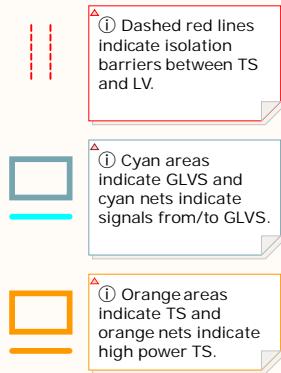


A



Specifications:

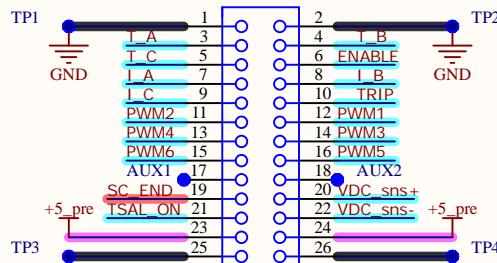
V_{in}, max = 600 VDC
V_{out}, max = 245 VRMS (SVPWM)
f_{sw} = 50 kHz
P_{out}, max = 40kW
I_{out}, max = 80 ARMS
Liquid cooled with water at 50°C max

Changelog:

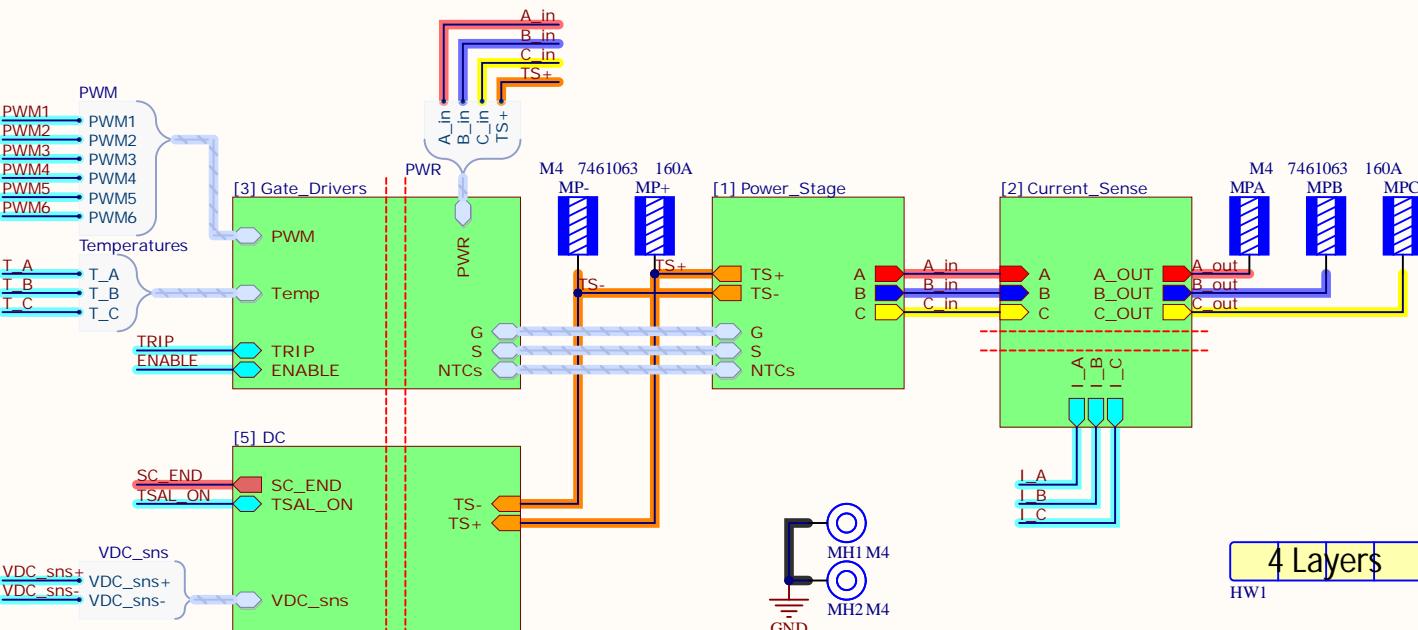
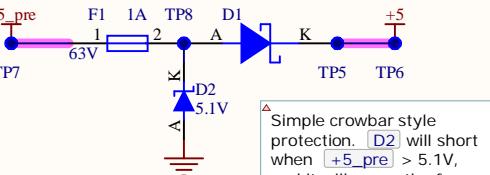
Version 1.0:
- Base version, sent to production 15-02-2024

Version 1.1:
- 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

LV Connector

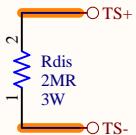


OCP, OVP, reverse

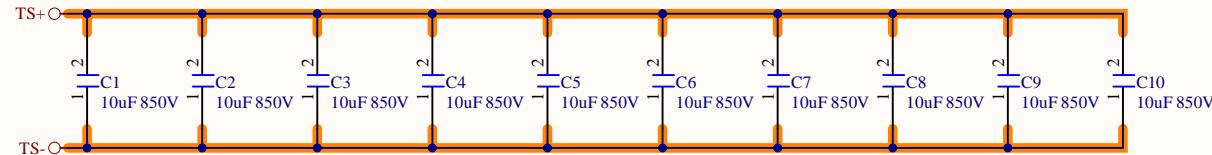


Company:	e-Tech Racing	e-techracing.es	
Project:	Inverter Power	Variant: Wolfspeed	
Size:	Page Contents: Inverter_Power.SchDoc	Version: 1.1	
		Department: Powertrain	
Author:	David Redondo	dredondovinolo@gmail.com	Sheet 1 of 5
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Passive discharge



DC Bus capacitors, 100uF, Murata FHA85Y106KS



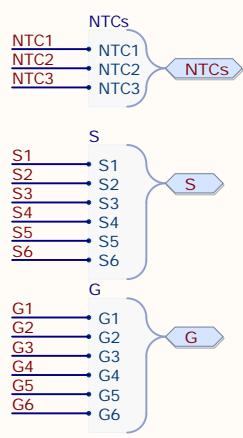
DC Link design considerations:

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

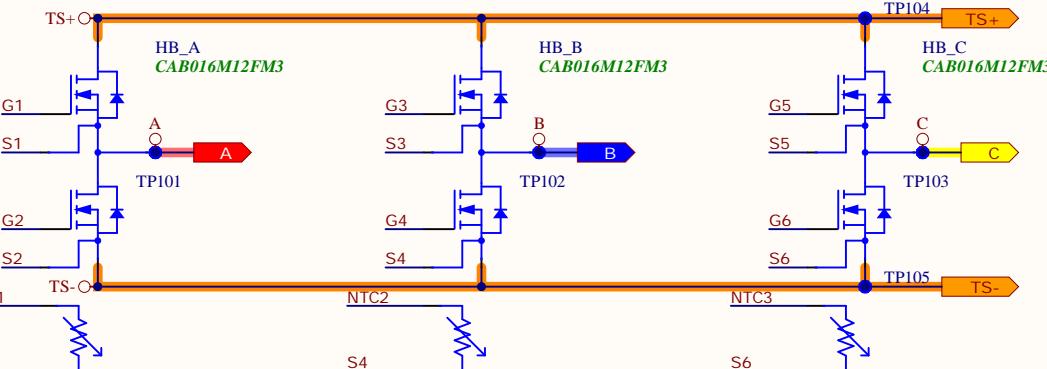
$I_{C,RMS} \approx 0.65 \cdot I_{phase,RMS} = 0.65 \cdot 80 A, RMS = 52 A, RMS \rightarrow 10 \times 5 A, RMS (\Delta T = 10 ^\circ C)$
 $C > I_{C,RMS} / (V_{ripple} \cdot f_{sw}) = 52 A, RMS / (15V \cdot 50 kHz) \approx 79 \mu F \rightarrow 10 \times 10 \mu F$

Lowering the switching frequency will proportionally lower the current rating for the same voltage ripple or proportionally increase the voltage ripple for the same output current. Check:
<https://www.specterengineering.com/blog/2019/9/7/dc-link-capacitor-selection-for-your-inverter>

INPUTS/OUTPUTS



SiC Half-Bridges



Semiconductor details:

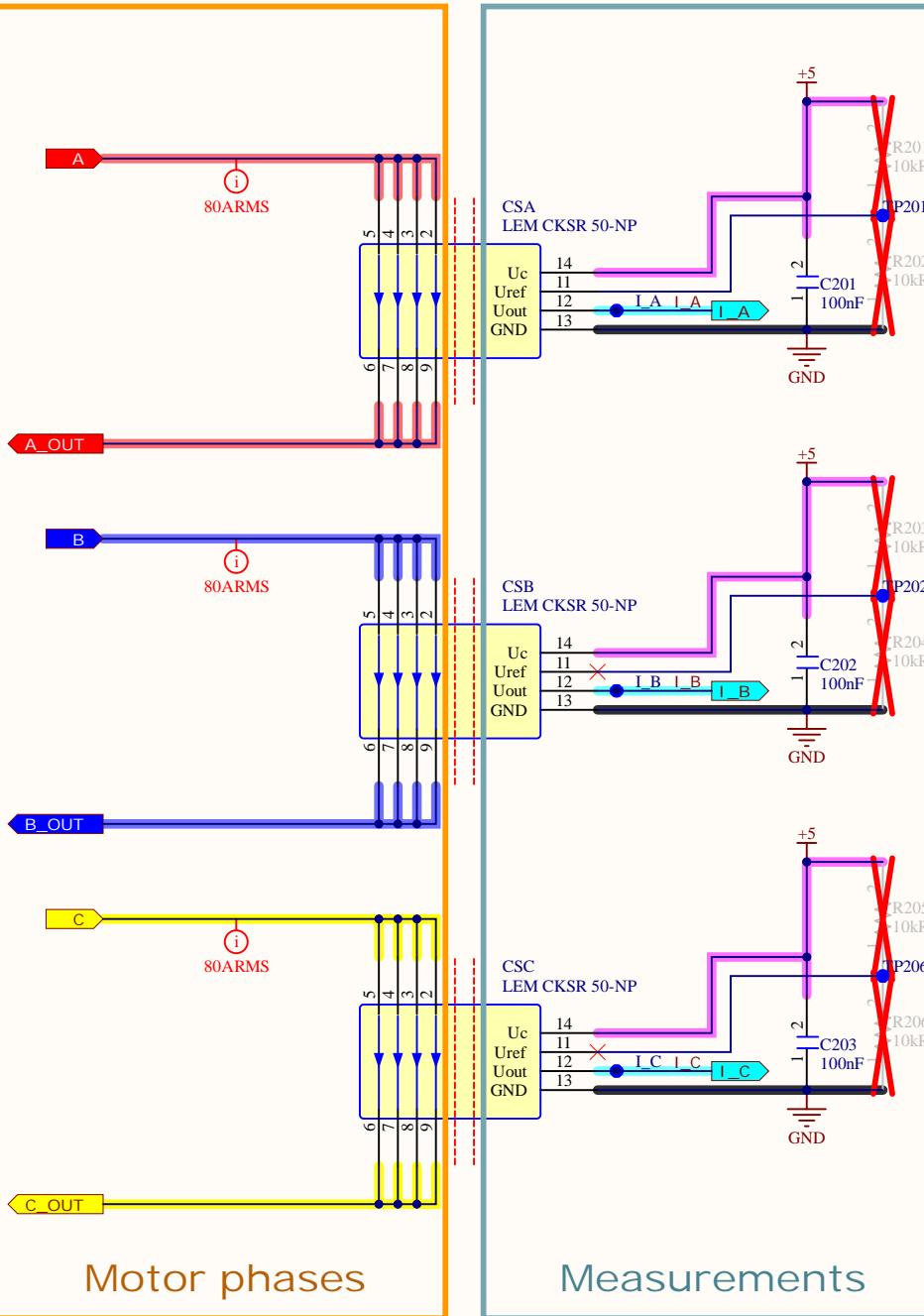
$V_{DSS}(\text{breakdown}) = 1200 V // 1200 V$
 $R_{on} = 5.5 .. 13 m\Omega // 16.0 .. 28.8 m\Omega$
 $V_{f,D} = 3.3 .. 4 V // 4.9 .. 5.5 V$
 $T_{rr} = 41.5 .. 45 ns // 20.0 ns$
 $Q_{rr} = 2.19 .. 3.94 \mu C // 1.30 \mu C$
 $R_{th,Jc} = 0.12 .. 0.15 K/W // 0.543 K/W$
 $Q_G = 520 nC // 236 nC$
 $C_{in} = 14.5 nF // 6.6 nF$
 $R_G(\text{int}) = 1.9 \Omega // 2.4 \Omega$
 $V_{GS(th)} = 2.8 .. 4.8 V // 1.8 .. 3.6 V$

Company:	e-Tech Racing	e-techracing.es	
Project:	Inverter Power	Variant: Wolfspeed	
Size:	Page Contents: [1]Power_Stages.SchDoc	Version: 1.1	
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Author:	David Redondo	dredondovinolo@gmail.com	Sheet 2 of 5
Checked by:	_		Date: 28/03/2024

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:

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

D

Company:	e-Tech Racing	e-techracing.es	
Project:	Inverter Power	Variant:	Wolfspeed
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:	28/03/2024

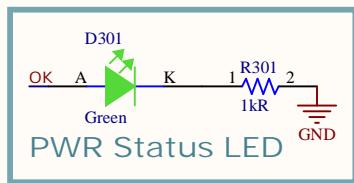
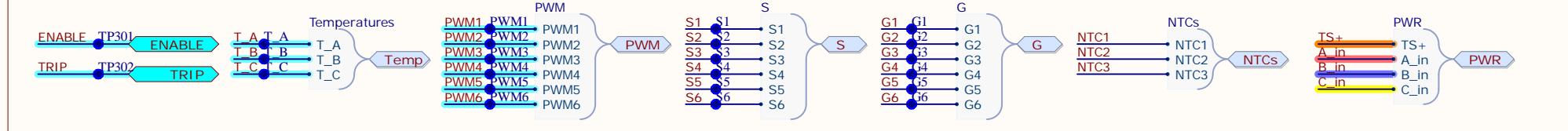
1

2

3

4

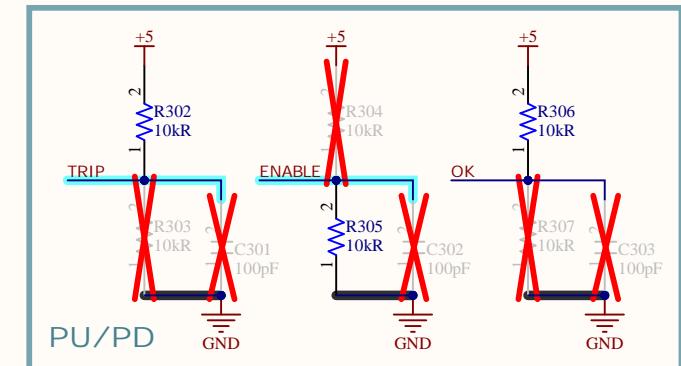
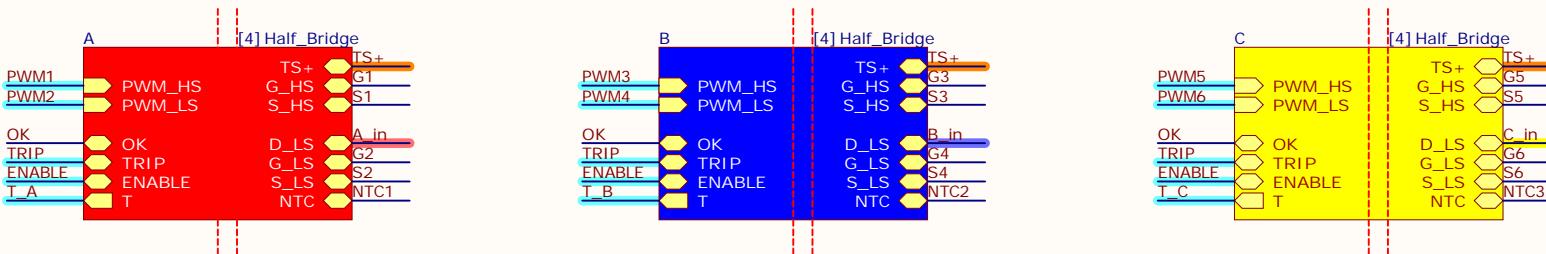
INPUTS/OUTPUTS



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

B

B



Company:	e-Tech Racing	e-techracing.es	
Project:	Inverter Power	Variant:	Wolfspeed
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-		Department:	Powertrain
Author:	David Redondo	dredondovinolo@gmail.com	Sheet 4 of 5
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1

2

3

4

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.
 - Overscurrent 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.

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

$$R_1 + R_2 \approx 100 \text{ k}\Omega$$

Leapers $\rightarrow R_1 = 36 \text{ k}\Omega$, $R_2 = 56 \text{ k}\Omega$

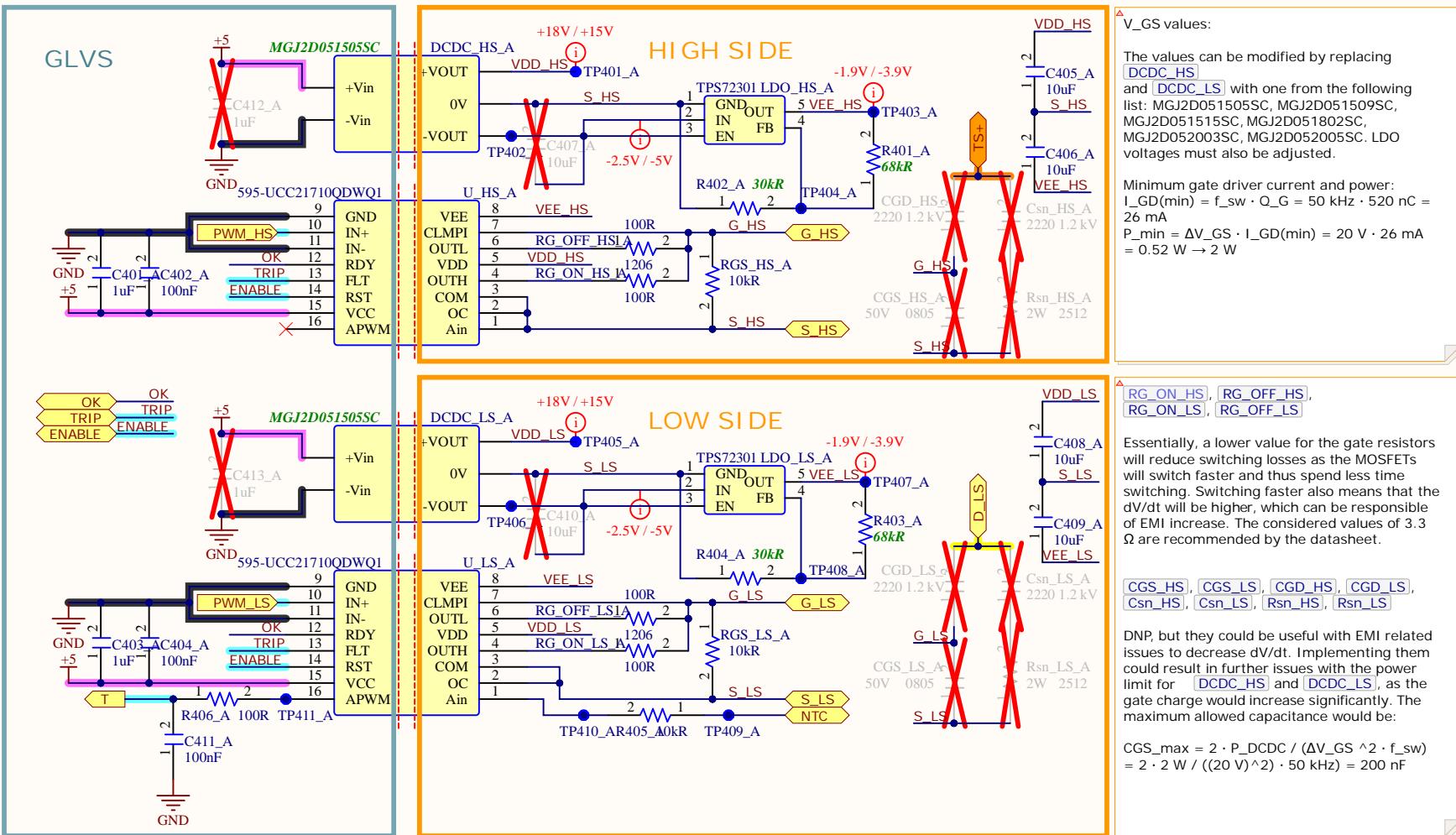
Wolfspeed → R1 = 68 kΩ, R2 = 30 kΩ

△

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

U_HS, **U_LS**

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



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Project:	Inverter Power	Variant: Wolfspeed	
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		Department:	Powertrain
Author:	David Redondo	dredondovinolo@gmail.com	Sheet 5 of 5
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A ▲ **U_HS, U_LS**

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- IN- is not used and tied to **GND**.
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- 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.

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.

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

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

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

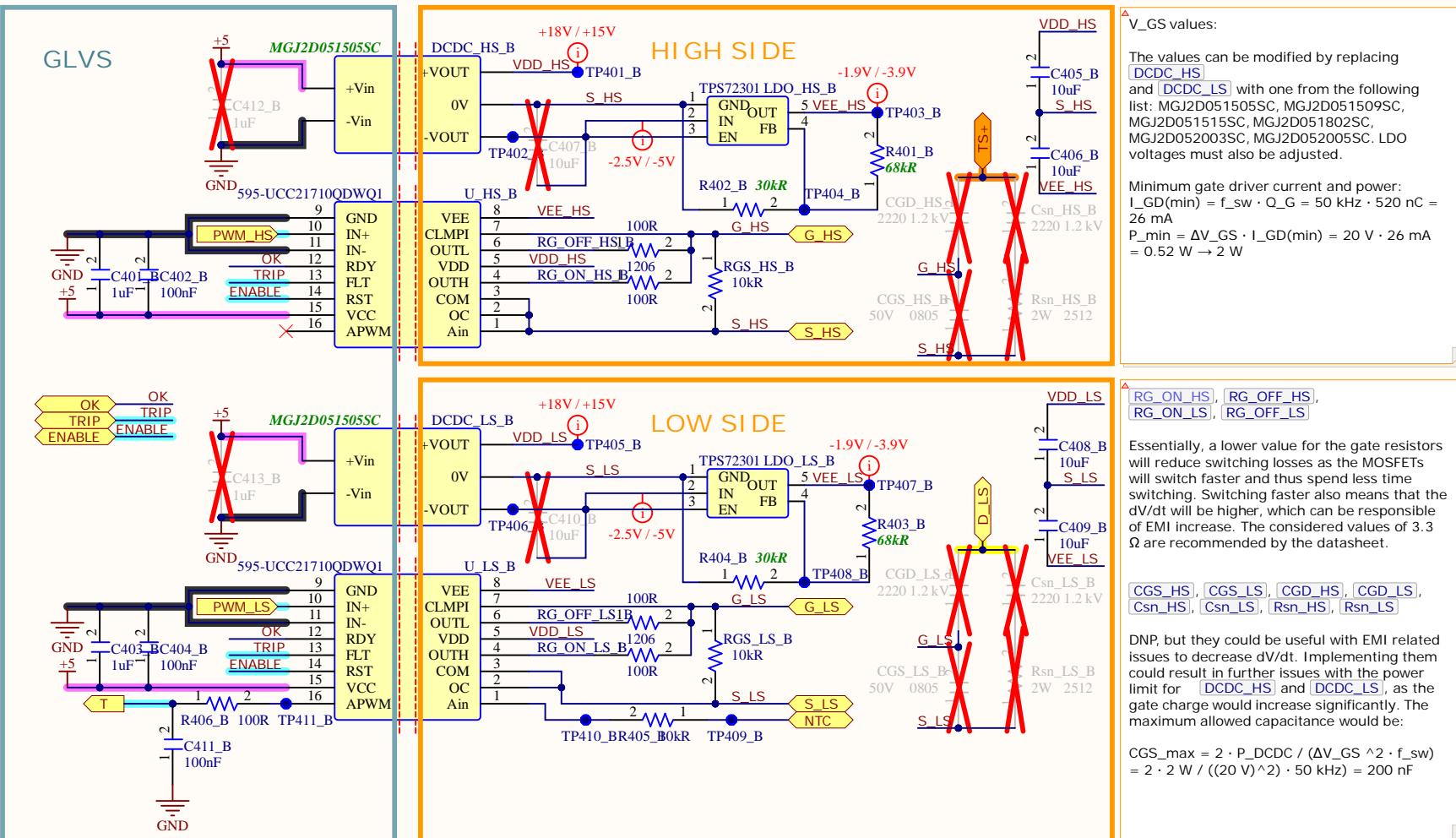
Wolfspeed $\rightarrow R1 = 68 \text{ k}\Omega$, $R2 = 30 \text{ k}\Omega$

C ▲ **DCDC_HS, DCDC_LS**

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

D ▲ **U_HS, U_LS**

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

**A** ▲ **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:
 $I_{GD(\min)} = f_{sw} \cdot O_G = 50 \text{ kHz} \cdot 520 \text{ nC} = 26 \text{ mA}$
 $P_{\min} = \Delta V_{GS} \cdot I_{GD(\min)} = 20 \text{ V} \cdot 26 \text{ mA} = 0.52 \text{ W} \rightarrow 2 \text{ W}$

B ▲ **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:

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

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Project:	Inverter Power	Variant: Wolfspeed	
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Author:	David Redondo	dredondovinolo@gmail.com	Sheet 5 of 5
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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**.
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- 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.

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.

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

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

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

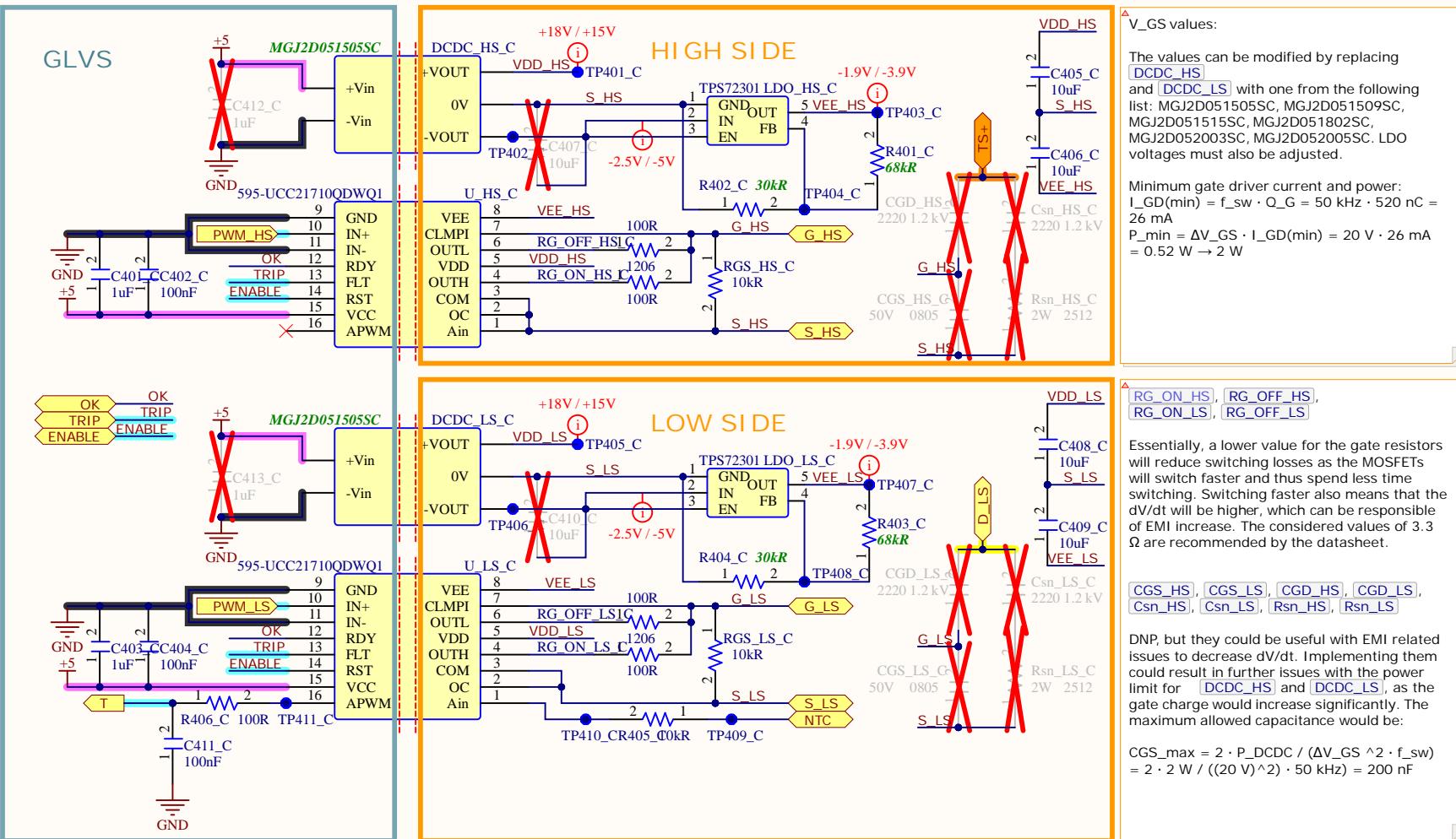
Wolfspeed $\rightarrow R1 = 68 \text{ k}\Omega$, $R2 = 30 \text{ k}\Omega$

C ▲ **DCDC_HS, DCDC_LS**

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

D ▲ **U_HS, U_LS**

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



Company:	e-Tech Racing	e-techracing.es	
Project:	Inverter Power	Variant: Wolfspeed	
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A

Discharge resistors:

$$t_{dis} = R_{dis} \cdot C \cdot \ln(V_{initial}/V_{final}) = (470 \text{ k}\Omega / 24) \cdot (100 \mu\text{F}) \cdot \ln(600 \text{ V} / 60 \text{ V}) = 4.509 \text{ s}$$

$$P(R_{dis}, \text{max}) = V_{max}^2 / R_{dis} = 600 \text{ V}^2 / 470 \text{ k}\Omega = 0.766 \text{ W} < 1 \text{ W}$$

$$I_{dis, \text{max}} = 600 \text{ V} / (470 \text{ k}\Omega / 24) = 30.64 \text{ mA}$$

U503

Single supply configuration as per datasheet.

$$\text{Maximum differential input voltage} = 6.833 \text{ V} - 677 \text{ mV} = 6.156 \text{ V} < 30 \text{ V}$$

$$VDC_{div} = (TS+ - TS-) \cdot 4.7 \text{ k}\Omega / (4.7 \text{ k}\Omega + 6 \cdot 68 \text{ k}\Omega)$$

$$600 \text{ V} \cdot 4.7 \text{ k}\Omega / (4.7 \text{ k}\Omega + 6 \cdot 68 \text{ k}\Omega) = 6.833 \text{ V}$$

$$60 \text{ V} \cdot 4.7 \text{ k}\Omega / (4.7 \text{ k}\Omega + 6 \cdot 68 \text{ k}\Omega) = 683 \text{ mV}$$

$$P_{R4} = I_{R4}^2 \cdot R_4 = ((600 \text{ V} / (4.7 \text{ k}\Omega + 6 \cdot 68 \text{ k}\Omega)) / 68 \text{ k}\Omega)^2 \cdot 68 \text{ k}\Omega = 144 \text{ mW} \rightarrow 1206 \text{ package}$$

$$V_{TSAL} = 5 \text{ V} \cdot 4.7 \text{ k}\Omega / (4.7 \text{ k}\Omega + 30 \text{ k}\Omega) = 677 \text{ mV} \equiv 59.46 \text{ V in } TS+ - TS-$$

INPUTS/OUTPUTS

SC_END → SC_END

TP506 → VDC_sns

VDC_sns+ → VDC_sns+

VDC_sns+ → VDC_sns-

TP507 → TSAL_ON

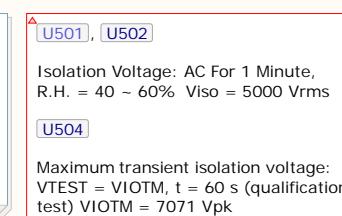
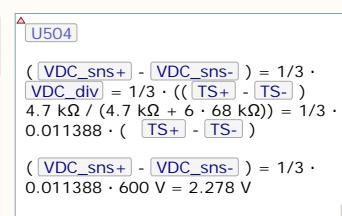
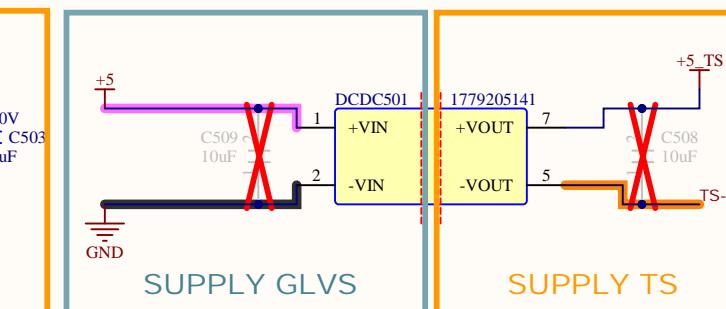
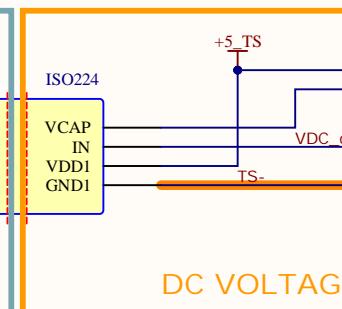
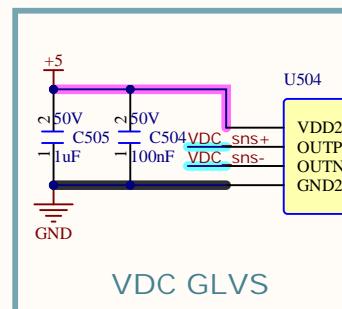
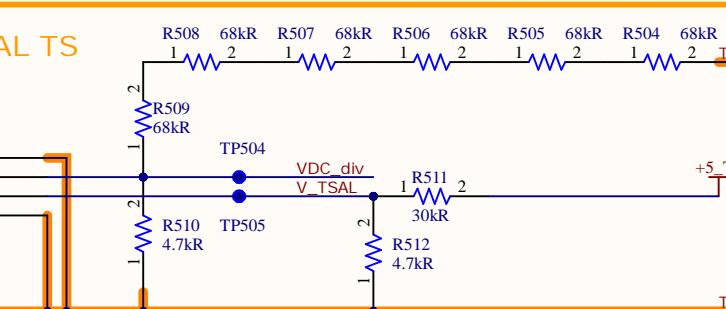
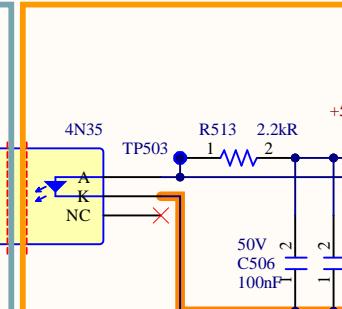
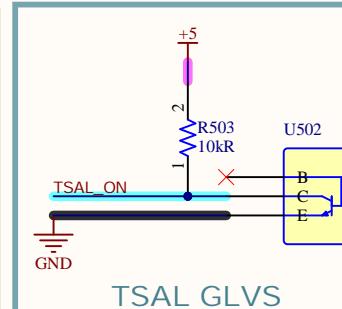
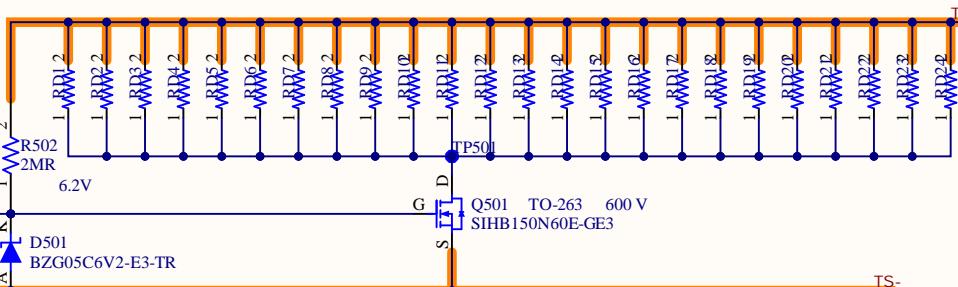
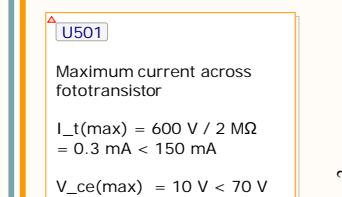
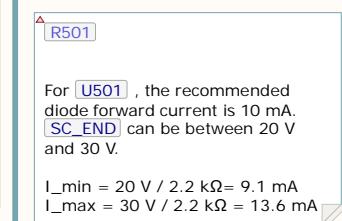
TSAL_ON → TSAL_ON

TS+ → TS+

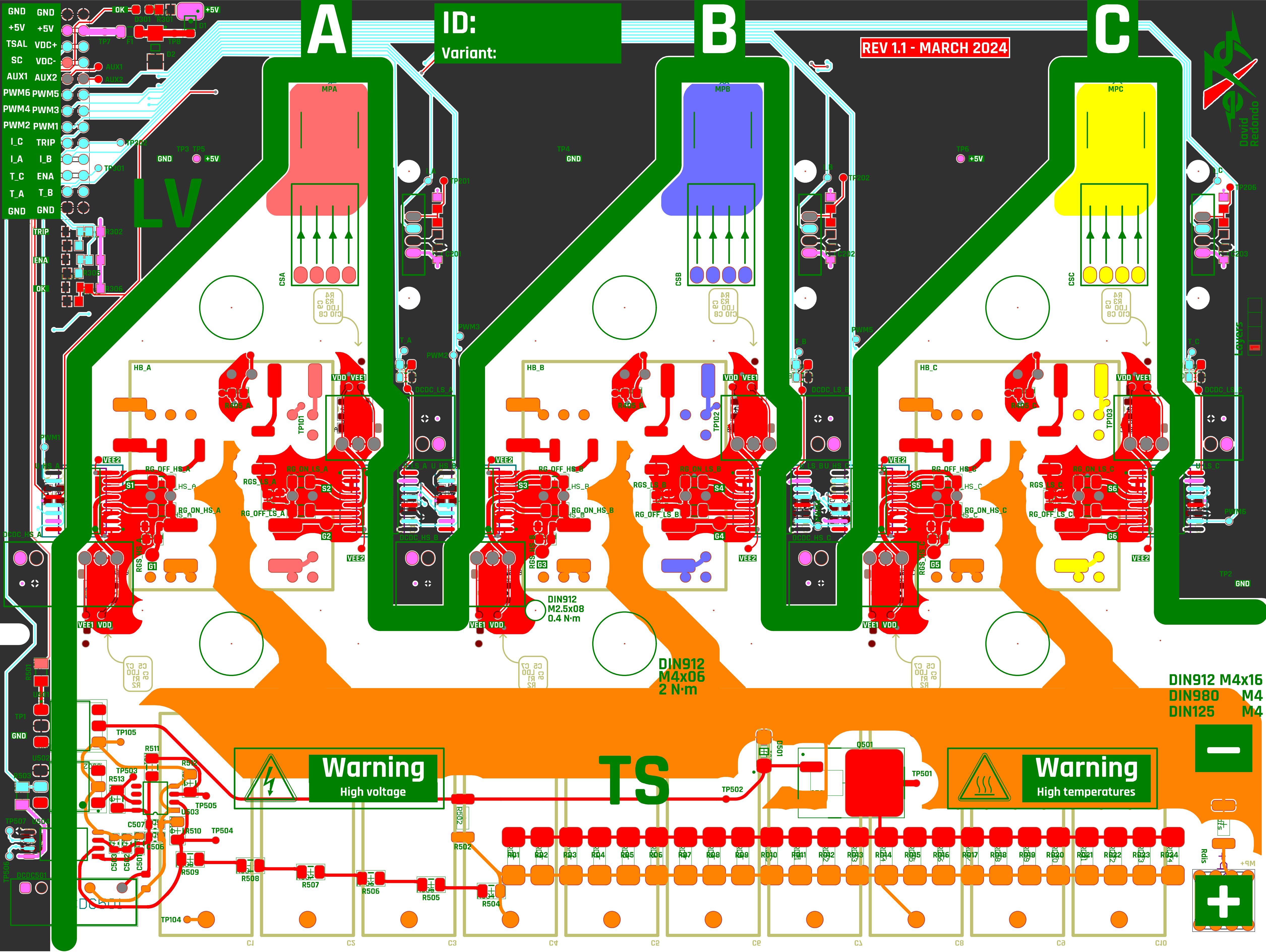
TS- → TS-

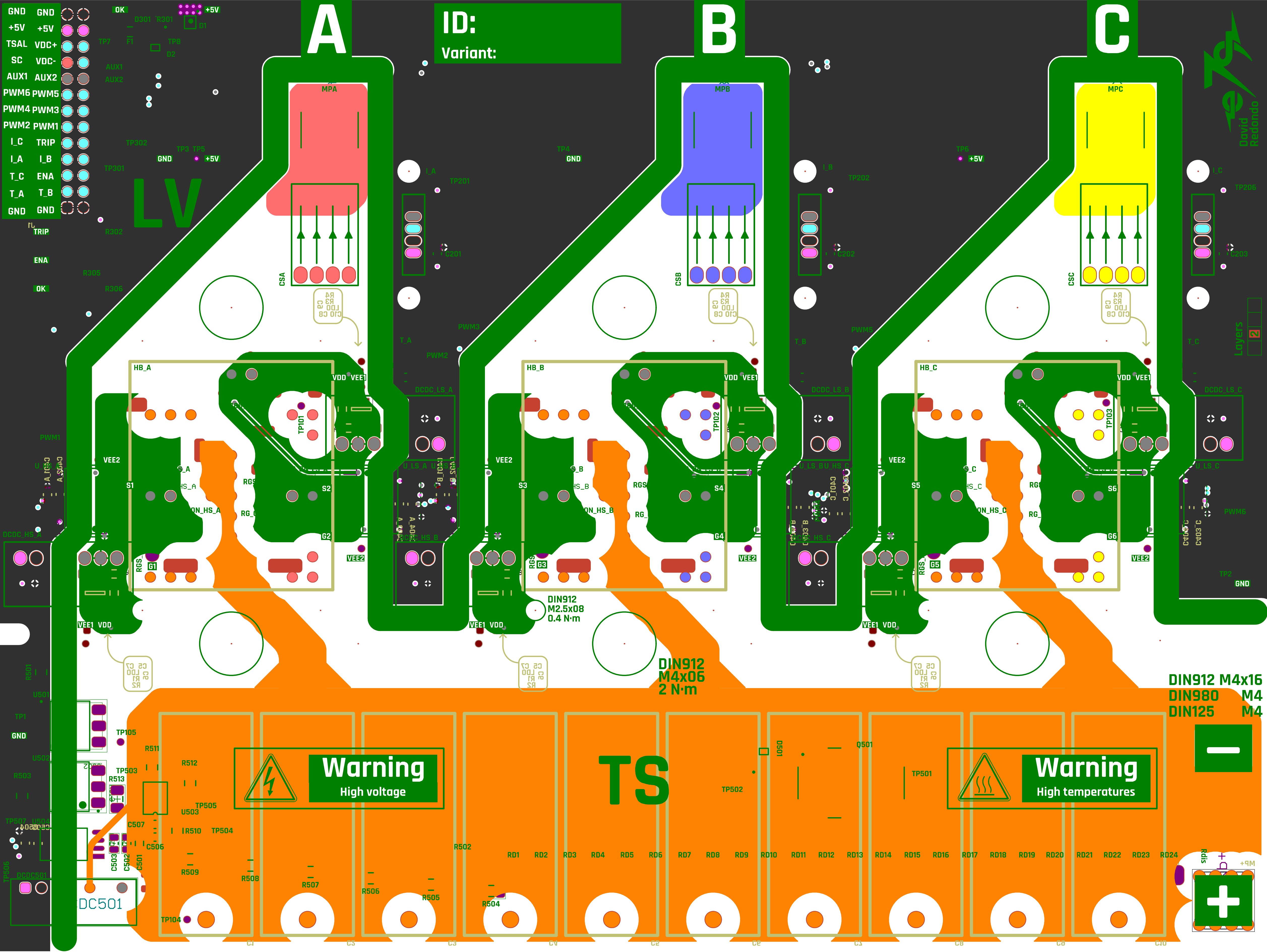
(TS+ - TS-) > 60V → TSAL_ON = 0V

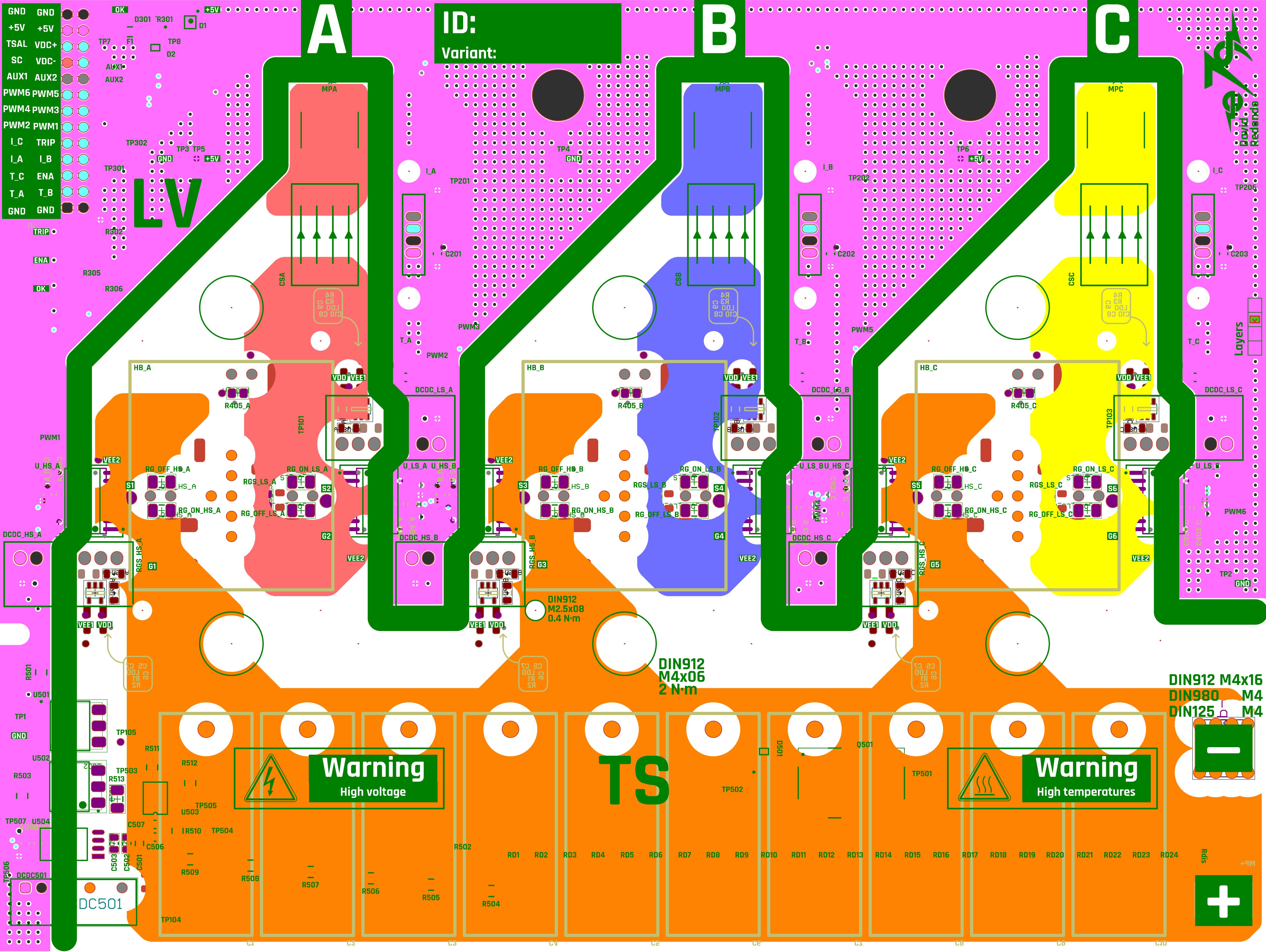
(TS+ - TS-) < 60V → TSAL_ON = 5V

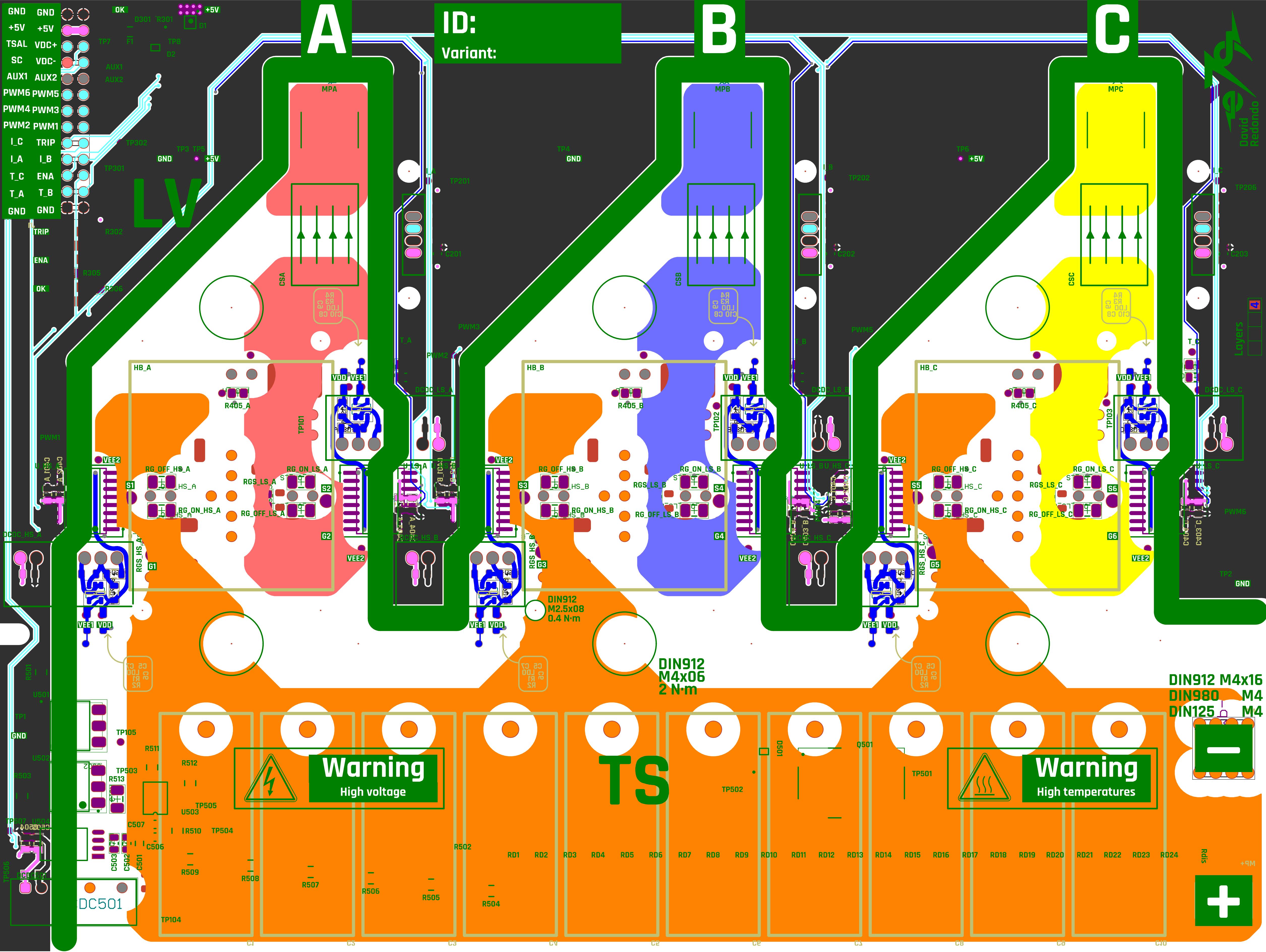


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Project:	Inverter Power	Variant: Wolfspeed	
Size:	Page Contents: [5]DC.SchDoc	Version: 1.1	
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Author:	David Redondo	dredondovinolo@gmail.com	Sheet * of *
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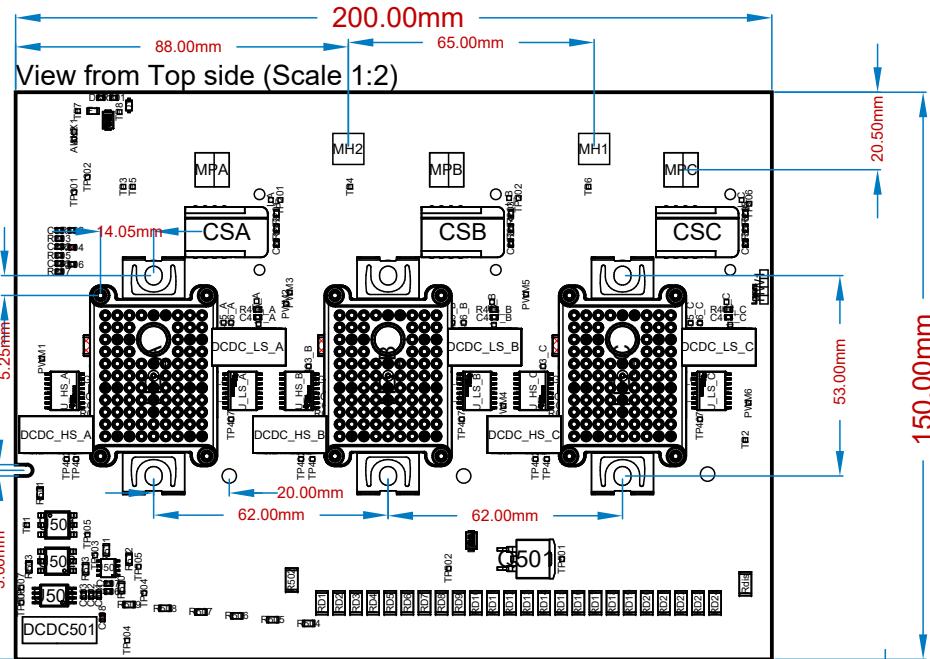




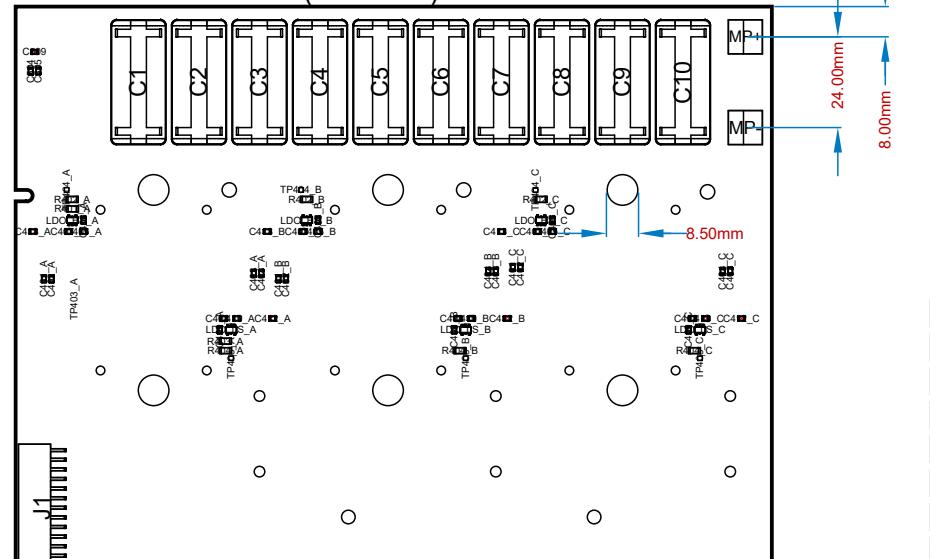




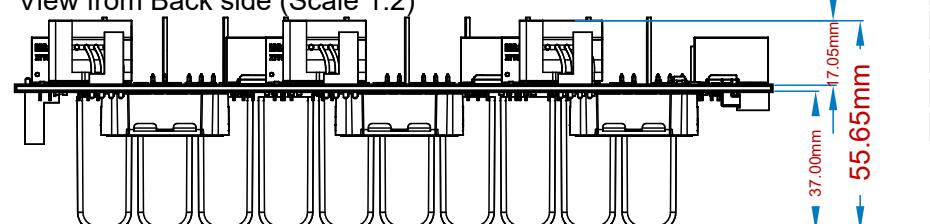
Inverter Power



View from Top side (Scale 1:2)



View from Bottom side (Scale 1:2)



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	Signal GTL
	Prepreg	0.10mm	PP-006		Dielectric
	Prepreg	0.10mm	PP-006		Dielectric
Copper	GND	0.07mm		Signal G1	Signal G1
	FR-4	0.90mm			Dielectric
Copper	PWR	0.07mm	PP-006		Signal G2
	Prepreg	0.10mm	PP-006		Dielectric
	Prepreg	0.10mm	PP-006		Dielectric
CF-004	BOT	0.07mm		Signal GBL	Solder Mask GBS
	Surface Material	0.01mm		Solder Resist	Legend GBO
	Bottom Overlay				

Total thickness: 1.60mm

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
F1	0437001WRA	1
DCDC501	1779205141	1
J1	613026243121	1
D2	BZG05C5V1-E3-TR	1
HB_A, HB_B, HB_C	CAB016M12FM3	3
R402_A, R402_B, R402_C, R404_A, R404_B, R404_C	CR1206-JV-303ELF	6
R401_A, R401_B, R401_C, R403_A, R403_B, R403_C	CR1206-JV-683ELF	6
R503	CROW120610K0FKEA	1
R511	CROW120630K0FKEA	1
HW1	LOGO CAPAS (4)	1
MP-, MP+, MPA, MPB, MPC	M4	5
DCDC_HS_A, DCDC_HS_B, DCDC_HS_C, DCDC_LS_A, DCDC_LS_B, DCDC_LS_C	MBR0530	1
MH1, MH2	MGJ6-series	6
RD1, RD2, RD3, RD4, RD5, RD6, RD7, RD8, RD9, RD10, RD11, RD12, RD13, RD14, RD15, RD16, RD17, RD18, RD19, RD20, RD21, RD22, RD23, RD24	Mounting Hole M4	24
R406_A, R406_B, R406_C	RCV2512470KFKEG	24
R301	CR0805-FX-1000ELF	3
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-JV-102ELF	1
R504, R505, R506, R507, R508, R509	CR0805-JV-103ELF	12
R501, R513	CR1206-FX-6802EAS	6
R510, R512	CR1206-FX-2201ELF	2
CSA, CSB, CSC	CRS1206-FX-4701ELF	2
U503	LEM CCSR 50-NP	3
C501	LM311DR2G	1
RG_OFF_HS_A, RG_OFF_HS_B, RG_OFF_HS_C, RG_OFF_LS_A, RG_OFF_LS_B, RG_OFF_LS_C, RG_ON_HS_A, RG_ON_HS_B, RG_ON_HS_C, RG_ON_LS_A, RG_ON_LS_B, RG_ON_LS_C	885012208058	1
U504	CRG1206F100R	12
LDO_HS_A, LDO_HS_B, LDO_HS_C, LDO_LS_A, LDO_LS_B, LDO_LS_C	ISO224	1
U_HS_A, U_HS_B, U_HS_C, U_LS_A, U_LS_B, U_LS_C	TPS72301	6
Q501	UCC21710	6
R502, Rds	SIH150N60E-GE3	1
U501, U502	R2M-2512FTK	2
D501	4N35	2
D301	BZG05C6V2-E3-TR	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	150080GS75000	1
C401_A, C401_B, C401_C, C403_A, C403_B, C403_C, C503, C505, C507	885012207098	15
	885012207103	9

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