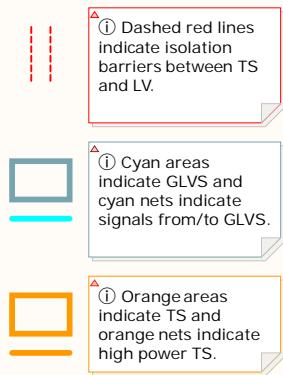


A



Specifications:

$f_{sw} = 50 \text{ kHz}$

$V_{in, max} = 600 \text{ VDC}$
 $V_{out, max} = 245 \text{ V,RMS,ph-n (SVPWM)}$
 $I_{out, max} = 80 \text{ A,RMS}$
 $I_{out, cont} = 32 \text{ A,RMS}$

$P_{out, max} = 53 \text{ kW}$
 $P_{out, cont} = 23.5 \text{ kW}$

Liquid cooled with water at 50°C max

Changelog:

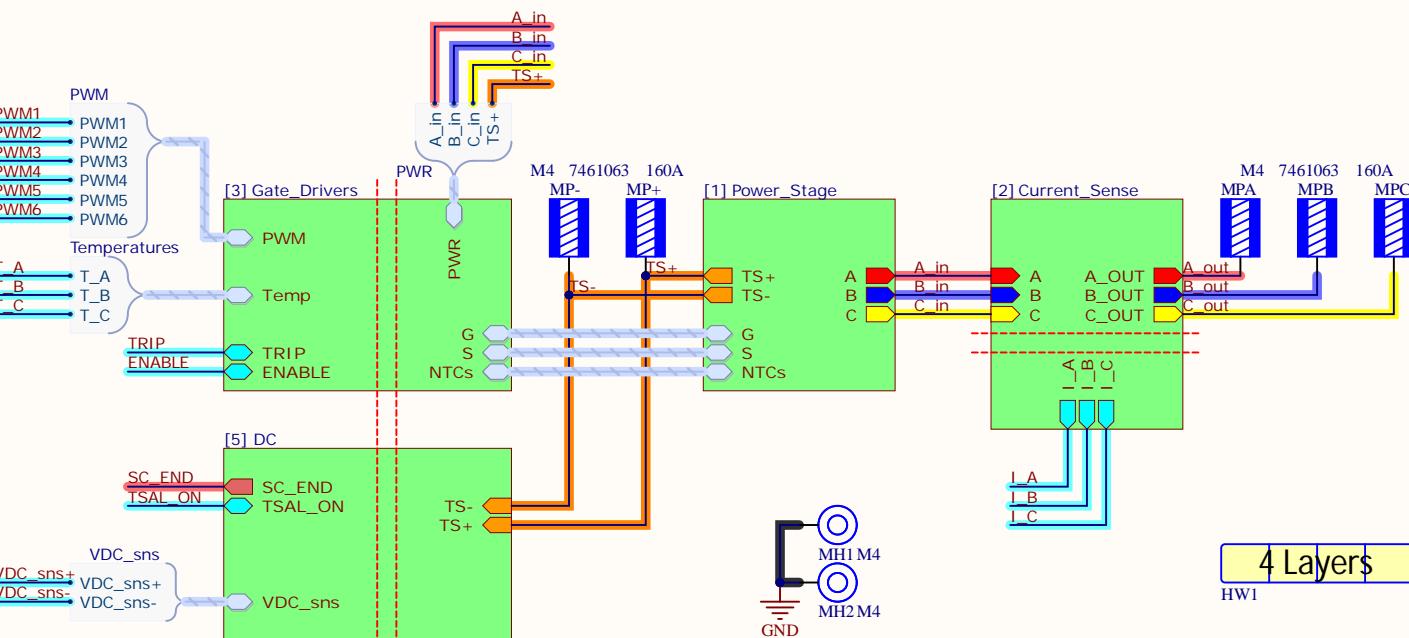
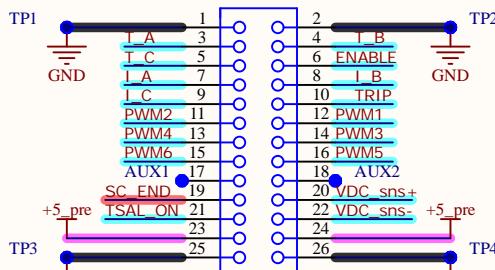
Version 1.0: (sent to production 15-02-2024)
- Base version

Version 1.1: (sent to production 28-03-2024)
- Added 5V supply protections
- Swapped pins 4 and 5 in gate drivers' LDOs
- Swapped MP+ and MP-, and their silkscreen
- Added testpoints for current sensors' reference
- Added testpoints for VDC_{sns+} and VDC_{sns-}
- Renamed testpoints in [3]
- Added various silkscreen texts and indications
- Added layer physical logo

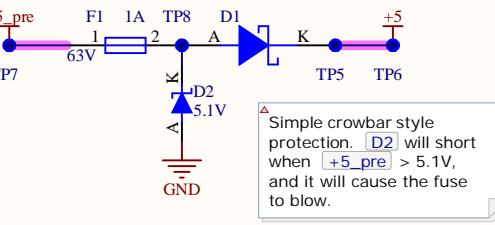
Changes in SCH but not in PCB:

19-04-2024: Added decoupling capacitors to semiconductor terminals (TS_+ / TS_-).

LV Connector

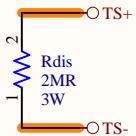


OCP, OVP, reverse

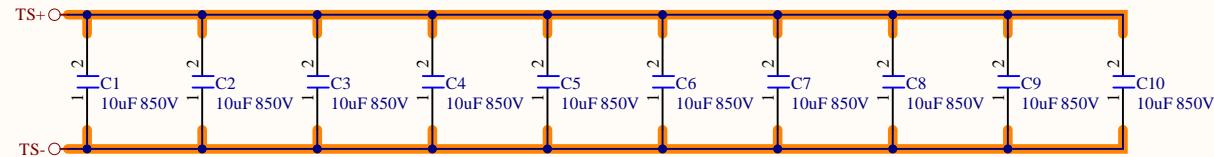


Company:	e-Tech Racing	e-techracing.es	
Project:	Inverter Power	Variant: Leapers	
Size:	Page Contents: Inverter_Power.SchDoc	Version: 1.1	
		Department: Powertrain	
Author:	David Redondo	dredondovinolo@gmail.com	Sheet 1 of 5
Checked by:		Date: 19/04/2024	

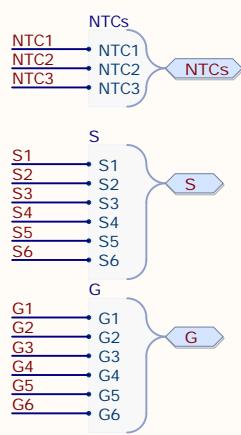
Passive discharge



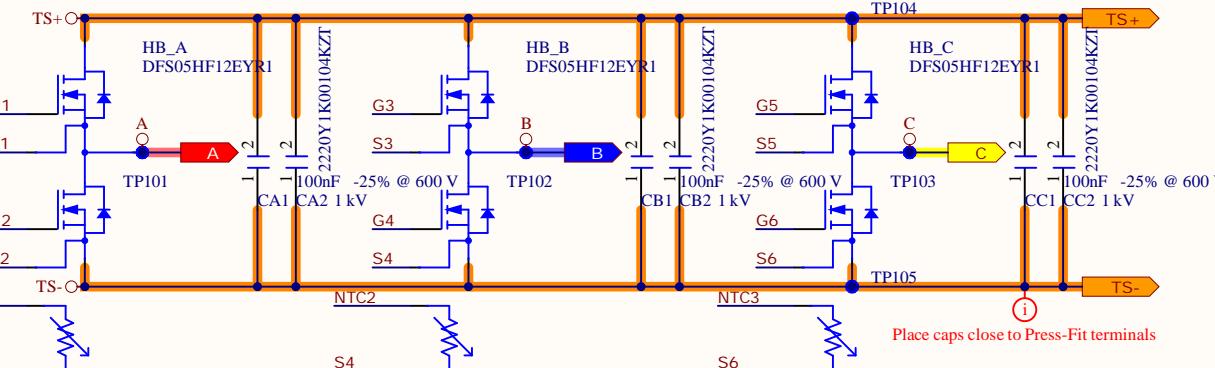
DC Bus capacitors, 100uF, Murata FHA85Y106KS



INPUTS/OUTPUTS



SiC Half-Bridges



DC Link design considerations:

$V_{_C} > 1.1 \cdot V_{max} = 1.1 \cdot 600 V = 660 V \rightarrow 850 V$

$I_{_C,RMS} \approx 0.65 \cdot I_{_phase,RMS} = 0.65 \cdot 80 A, RMS = 52 A, RMS \rightarrow 10 \times 5 A, RMS (\Delta T = 10 ^\circ C)$

$C > I_{_C,RMS} / (V_{ripple} \cdot f_{sw}) = 52 A, RMS / (15V \cdot 50 kHz) \approx 79 \mu F \rightarrow 10 \times 10 \mu F$

Check:
<https://www.specterengineering.com/blog/2019/9/7/dc-link-capacitor-selection-for-y>

Semiconductor details:

$V_{DSS}(\text{breakdown}) = 1200 V // 1200 V$

$R_{on} = 5.5 .. 13 m\Omega // 16.0 .. 28.8 m\Omega$

$V_{f,D} = 3.3 .. 4.4 V // 4.9 .. 5.5 V$

$T_{rr} = 41.5 .. 45 ns // 20.0 ns$

$Q_{rr} = 2.19 .. 3.94 \mu C // 1.30 \mu C$

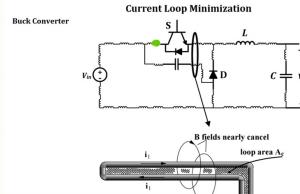
$R_{th,jc} = 0.12 .. 0.15 K/W // 0.543 K/W$

$Q_G = 520 nC // 236 nC$

$C_{in} = 14.5 nF // 6.6 nF$

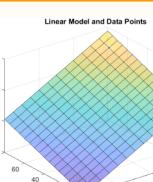
$R_G(\text{int}) = 1.9 \Omega // 2.4 \Omega$

$V_{GS(th)} = 2.8 .. 4.8 V // 1.8 .. 3.6 V$

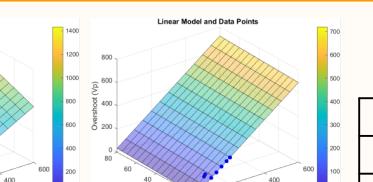


Current Loop Minimization
Current loop between top and bottom MOSFETs will cause excessive overshoot due to parasitic inductance and low parasitic capacitance. Increasing capacitance to hundreds of nF mitigates the effect. The capacitors essentially work as a switching decoupling. MLCCs with low DC bias or film, but MLCCs are way more compact. Place as close as possible to semiconductor terminals.

Overshoot analysis can be performed using a linear model proportional to DC bus voltage and output current. Easiest way to do it is using only one half bridge as a synchronous buck and varying input voltage with a fixed duty cycle and a R or RL load.



No C leads to 1430 Vp at max. specs.



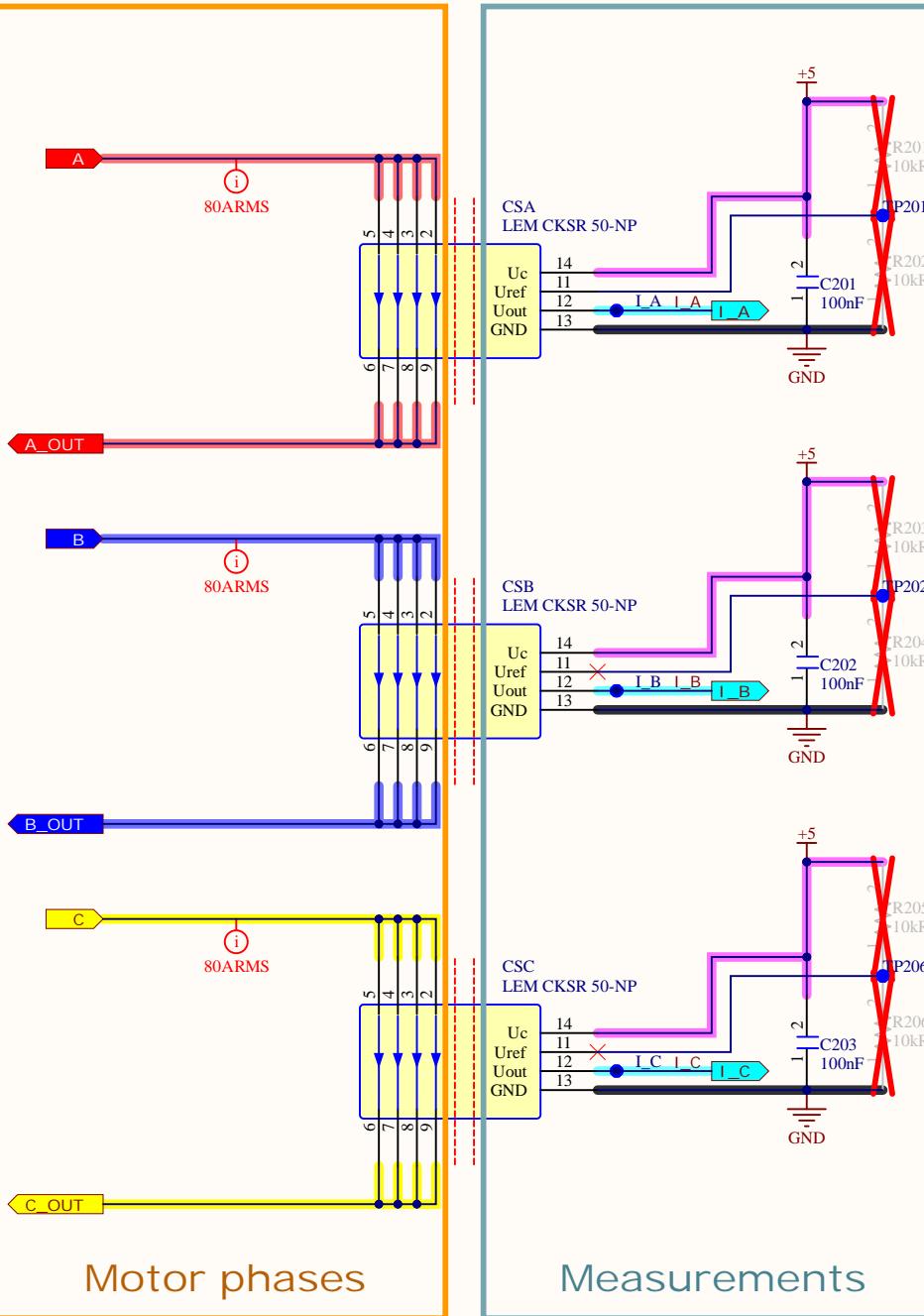
C brings it down to 720 Vp at max. specs.

Company:	e-Tech Racing	e-techracing.es	
Project:	Inverter Power	Variant: Leapers	
Size:	Page Contents:	Version: 1.1	
-	[1]Power_Stages.SchDoc	Department: Powertrain	
Author:	David Redondo	dredondovinolo@gmail.com	Sheet 2 of 5
Checked by:		Date: 19/04/2024	

A

CSA , CSB , CSC

CKSR 50-NP/SP1 configured with Number of primary turns = 1 (R_phase-connector = 0.18 mΩ)



B

CSA , CSB , CSC

CKSR 50-NP/SP1 2.5V internal reference is used in order to have equal measuring range for positive and negative values. Voltage divider implemented just in case.

I_A , I_B , I_C

$$U_{\text{meas}} = (12.5 \text{mV/A} \cdot I_{\text{meas}} + U_{\text{ref}})$$

For ±150Apk:
 $V_{\text{meas_pk+}} = 4.375 \text{V}$
 $V_{\text{meas_pk-}} = 0.625 \text{V}$

C201 , C202 , C203

The fluxgate oscillator draws current pulses of up to 30 mA at a rate of ca. 900 kHz. In the case of a power supply with high impedance, it is advised to provide local decoupling (100 nF or more, located close to the transducer).

C

CSA , CSB , CSC

AC insulation test
RMS voltage, 50 Hz,
1 min:

$$U_d = 4.3 \text{ kV} > 3 \cdot V_{\text{max}} = 1.8 \text{ kV}$$

Company:	e-Tech Racing	e-techracing.es	
Project:	Inverter Power	Variant: Leapers	
Size:	Page Contents: [2]Current_Sense.SchDoc	Version: 1.1	
		Department: Powertrain	
Author:	David Redondo	dredondovinolo@gmail.com	Sheet 3 of 5
Checked by:			Date: 19/04/2024

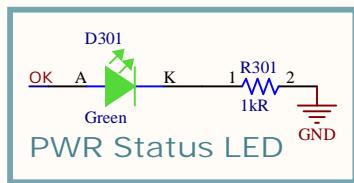
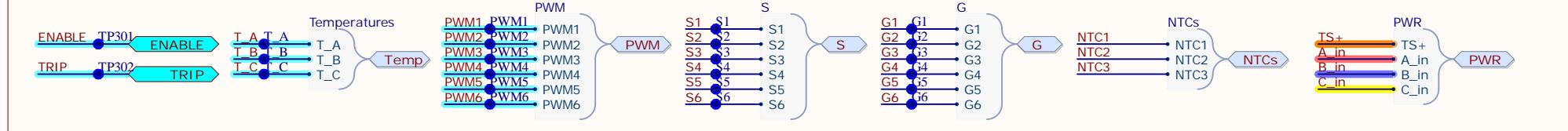
1

2

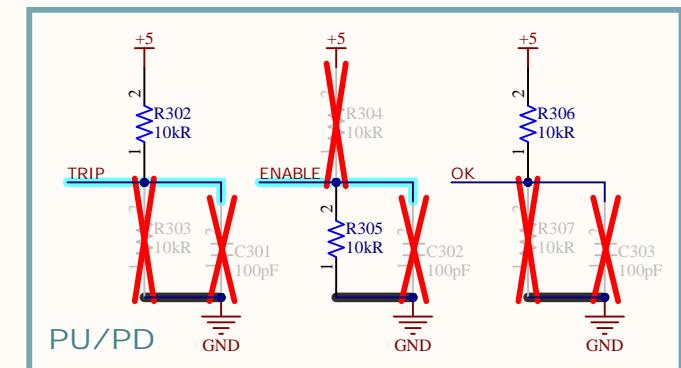
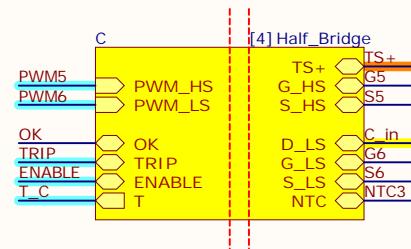
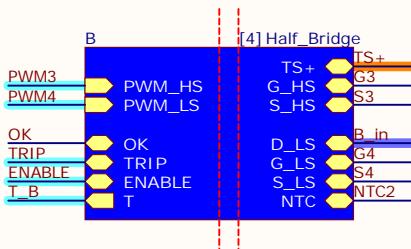
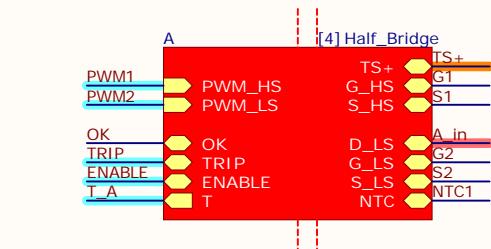
3

4

INPUTS/OUTPUTS



[T_A, T_B, T_C]
Look-up table obtained with MATLAB script which can be found in the simulations folder.
For different temperatures:
 $V_{meas}(0^\circ\text{C}) = 0.246\text{V}$
 $V_{meas}(25^\circ\text{C}) = 2\text{V}$
 $V_{meas}(50^\circ\text{C}) = 2.578\text{V}$
 $V_{meas}(90^\circ\text{C}) = 2.864\text{V}$



Company:	e-Tech Racing	e-techracing.es	
Project:	Inverter Power	Variant: Leapers	
Size:	Page Contents: [3]Gate_Drivers.SchDoc	Version: 1.1	
-		Department: Powertrain	
Author:	David Redondo	dredondovinolo@gmail.com	Sheet 4 of 5
Checked by:			Date: 19/04/2024

1

2

3

4

A

U_HS, U_LS

- TRIP** and **OK** signals are in open drain configuration, so they can be paralleled.
- IN- is not used and tied to **GND**.
- ENABLE** to be given by MCU in active-high mode. When set to low for more than 1 μ s, **TRIP** is reset.
- Temperature sensing using low-side drivers. Ain outputs a current of 200 μ A. PWM to analog using a RC filter, to be fed directly to MCU ADC. **R405**, **R406** and **C411** from SPICE simulation.
- Miller clamp protection is used.
- RGS_HS**, **RGS_LS**: External gate pull-down is implemented even though the gate drivers implement an active pull-down.
- Overcurrent detection is not implemented.

LDO_HS, LDO_LS

An LDO is implemented to trim **VEE_HS_A** and **VEE_LS_A** during testing to fine tune the necessary negative gate voltage. Feedback voltage divider adjusted with a Python script which can be found in the simulations folder.

$$\text{VEE} = -1.186 \cdot (1 + R1/R2)$$

$$R1 + R2 \approx 100 \text{ k}\Omega$$

Leapers $\rightarrow R1 = 36 \text{ k}\Omega$, $R2 = 56 \text{ k}\Omega$

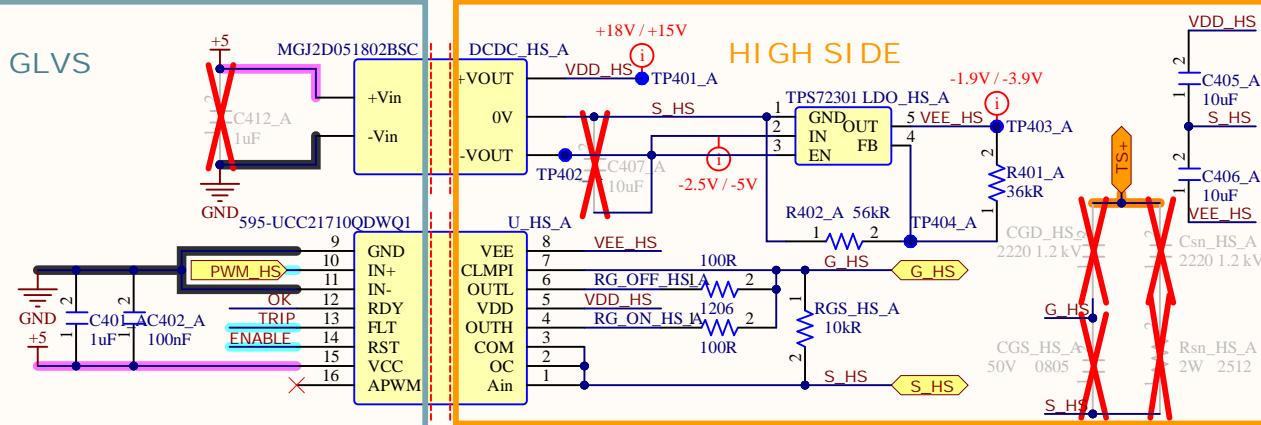
Wolfspeed $\rightarrow R1 = 68 \text{ k}\Omega$, $R2 = 30 \text{ k}\Omega$

DCDC_HS, DCDC_LS

Isolation test voltage (Qualification tested for 1 minute): 5200 VDC

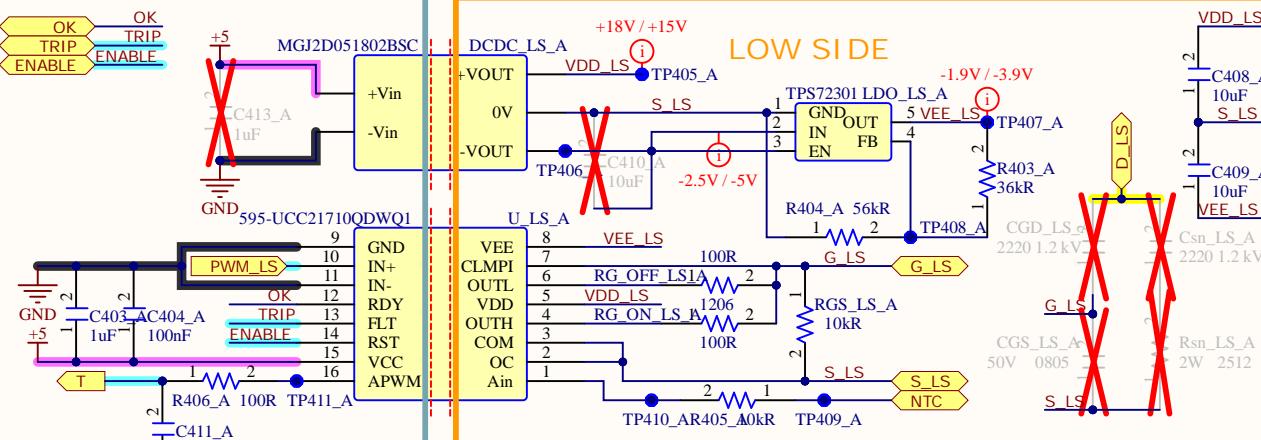
U_HS, U_LS

VIOTM ($t = 60$ s (qualification test)): 8000 VPK

GLVS**HIGH SIDE****V_GS values:**

The values can be modified by replacing **DCDC_HS** and **DCDC_LS** with one from the following list: MGJ2D051505SC, MGJ2D051509SC, MGJ2D051515SC, MGJ2D051802SC, MGJ2D052003SC, MGJ2D052005SC. LDO voltages must also be adjusted.

Minimum gate driver current and power:
 $I_{GD(\min)} = f_{sw} \cdot O_G = 50 \text{ kHz} \cdot 520 \text{ nC} = 26 \text{ mA}$
 $P_{\min} = \Delta V_{GS} \cdot I_{GD(\min)} = 20 \text{ V} \cdot 26 \text{ mA} = 0.52 \text{ W} \rightarrow 2 \text{ W}$

OK**TRIP****ENABLE****LOW SIDE****RG_ON_HS, RG_OFF_HS, RG_ON_LS, RG_OFF_LS**

Essentially, a lower value for the gate resistors will reduce switching losses as the MOSFETs will switch faster and thus spend less time switching. Switching faster also means that the dV/dt will be higher, which can be responsible of EMI increase. The considered values of 3.3 Ω are recommended by the datasheet.

CGS_HS, **CGS_LS**, **CGD_HS**, **CGD_LS**, **Csn_HS**, **Csn_LS**, **Rsn_HS**, **Rsn_LS**

DNP, but they could be useful with EMI related issues to decrease dV/dt . Implementing them could result in further issues with the power limit for **DCDC_HS** and **DCDC_LS**, as the gate charge would increase significantly. The maximum allowed capacitance would be:

$$CGS_{\max} = 2 \cdot P_{DCDC} / (\Delta V_{GS}^2 \cdot f_{sw}) = 2 \cdot 2 \text{ W} / ((20 \text{ V})^2 \cdot 50 \text{ kHz}) = 200 \text{ nF}$$

Company: e-Tech Racing e-techracing.es



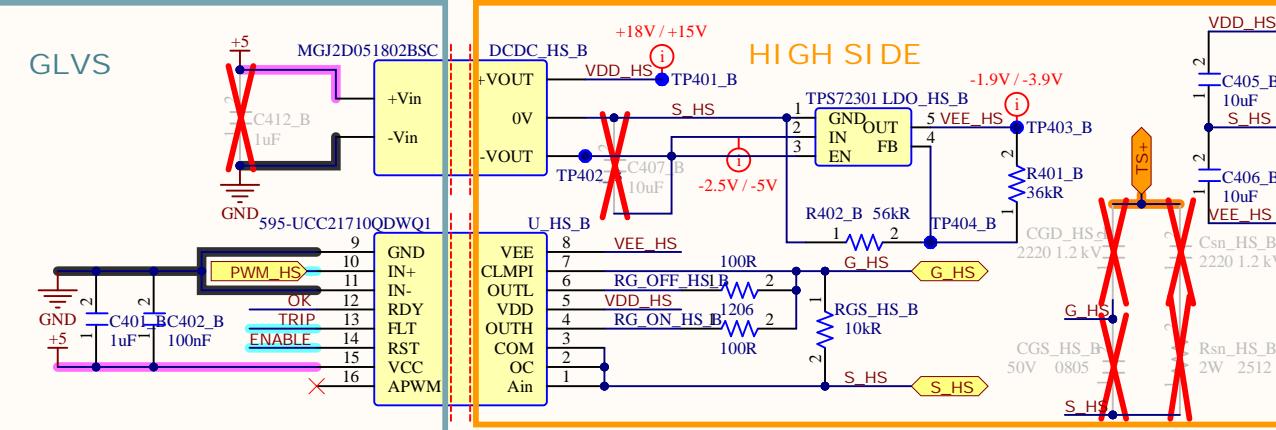
Project: Inverter Power Variant: Leapers

Size:	Page Contents: [4]Half_Bridge.SchDoc	Version: 1.1
Department:		Powertrain
Author:	dredondovinolo@gmail.com	Sheet 5 of 5
Checked by:		Date: 19/04/2024

A

U_HS, U_LS

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- RGS_HS**, **RGS_LS**: External gate pull-down is implemented even though the gate drivers implement an active pull-down.
- Overcurrent detection is not implemented.

GLVS

B

LDO_HS, LDO_LS

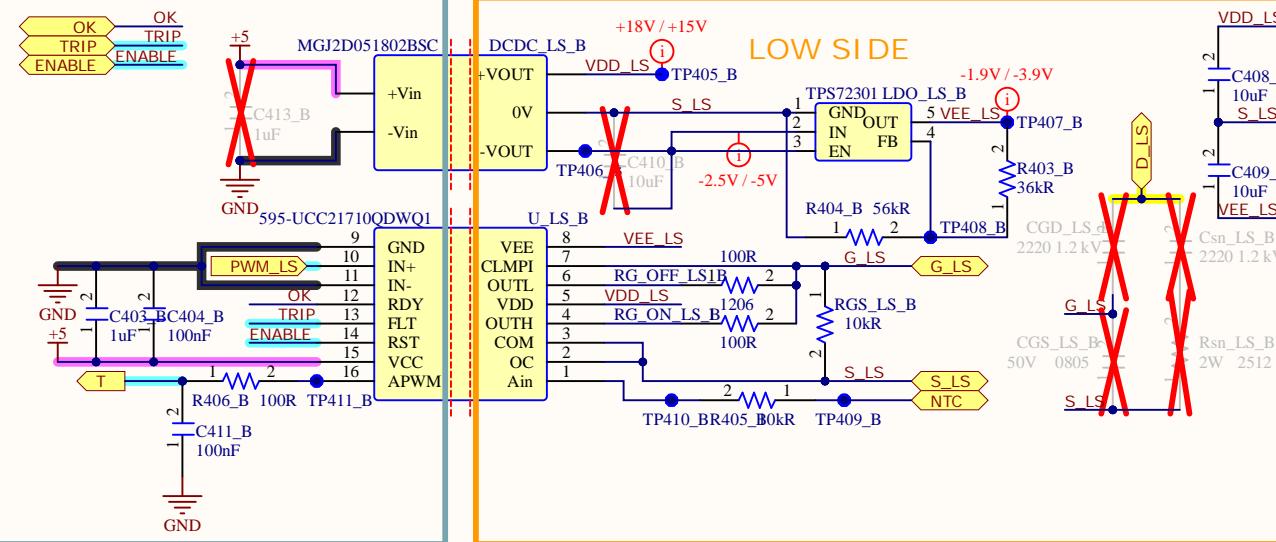
An LDO is implemented to trim **VEE_HS_A** and **VEE_LS_A** during testing to fine tune the necessary negative gate voltage. Feedback voltage divider adjusted with a Python script which can be found in the simulations folder.

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Leapers $\rightarrow R1 = 36 \text{ k}\Omega$, $R2 = 56 \text{ k}\Omega$

Wolfspeed $\rightarrow R1 = 68 \text{ k}\Omega$, $R2 = 30 \text{ k}\Omega$

OK TRIP ENABLE

C

DCDC_HS, DCDC_LS

Isolation test voltage (Qualification tested for 1 minute): 5200 VDC

U_HS, U_LS

VIOTM ($t = 60$ s (qualification test)): 8000 VPK

V_GS values:

The values can be modified by replacing **DCDC_HS** and **DCDC_LS** with one from the following list: MGJ2D051505SC, MGJ2D051509SC, MGJ2D051515SC, MGJ2D051802SC, MGJ2D052003SC, MGJ2D052005SC. LDO voltages must also be adjusted.

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RG_ON_HS, RG_OFF_HS, RG_ON_LS, RG_OFF_LS

Essentially, a lower value for the gate resistors will reduce switching losses as the MOSFETs will switch faster and thus spend less time switching. Switching faster also means that the dV/dt will be higher, which can be responsible of EMI increase. The considered values of 3.3 Ω are recommended by the datasheet.

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Company:	e-Tech Racing	e-techracing.es	
Project:	Inverter Power	Variant: Leapers	
Size:	Page Contents: [4]Half_Bridge.SchDoc	Version: 1.1	
Department:	Powertrain		
Author:	David Redondo	dredondovinolo@gmail.com	Sheet 5 of 5
Checked by:			Date: 19/04/2024

A

U_HS, U_LS

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- Overcurrent detection is not implemented.

B

LDO_HS, LDO_LS

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$$\text{VEE} = -1.186 \cdot (1 + R1/R2)$$

$$R1 + R2 \approx 100 \text{ k}\Omega$$

Leapers $\rightarrow R1 = 36 \text{ k}\Omega$, $R2 = 56 \text{ k}\Omega$

Wolfspeed $\rightarrow R1 = 68 \text{ k}\Omega$, $R2 = 30 \text{ k}\Omega$

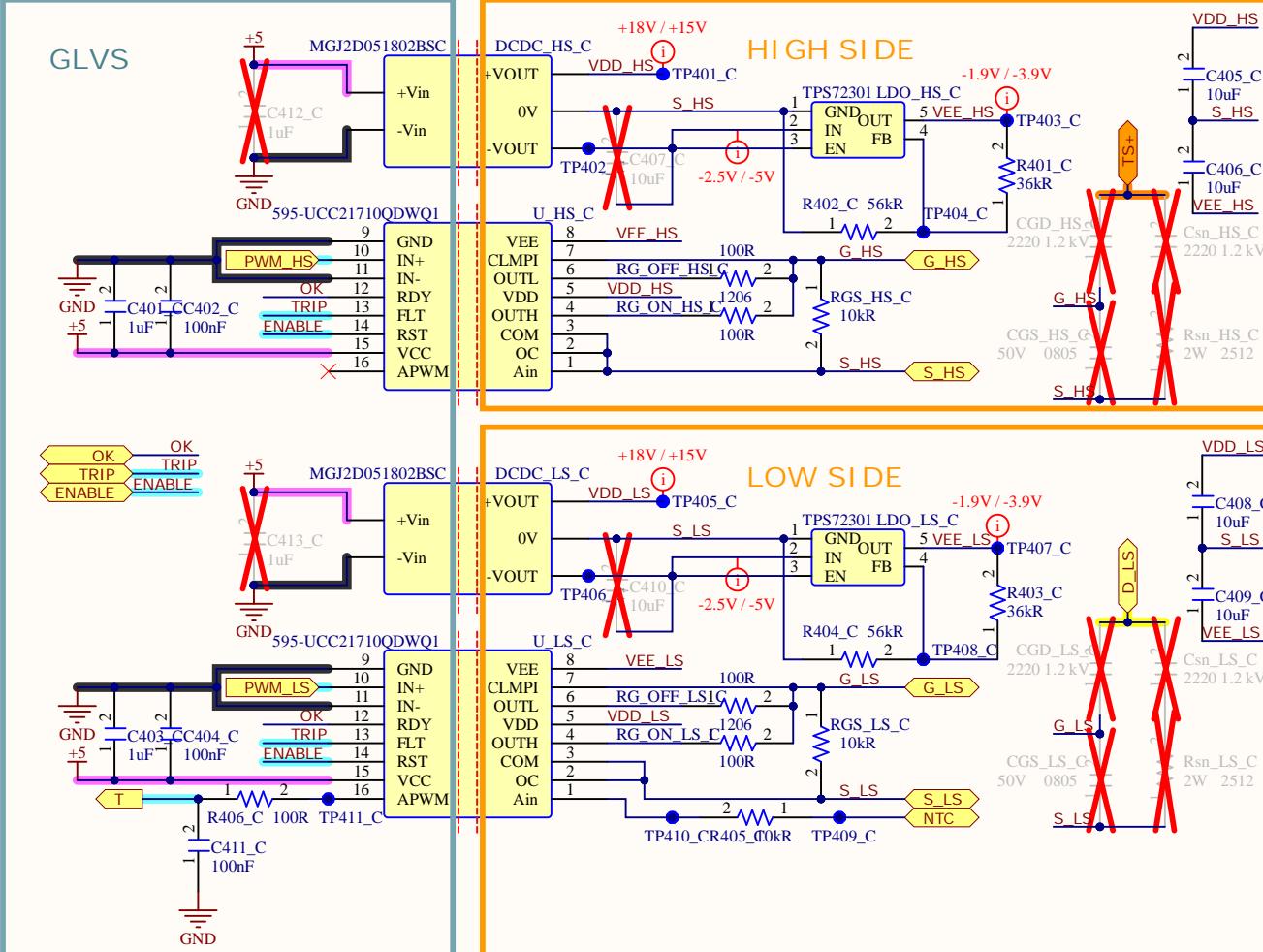
C

DCDC_HS, DCDC_LS

Isolation test voltage (Qualification tested for 1 minute): 5200 VDC

U_HS, U_LS

VIOTM ($t = 60$ s (qualification test)): 8000 VPK

**V_GS values:**

The values can be modified by replacing **DCDC_HS** and **DCDC_LS** with one from the following list: MGJ2D051505SC, MGJ2D051509SC, MGJ2D051515SC, MGJ2D051802SC, MGJ2D052003SC, MGJ2D052005SC. LDO voltages must also be adjusted.

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 $P_{\min} = \Delta V_{GS} \cdot I_{GD(\min)} = 20 \text{ V} \cdot 26 \text{ mA} = 0.52 \text{ W} \rightarrow 2 \text{ W}$

RG_ON_HS, RG_OFF_HS, RG_ON_LS, RG_OFF_LS

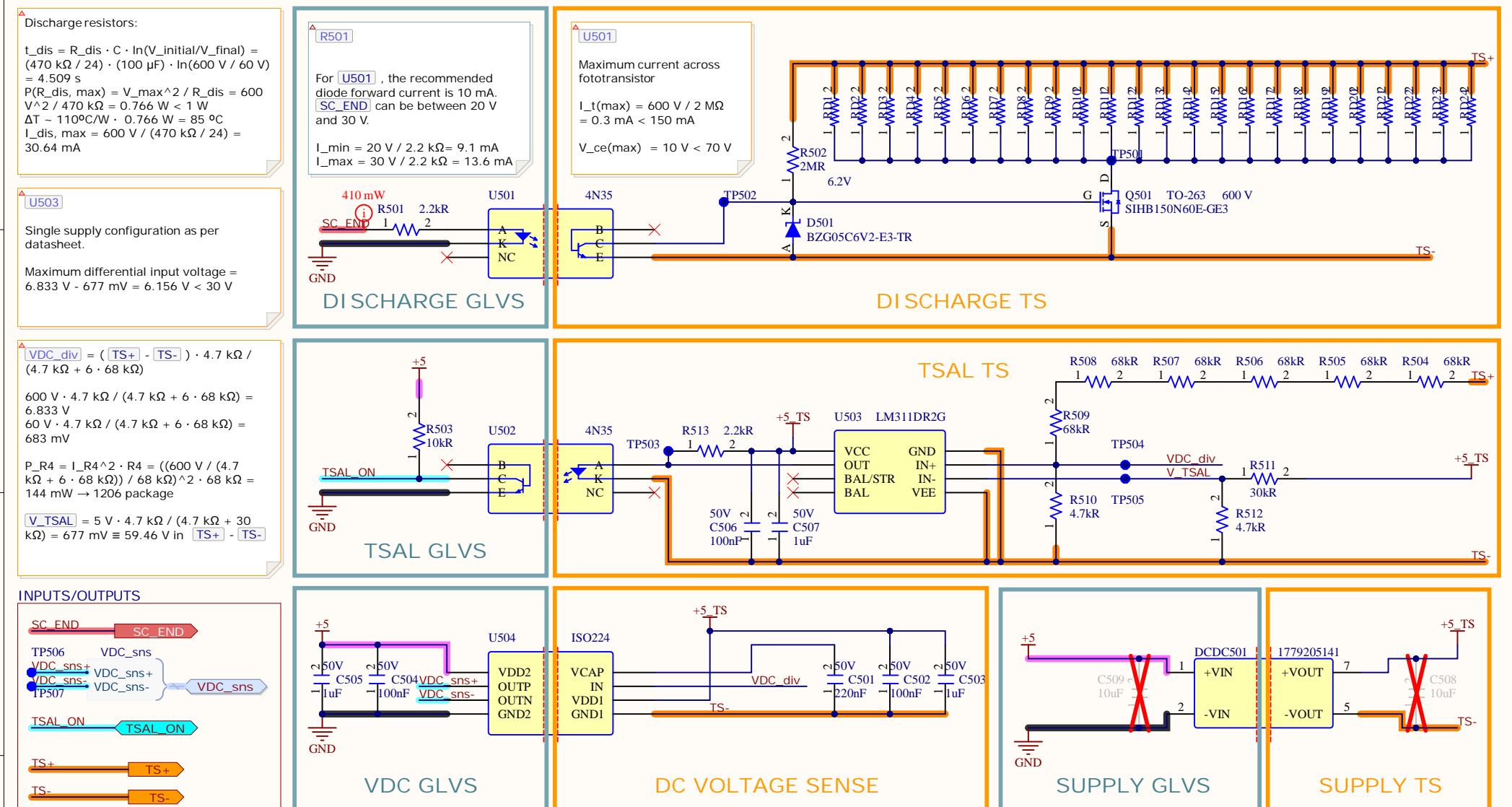
Essentially, a lower value for the gate resistors will reduce switching losses as the MOSFETs will switch faster and thus spend less time switching. Switching faster also means that the dV/dt will be higher, which can be responsible of EMI increase. The considered values of 3.0 Ω are recommended by the datasheet.

CGS_HS, **CGS_LS**, **CGD_HS**, **CGD_LS**, **Csn_HS**, **Csn_LS**, **Rsn_HS**, **Rsn_LS**

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Company:	e-Tech Racing	e-techracing.es	
Project:	Inverter Power	Variant: Leapers	
Size:	Page Contents: [4]Half_Bridge.SchDoc	Version: 1.1	
		Department: Powertrain	
Author:	David Redondo	dredondovinolo@gmail.com	Sheet 5 of 5
Checked by:			Date: 19/04/2024



$(TS+ - TS-) > 60V \rightarrow TSAL_ON = 0V$
 $(TS+ - TS-) < 60V \rightarrow TSAL_ON = 5V$

$$\begin{aligned} & \Delta \quad \text{U504} \\ \\ & (\frac{\text{VDC_sns+}}{\text{VDC_div}} - \frac{\text{VDC_sns-}}{\text{VDC_div}}) = 1/3 \cdot \\ & 4.7 \text{ k}\Omega / (4.7 \text{ k}\Omega + 6 \cdot 68 \text{ k}\Omega) = 1/3 \cdot \\ & 0.011388 \cdot (\frac{\text{TS+}}{\text{TS-}} - \frac{\text{TS-}}{\text{TS+}}) \\ \\ & (\frac{\text{VDC_sns+}}{\text{VDC_div}} - \frac{\text{VDC_sns-}}{\text{VDC_div}}) = 1/3 \cdot \\ & 0.011388 \cdot 600 \text{ V} = 2.278 \text{ V} \end{aligned}$$

U501, **U502**

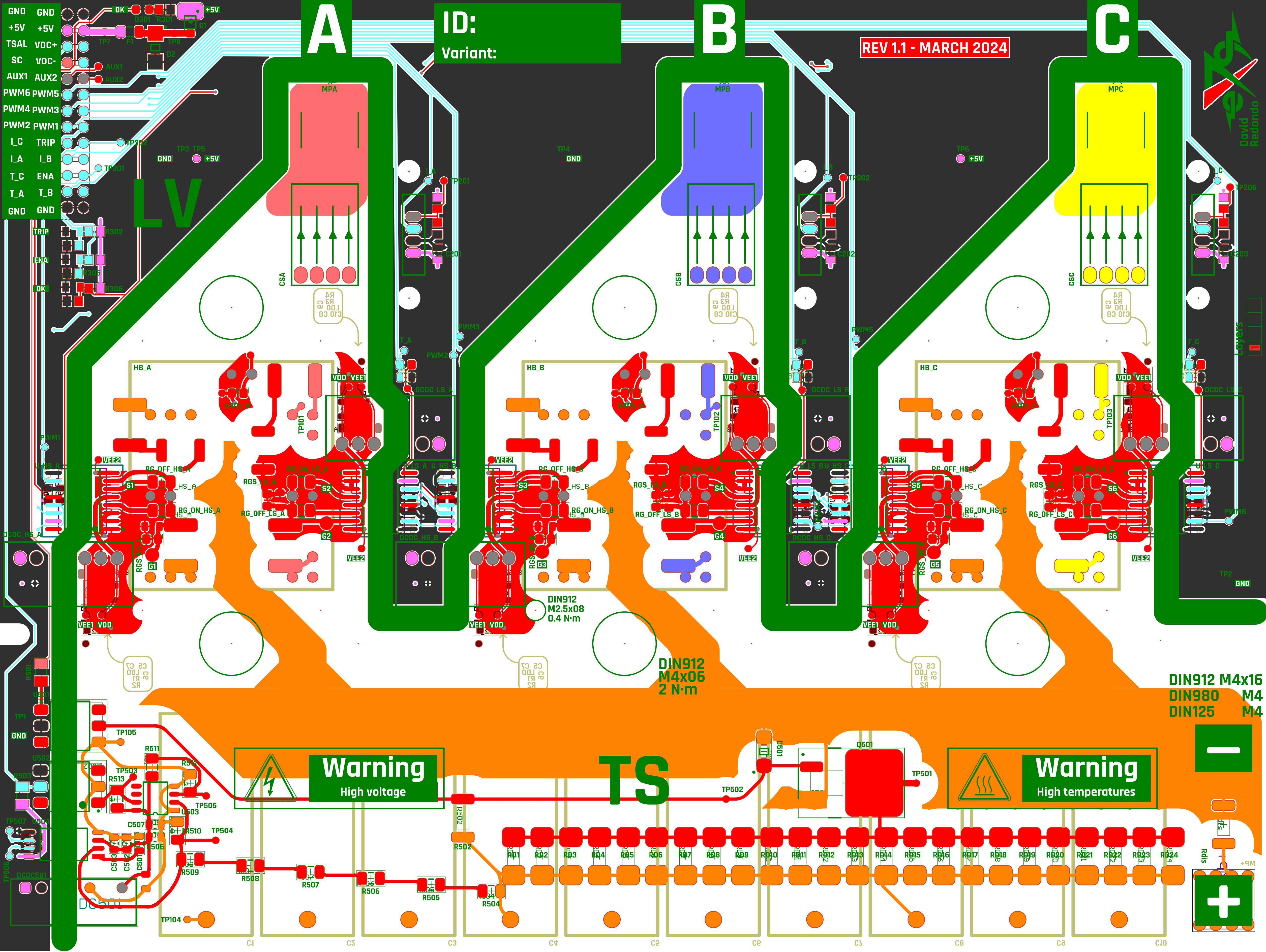
Isolation Voltage: AC For 1 Minute,
R.H. = 40 ~ 60% Viso = 5000 Vrms

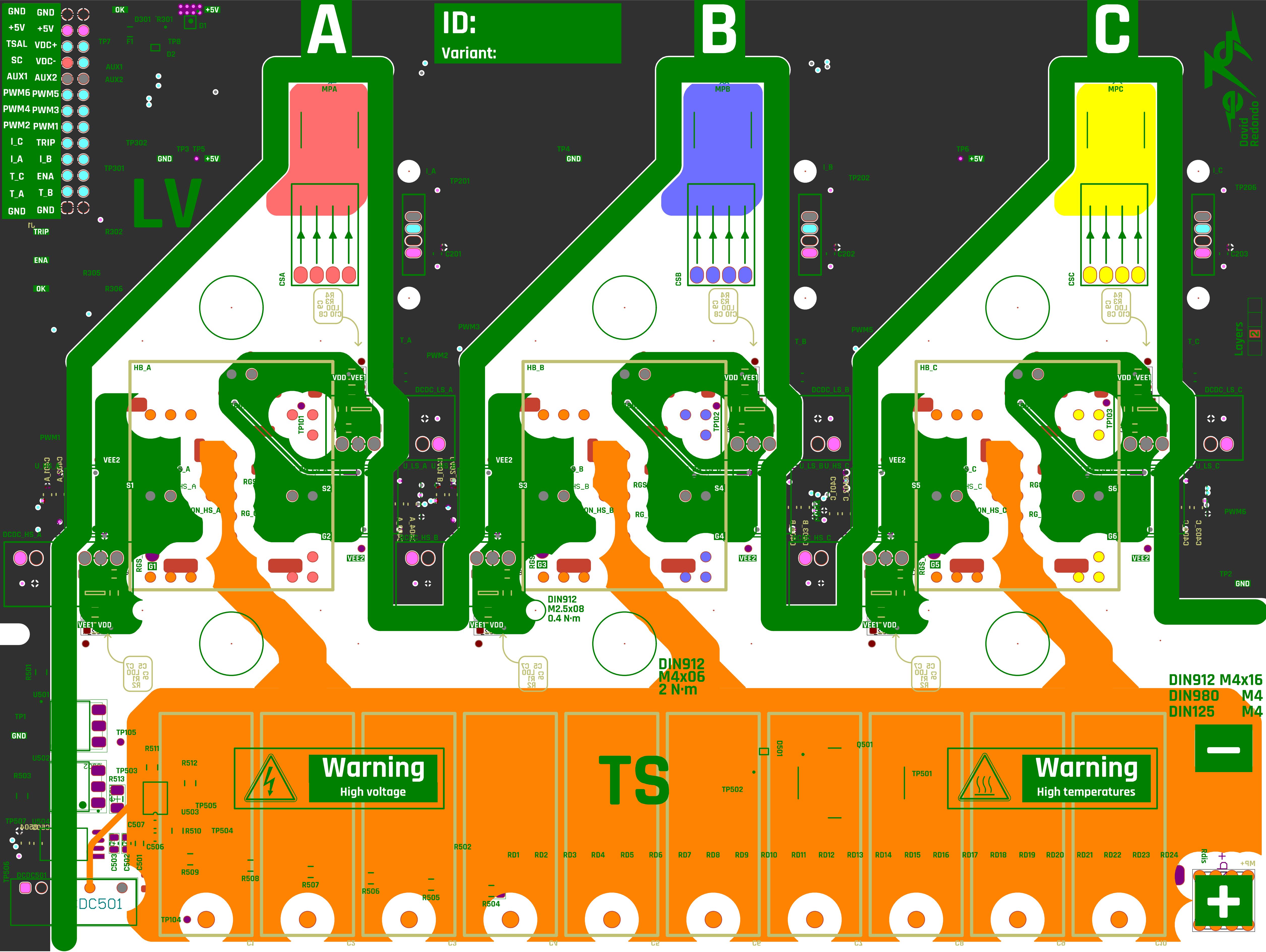
U504

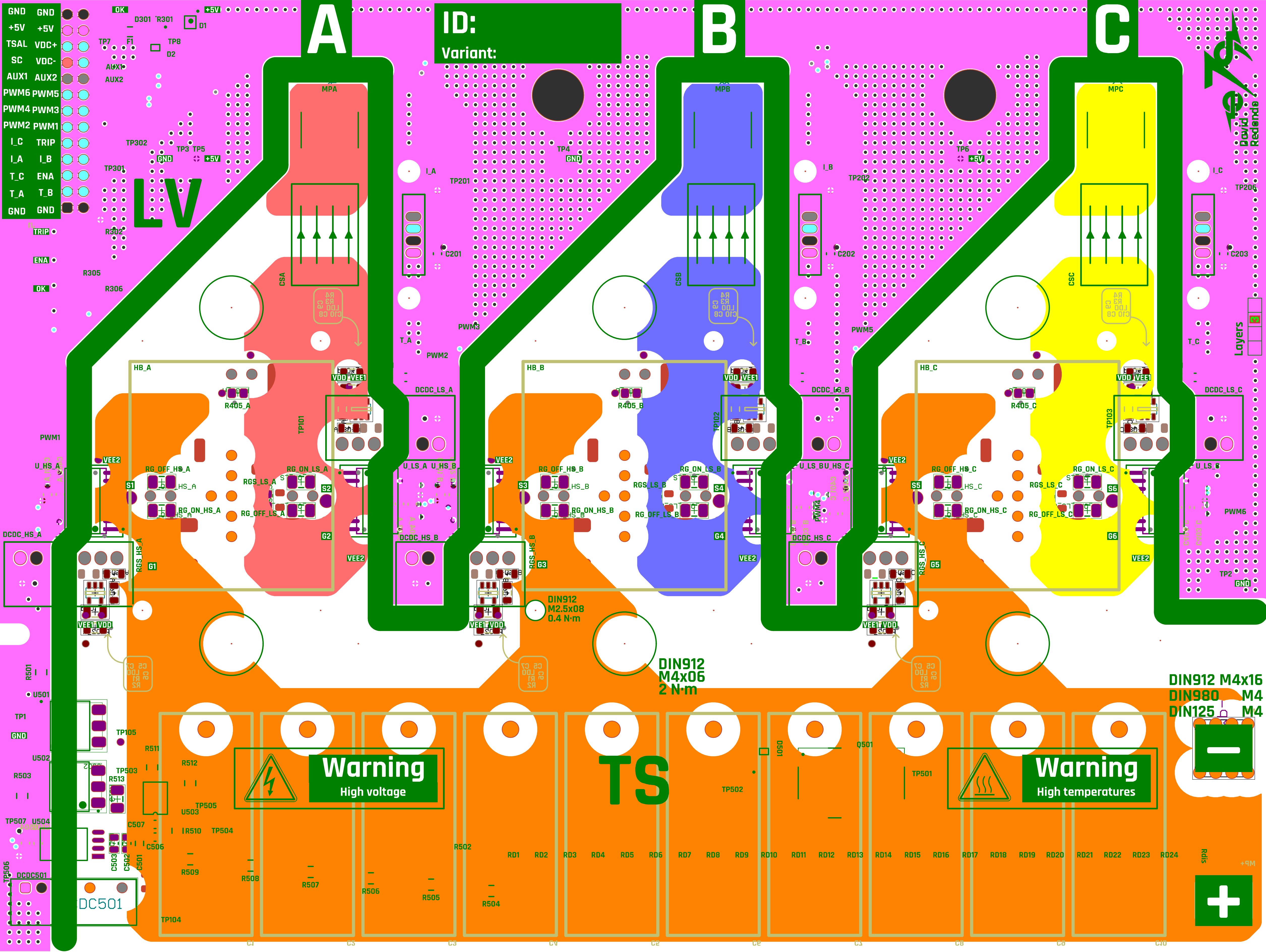
Maximum transient isolation voltage:
VTEST = VIOTM, $t = 60$ s (qualification
test) VIOTM = 7071 Vpk

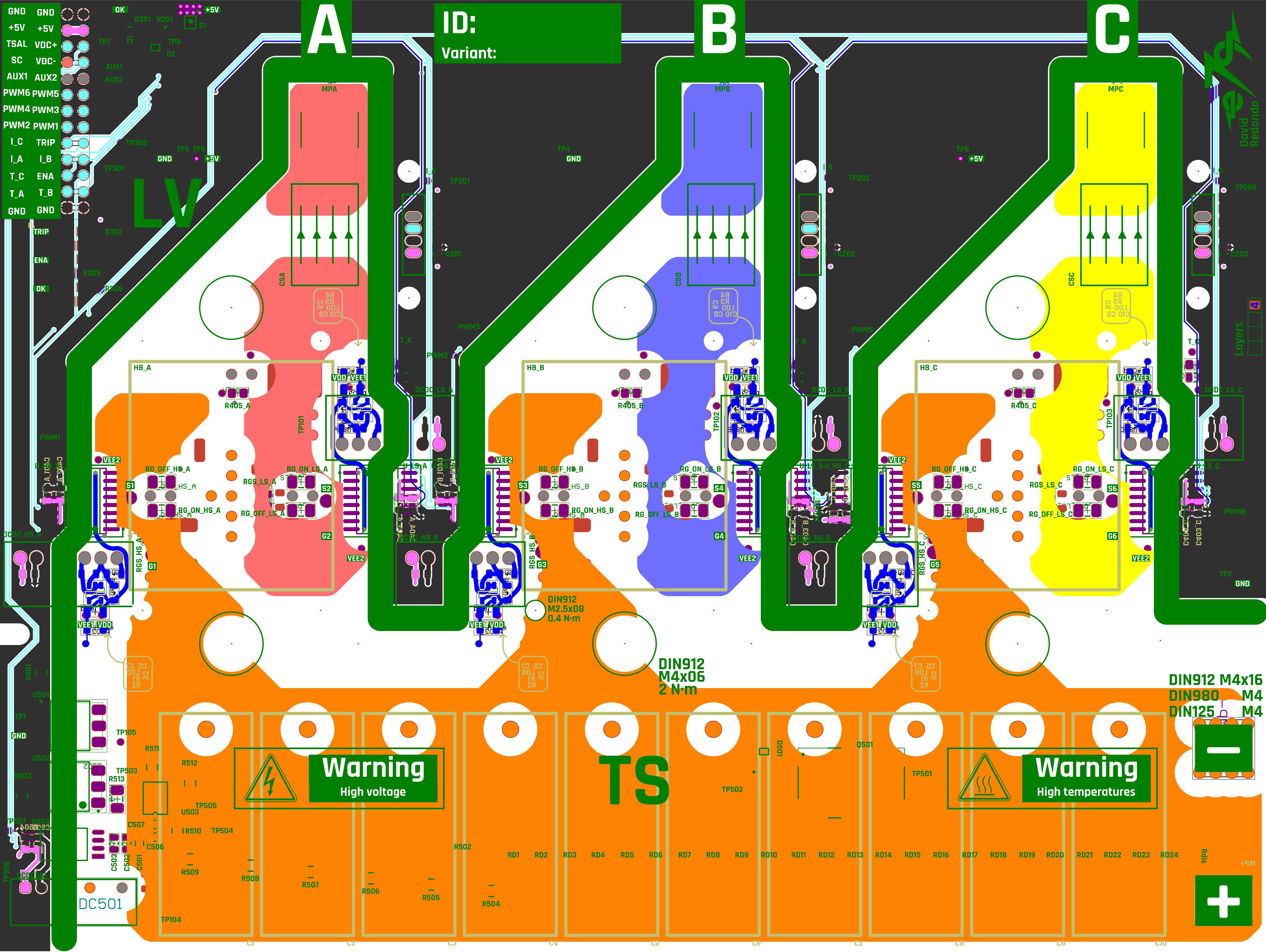
DCDC501

Company: e-Tech Racing		e-tchracing.es	
Project: Inverter Power		Variant: Leapers	
Size: -	Page Contents: [5]DC.SchDoc		Version: 1.1
			Department: Powertrain
Author: David Redondo		dredondovinolo@gmail.com	Sheet * of *
Checked by: -		Date: 19/04/2024	

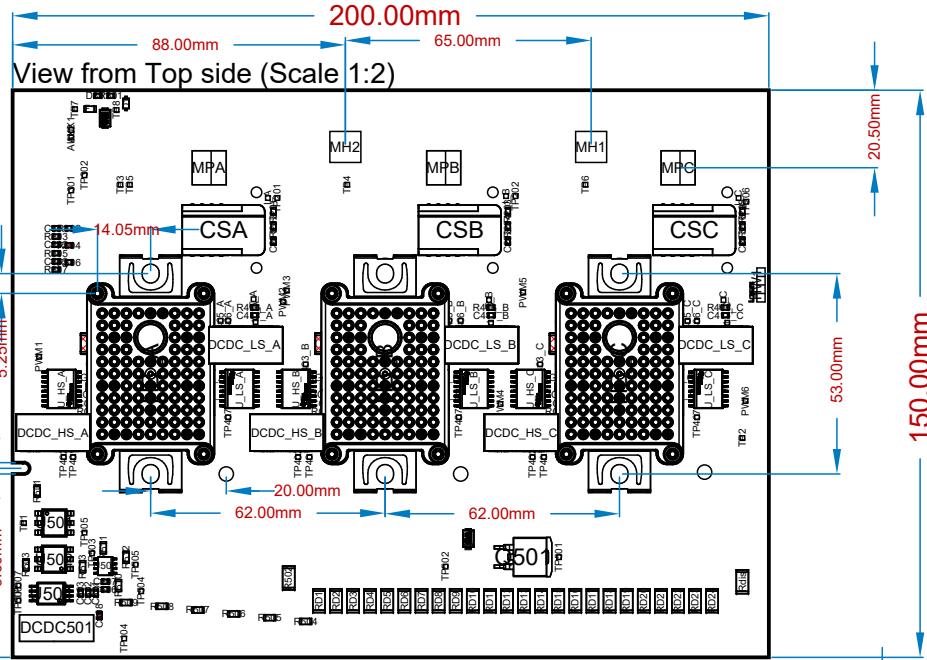




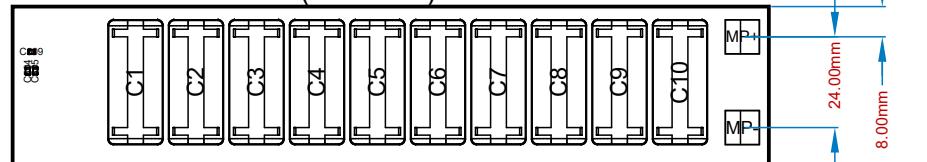




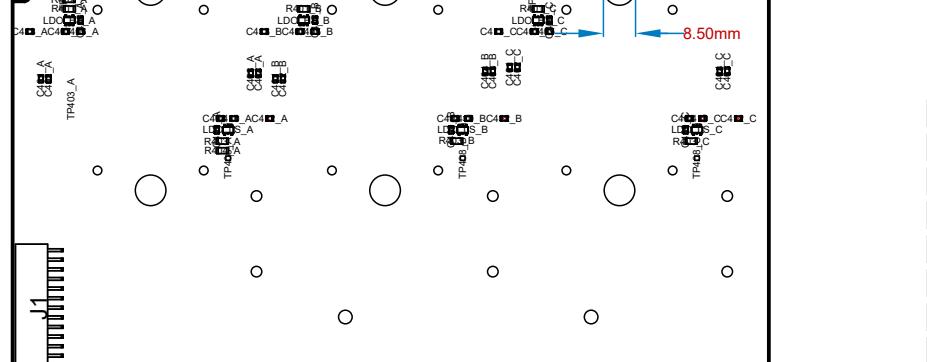
Inverter Power



View from Top side (Scale 1:2)



View from Bottom side (Scale 1:2)



View from Back side (Scale 1:2)

Bill Of Materials

Designator	Name	Quantity
C405_A, C405_B, C405_C, C406_A, C406_B, C406_C, C408_A, C408_B, C408_C, C409_A, C409_B, C409_C	10uF	12
C1, C2, C3, C4, C5, C6, C7, C8, C9, C10	10uF 850V	10
CA1, CA2, CB1, CB2, CC1, CC2	2220Y1K0104KZT	6
F1	0437001.WRA	1
D2	1779205141	1
R401_A, R401_B, R401_C, R403_A, R403_B, R403_C	BZC05C5V1-E3-TR	1
R402_A, R402_B, R402_C, R404_A, R404_B, R404_C	CR1206-JW-363ELF	6
R503	CR1206-JW-563ELF	6
R511	CRCW120610K0FKEA	1
HB_A, HB_B, HB_C	CRCW120630K0FKEA	1
HW1	DF505HF12EYR1	3
MP-, MP+, MPA, MPB, MPC	LOGO CAPAS (4)	1
M4	M4	5
D1	MBR0530	1
MH1, MH2	Mounting Hole M4	2
RD1, RD2, RD3, RD4, RD5, RD6, RD7, RD8, RD9, RD10, RD11, RD12, RD13, RD14, RD15, RD16, RD17, RD18, RD19, RD20, RD21, RD22, RD23, RD24	RCV2512470KFKEG	24
R406_A, R406_B, R406_C	CR0805-FX-1000ELF	3
R301	CR0805-JW-102ELF	1
R302, R305, R306, R405_A, R405_B, R405_C, RGS_HS_A, RGS_HS_B, RGS_HS_C, RGS_LS_A, RGS_LS_B, RGS_LS_C	CR0805-JW-103ELF	12
R504, R505, R506, R507, R508, R509	CR1206AFX-6802EAS	6
R501, R513	CR1206-FX-2201ELF	2
R510, R512	CRS1206-FX-4701ELF	2
CSA, CSB, CSC	LEM CKSR 50-NP	3
DDCD_HS_A, DDCD_HS_B, DDCD_HS_C, DDCD_LS_A, DDCD_LS_B, DDCD_LS_C	MGJ6-series	6
U503	LM311DR2G	1
C501	885012208058	1
RG_OFF_HS_A, RG_OFF_HS_B, RG_OFF_HS_C, RG_OFF_HS_A, RG_OFF_HS_B, RG_OFF_HS_C, RG_ON_HS_A, RG_ON_HS_B, RG_ON_HS_C, RG_ON_HS_A, RG_ON_HS_B, RG_ON_HS_C	CRG1206F100R	12
U504	ISO224	1
LDO_HS_A, LDO_HS_B, LDO_HS_C, LDO_LS_A, LDO_LS_B, LDO_LS_C	TPS72301	6
U_HS_A, U_HS_B, U_HS_C, U_LS_A, U_LS_B, U_LS_C	UCC21710	6
Q501	SIH150N60E-GE3	1
R502, Rds	R2M-2512FTK	2
U501, U502	4N35	2
D501	BZG05C6V2-E3-TR	1
D301	150080GS75000	1
C201, C202, C203, C402_A, C402_B, C402_C, C404_A, C404_B, C404_C, C411_A, C411_B, C411_C, C502, C504, C506	885012207098	15
C401_A, C401_B, C401_C, C403_A, C403_B, C403_C, C503, C507	885012207103	9

Copper thickness in hole 25-50um, watch out for 1.10mm holes
Chemical tin 1-15um

Layer Stack Legend

Material	Layer	Thickness	Dielectric Material	Type	Gerber
	Top Overlay				Legend GTO
	Surface Material	0.01mm	Solder Resist		Solder Mask GTS
CF-004	TOP	0.07mm		Signal GTL	
	Prepreg	0.10mm	PP-006		Dielectric
	Prepreg	0.10mm	PP-006		Dielectric
	Copper	0.07mm	4N35	Signal G1	
	FR-4	0.90mm			Dielectric
	Copper	0.07mm	PP-006	Signal G2	
	Prepreg	0.10mm			Dielectric
	Prepreg	0.10mm	PP-006		Dielectric
CF-004	BOT	0.07mm		Signal GBL	
	Surface Material	0.01mm	Solder Resist		Solder Mask GBS
	Bottom Overlay				Legend GBO

Total thickness: 1.60mm