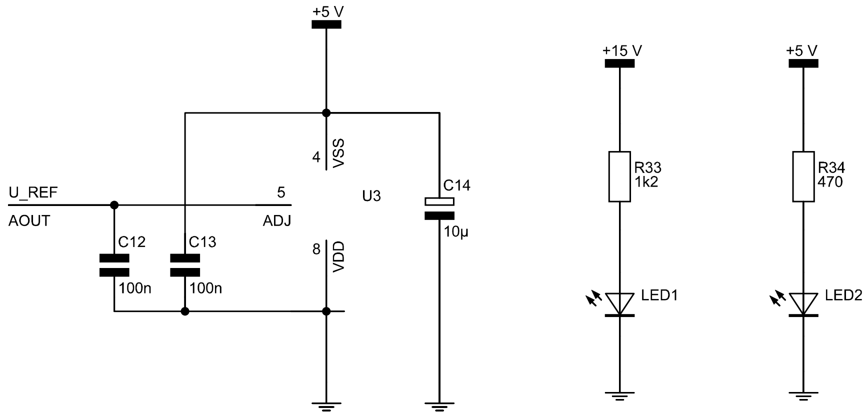


Figure 25: Voltage adjustment

8 BOM

Ordering code	Manufacture	Value	Position number
9C08052A3R30FGAFT	Yageo	3.3 Ω, 1%, 0805	R1
9C08052A2200FKAFT	Yageo	220 Ω, 1%, 0805	R3
9C08052A4700FKAFT	Yageo	470 Ω, 1%, 0805	R34
9C08052A1201FKAF3	Yageo	1.2 kΩ, 1%, 0805	R33
9C08052A8201FKAFT	Yageo	8.2 kΩ, 1%, 0805	R43, R47, R55, R59
9C08052A1002FKAFT	Yageo	10 kΩ, 1%, 0805	R44, R48, R56, R60
9C08052A3302FKAFT	Yageo	33 kΩ, 1%, 0805	R5
9C08052A4702FKAFT	Yageo	47 kΩ, 1%, 0805	R42, R49, R54, R61
9C08052A5602FKAFT	Yageo	56 kΩ, 1%, 0805	R_frek
9C08052A8202FKAFT	Yageo	82 kΩ, 1%, 0805	R4
9C08052A1003FKAFT	Yageo	100 kΩ, 1%, 0805	R39
9C12063A1002FKAF3	Yageo	10 kΩ, 1%, 1206	R8, R57, R58
9C12063A1502FKAF3	Yageo	15 kΩ, 1%, 1206	R_dc
9C12063A1203FKAF3	Yageo	120 kΩ, 1%, 1206	R52, R53
9C12063A2003FKAF3	Yageo	200 kΩ, 1%, 1206	R7
9C12063A2703FKAFT	Yageo	270 kΩ, 1%, 1206	R6
9C12063A3003FKAFT	Yageo	300 kΩ, 1%, 1206	R2
9C12063A8203FKAF3	Yageo	820 kΩ, 1%, 1206	R45, R46, R50, R51
C1206JKNP09BN471	Yageo	470 pF, 1206, 50V	C11, C31, C32
NPO102J50TRPF	Yageo	1 nF, 0805, 50V	C5
X7R104K50TRPF	Yageo	100 nF, 0805, 50V	C9, C36, C10, C6, C7, C19-20, C28-30, C33-35, C26
MKP21W34705D00M	WIMA	470 nF/250 VAC, X2	C1, C4
Y5V105M16TRPF	Yageo	1 uF, 0805, 16 V	C8
NACE470M35V6.3X6.3TR13F	Yageo	47 uF/35 V 6.3X6.3	C3
NRLRW471M450V35X50LF	NIC	470 uF / 450 V	C2
B82615B2602M001	Epcos	0.7 mH/6 A	L1
B82725S2602N041	Epcos	2x7.8 mH / 6 A	I1
P600M	Diotech	P600M	D1, D2
FA-170UYG	Forge	0805 green LED	LED1, LED2
MC 78M05CDTG	MOTOROLA	78M05	U2
TMLM 04115	Traco	230 V AC input, 15 V DC output	AC/DC1
ICE2PCS01	Infineon	ICE2PCS01	U1
LT 6231CS8	Linear Tech	LT 6231CS8	U6
LM 336M-2.5/SMD	NATIONAL SEMI	LM336	U3
44-01-84	Lomex	Fuse	F2
06ME2	Delta	one stage EMI filter	F1
44-01-85	Lomex		Fuse housing
AK100/4H-10mm	PTR MESSTECHNIC	connector	J1
SCMI20	TKP	IDC20 Connector	CONTROL
SCMI10	TKP	IDC10 Connector	AOUT
Module P95x series	Vincotech		M1