REV_B: Changes -
1) Removed I2C tie to 3p3V supply. Placed on top levels.
2) Switched 2 pins on Current Sense Circuit as per D3 review.
3) Changed 10k resistor to 4.99k resistor on Current Sense Circuit as per D3 review.
4) Added 1k ohm pull down resistor to Motor Control Circuit as per D3 review.
5) Removed the Bulk Capacitors from this design. They are added to the top level.
6) Changed Current limit resistor to 6.81k

D3_MOTOR_DRIVE Schematic Path = /3P_MD_2		
TENNANT		
Title: Thunderbolt: D3 - COVER		
Size: C	Document Number: <Doc>	Rev: B
Date: Monday, July 08, 2013	Sheet 0 of 24	

REV_B: Changes -
1) Removed I2C tie to 3p3V supply. Placed on top levels.
2) Switched 2 pins on Current Sense Circuit as per D3 review.
3) Changed 10k resistor to 4.99k resistor on Current Sense Circuit as per D3 review.
4) Added 1k ohm pull down resistor to Motor Control Circuit as per D3 review.
5) Removed the Bulk Capacitors from this design. They are added to the top level.
6) Changed Current limit resistor to 6.81k

D3_MOTOR_DRIVE Schematic Path = /3P_MD_1		
TENNANT		
Title: Thunderbolt: D3 - COVER		
Size: C	Document Number: <Doc>	Rev: B
Date: Monday, July 08, 2013	Sheet 0 of 24	

Thunderbolt Board
3-Phase Gate Drive

NOTE: GROUND RETURN PATHS ON AVDD,GVDD,DVDD
ARE VERY IMPORTANT. SEE TI APP NOTE: SLVA552

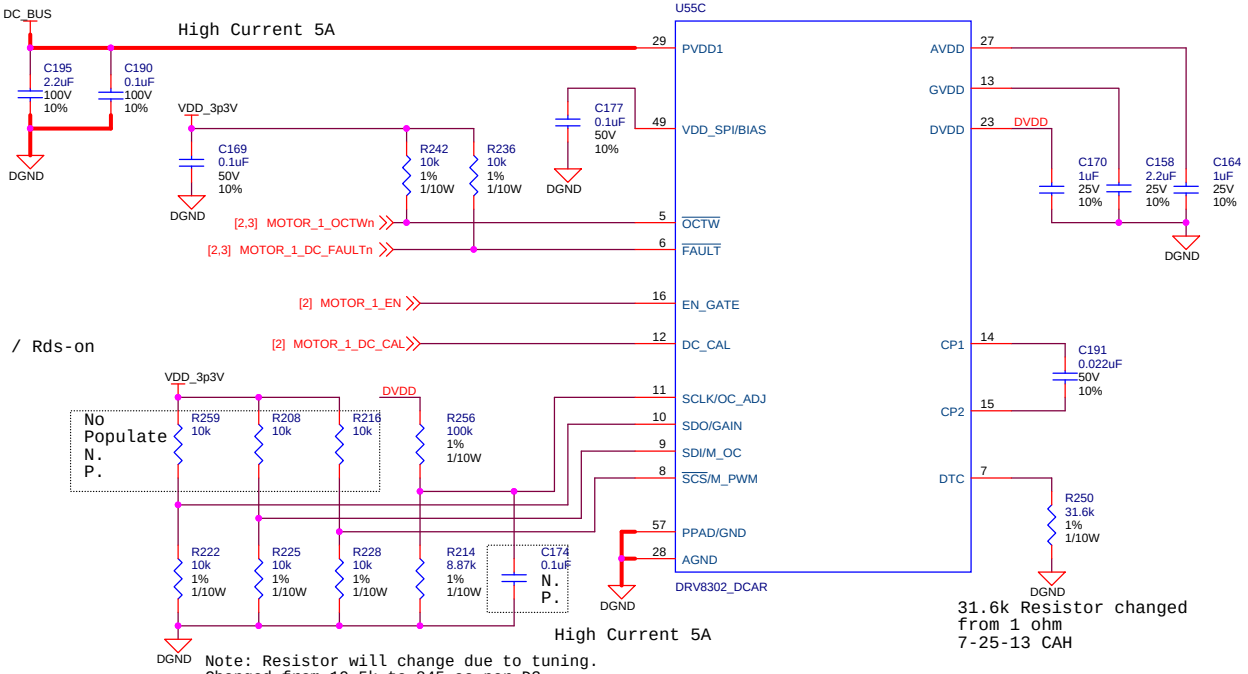
GAIN: (DIFF-AMP GAIN)
  LOW = 10V/V
  HIGH = 40V/V

M_OC: (OVER-CURRENT PROTECTION)
  LOW = CYCLE-BY-CYCLCE
  HIGH = LATCHED FAULT

M_PWM: (PWM MODE)
  LOW = 6 - INPUT
  HIGH = 3 - INPUT

DVDD = 3.3V

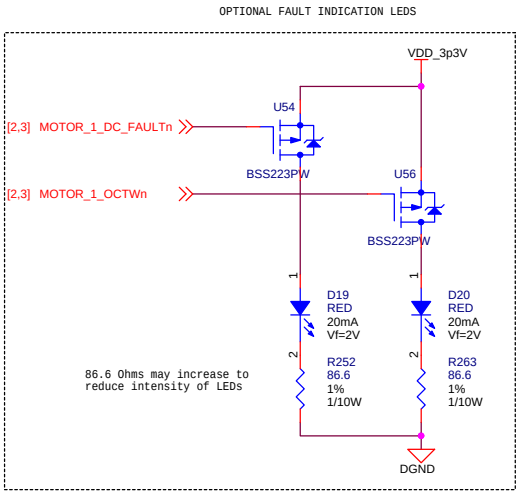
M_OC = (3.3V (19.6k / (100k+19.6k))) / Rds-on

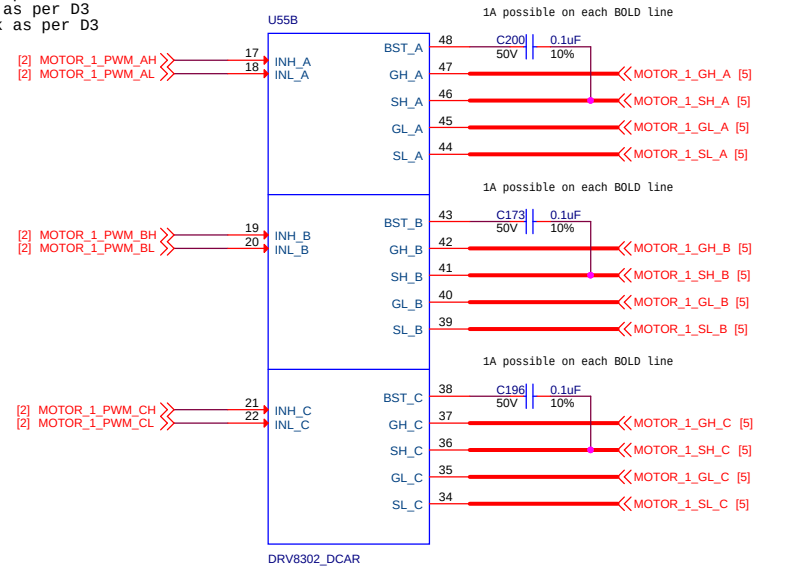


31.6k Resistor changed
from 1 ohm
7-25-13 CAH

High Current 5A

Note: Resistor will change due to tuning.
Changed from 19.5k to 845 as per D3
Changed from 845 to 3.5k as per D3
Changed from 3.5k to 6.81k as per D3
Changed from 6.81k to 8.87k as per D3





D3_MOTOR_DRIVE	Schematic Path = /3P_MD_2	
TENNANT		
Title	Thunderbolt: D3 - GATE DRIVE	
Size: Custom<Doc>	Document Number	Rev: B
Date: Wednesday, September 25, 2013	Sheet 0 of 24	

Thunderbolt Board
3-Phase Gate Drive

NOTE: GROUND RETURN PATHS ON AVDD,GVDD,DVDD
ARE VERY IMPORTANT. SEE TI APP NOTE: SLVA552

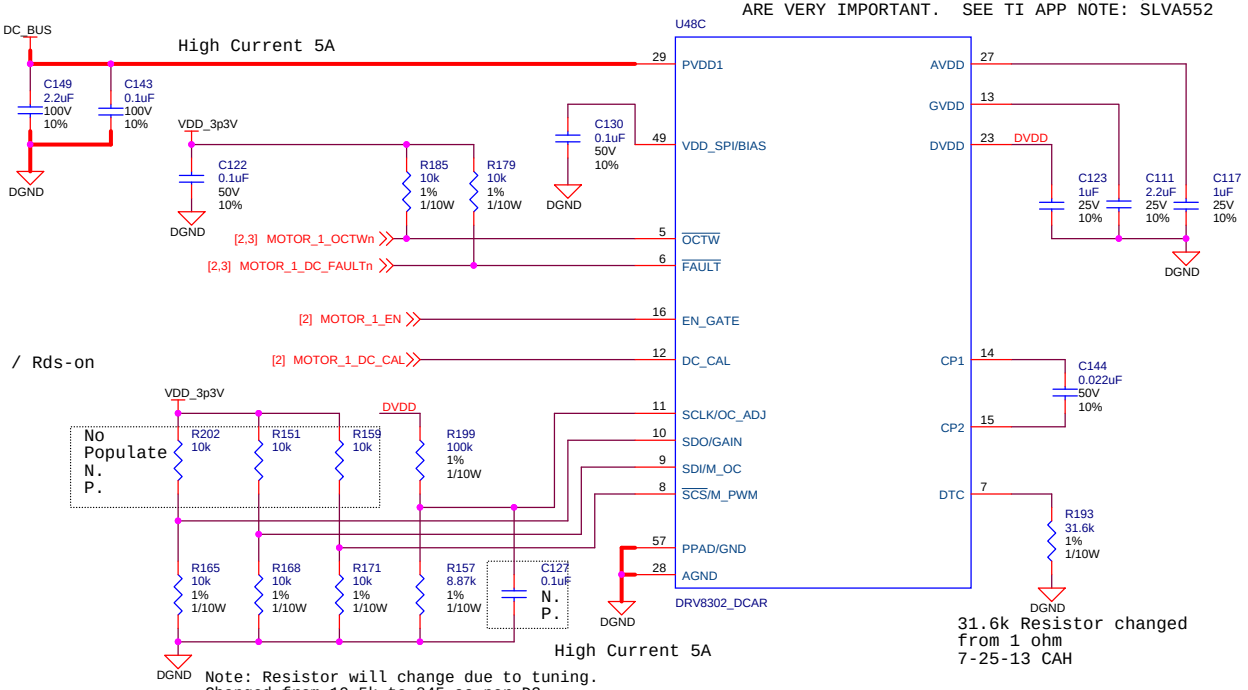
GAIN: (DIFF-AMP GAIN)
  LOW = 10V/V
  HIGH = 40V/V

M_OC: (OVER-CURRENT PROTECTION)
  LOW = CYCLE-BY-CYCLCE
  HIGH = LATCHED FAULT

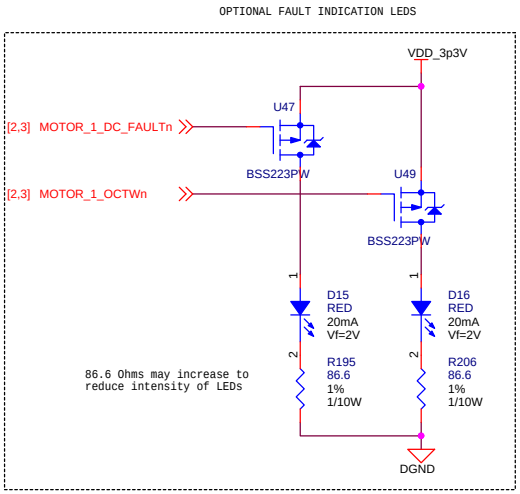
M_PWM: (PWM MODE)
  LOW = 6 - INPUT
  HIGH = 3 - INPUT

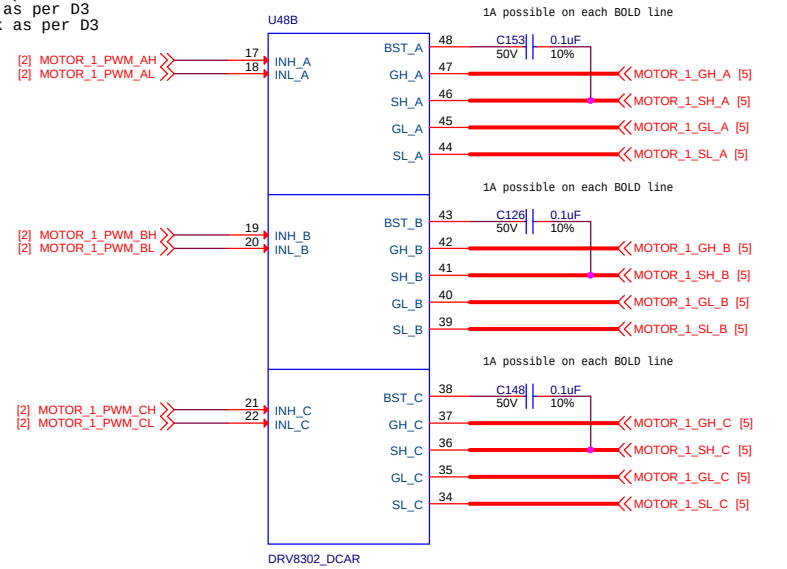
DVDD = 3.3V

M_OC = (3.3V (19.6k / (100k+19.6k))) / Rds-on



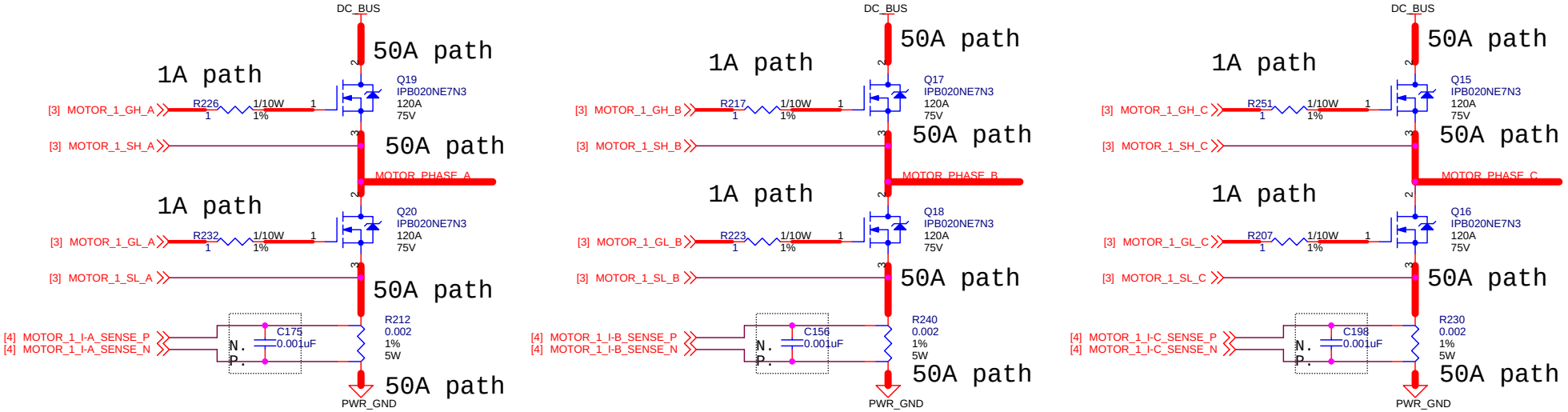
Note: Resistor will change due to tuning.
Changed from 19.5k to 845 as per D3
Changed from 845 to 3.5k as per D3
Changed from 3.5k to 6.81k as per D3
Changed from 6.81k to 8.87k as per D3



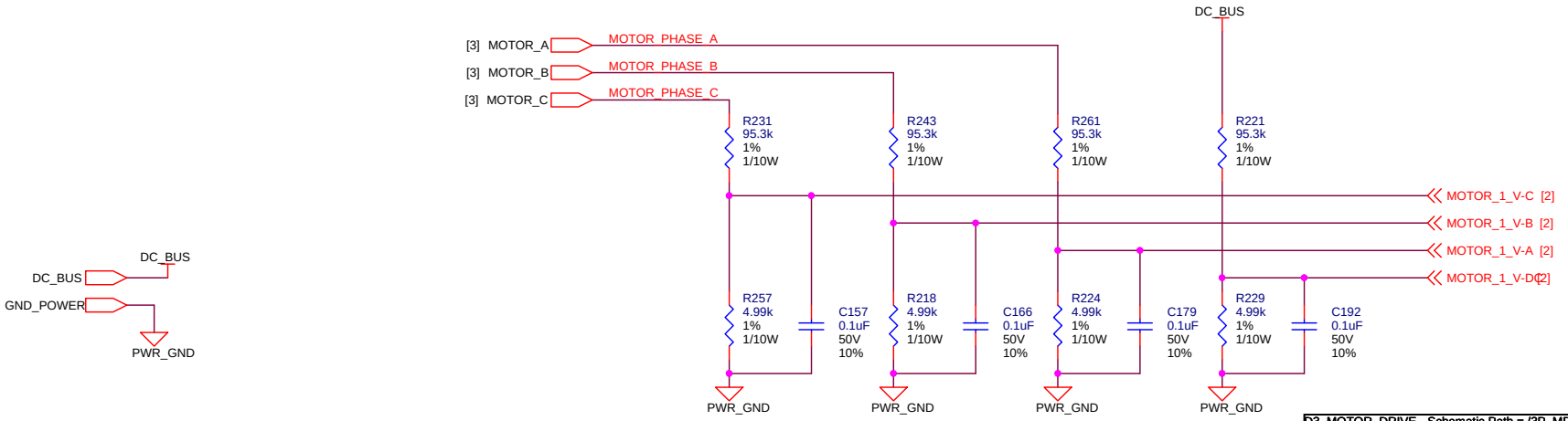


D3_MOTOR_DRIVE	Schematic Path = /3P_MD_1	
TENNANT		
Title	Thunderbolt: D3 - GATE DRIVE	
Size: Custom<Doc>	Document Number	Rev: B
Date: Wednesday, September 25, 2013	Sheet 0 of 24	

Thunderbolt Board
3-Phase Motor H-Bridge

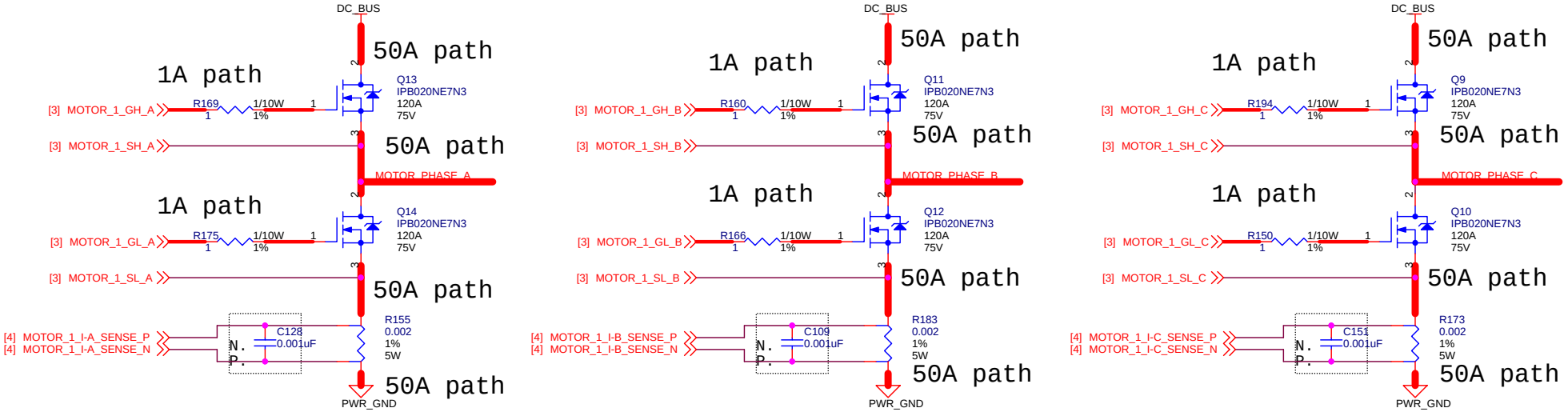


NOTE: KELVIN CONNECTIONS REQUIRED ON SENSE RESISTOR (3) PLCS

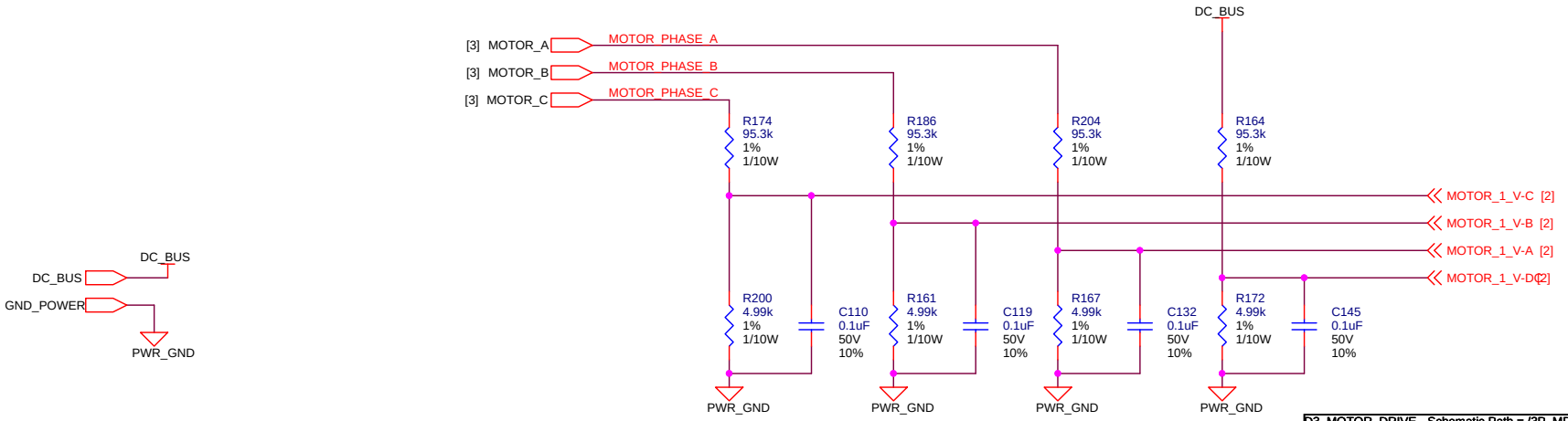


D3_MOTOR_DRIVE Schematic Path = /3P_MD_2		
TENNANT		
Title: Thunderbolt: D3 - MOTOR H-BRIDGE		
Size: Custom<Doc>	Document Number	Rev: B
Date: Friday, September 20, 2013	Sheet 0 of 24	

Thunderbolt Board
3-Phase Motor H-Bridge

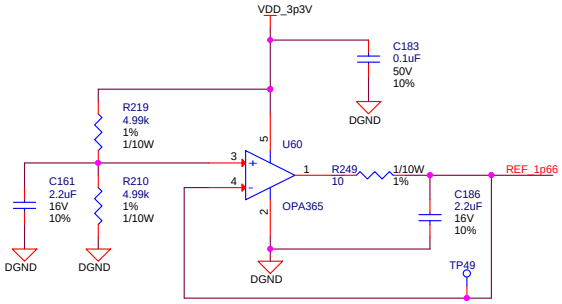


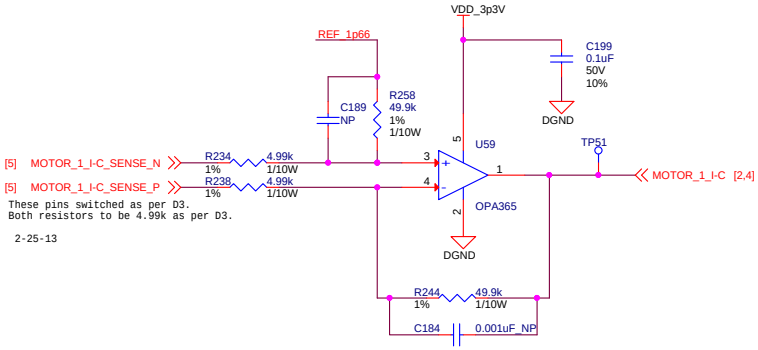
NOTE: KELVIN CONNECTIONS REQUIRED ON SENSE RESISTOR (3) PLCS



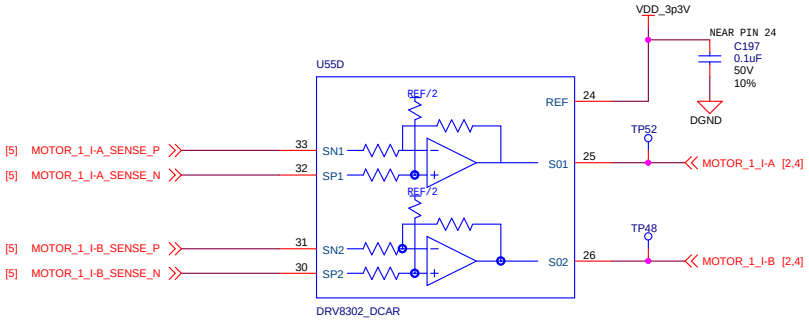
D3_MOTOR_DRIVE Schematic Path = /3P_MD_1		
TENNANT		
Title: Thunderbolt: D3 - MOTOR H-BRIDGE		
Size: Custom<Doc>	Document Number	Rev: B
Date: Friday, September 20, 2013	Sheet 0 of 24	

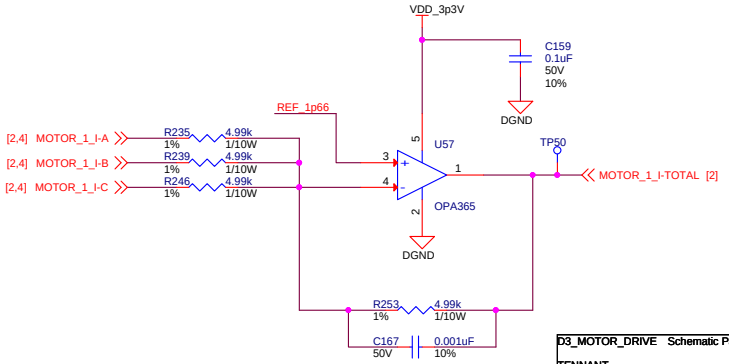
Thunderbolt Board
3-Phase Current Sense





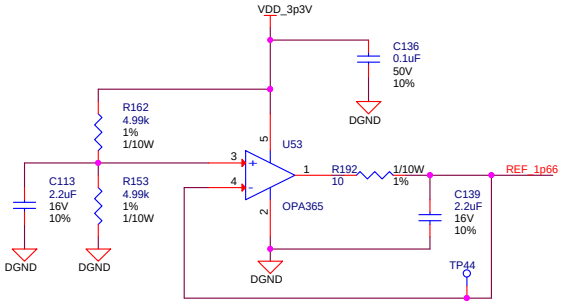
GAIN = 10 V/V

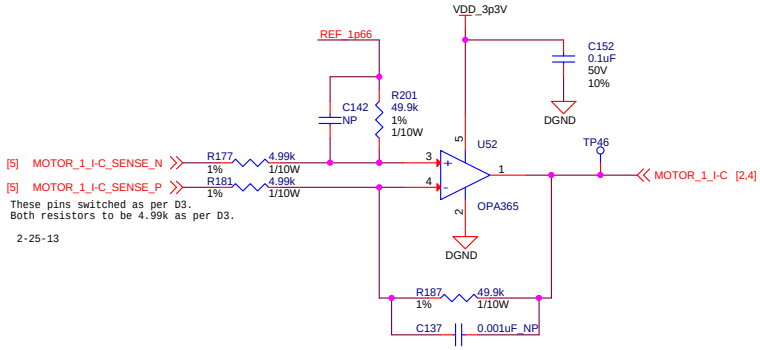




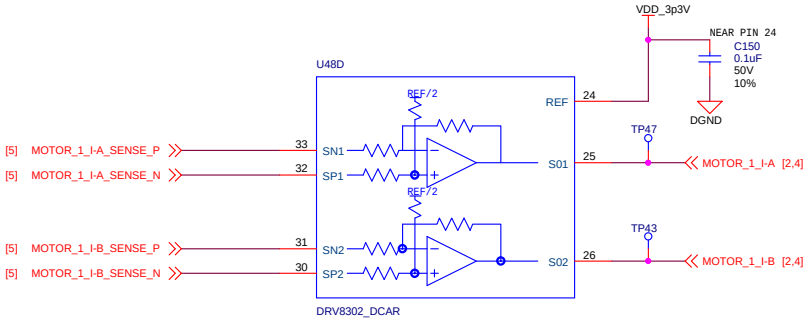
D3_MOTOR_DRIVE Schematic Path = /3P_MD_2		
TENNANT		
Title: Thunderbolt: D3 - CURRENT SENSE		
Size: Custom<Doc>	Document Number	Rev: B
Date: Friday, September 20, 2013	Sheet 0 of 24	

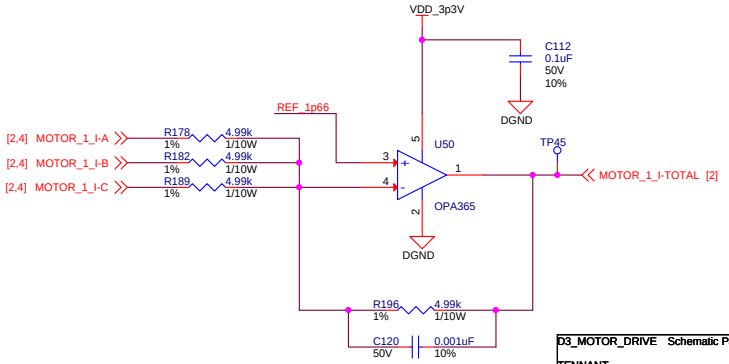
Thunderbolt Board
3-Phase Current Sense





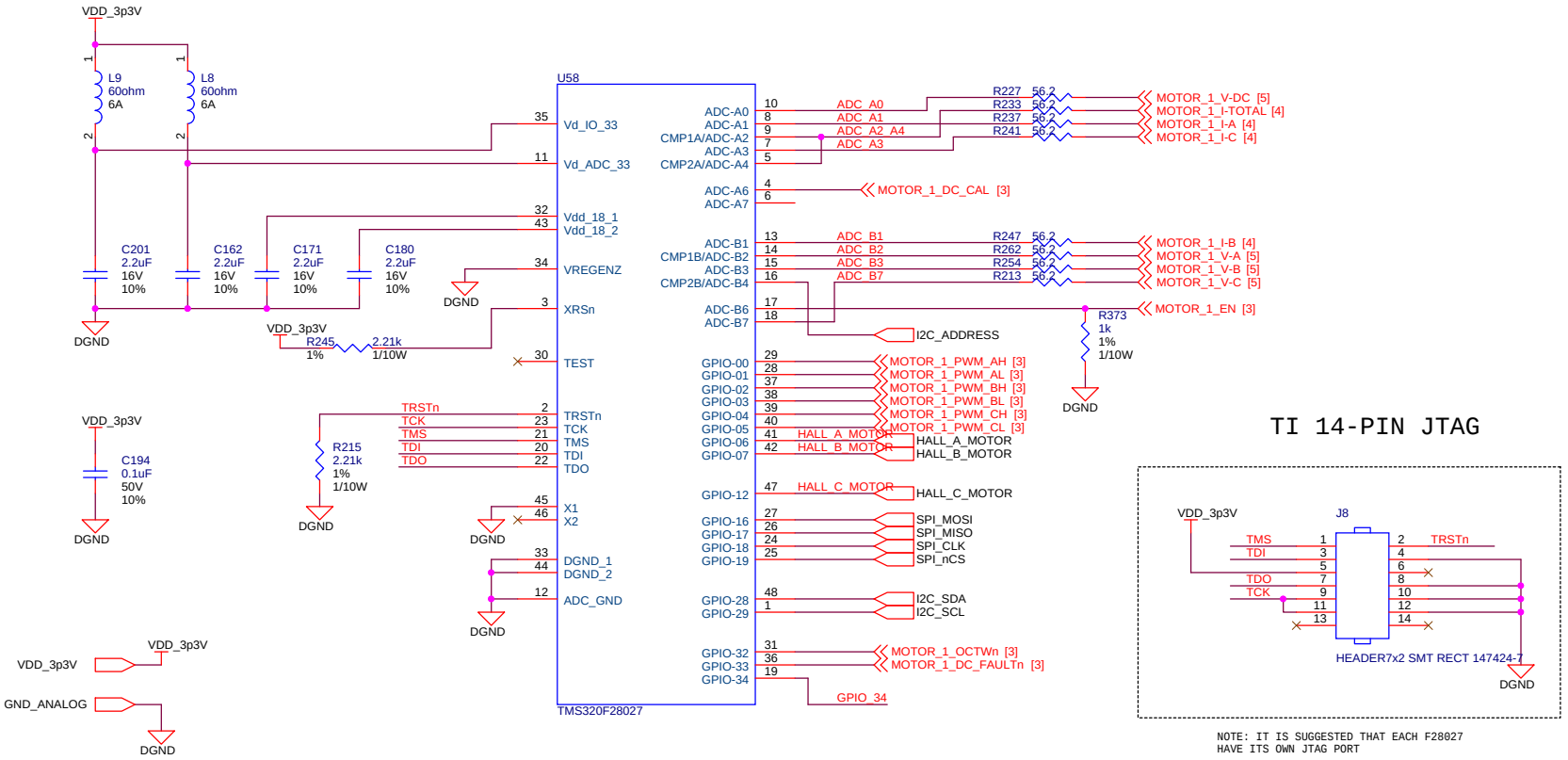
GAIN = 10 V/V





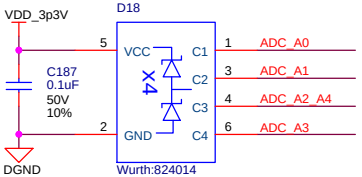
D3_MOTOR_DRIVE Schematic Path = /3P_MD_1		
TENNANT		
Title: Thunderbolt: D3 - CURRENT SENSE		
Size: Custom<Doc>	Document Number	Rev: B
Date: Friday, September 20, 2013	Sheet 0 of 24	

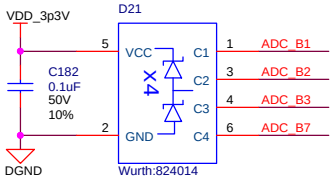
Thunderbolt Board
3-Phase Motor Control

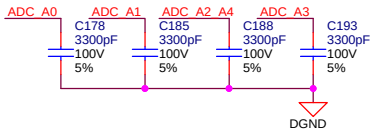


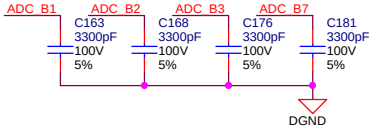
TI 14-PIN JTAG

NOTE: IT IS SUGGESTED THAT EACH F28027
HAVE ITS OWN JTAG PORT

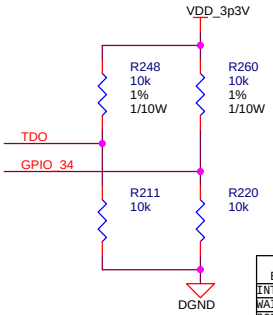








Boot-mode Selection



BOOTMODE	GPIO37/TDO	GPIO34
INT_FLASH	1	1
WAIT	1	0
SCI-A	0	1
PARALLEL IO	0	0

NOTE: WAIT STATE IS USED IF DEBUGGING WITH CODE SECURITY TURNED ON IS NEEDED

NOTE: JTAG WILL ASSERT TRSTn PIN TO ENTER EMU BOOT MODE (SEE PAGE 24 OF 28027 DATASHEET)

D3_MOTOR_DRIVE Schematic Path = /3P_MD_2

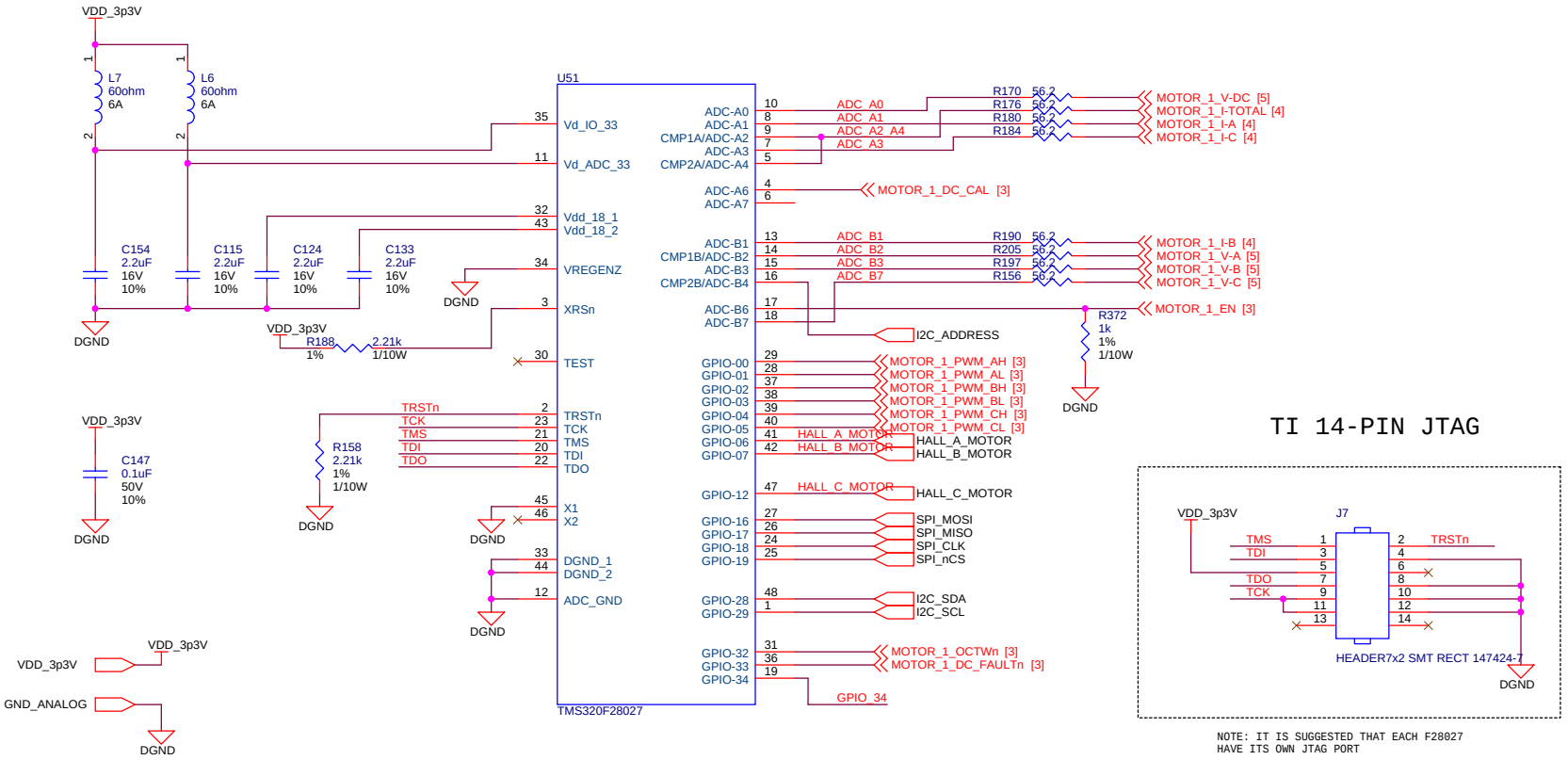
TENNANT

Title: Thunderbolt: D3 - MOTOR CONTROL DSP

Size: Custom | Document Number: <Doc> | Rev: B

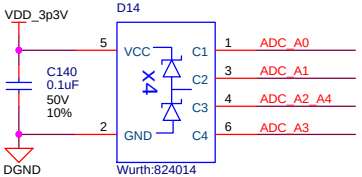
Date: Wednesday, September 25, 2013 | Sheet 0 of 24

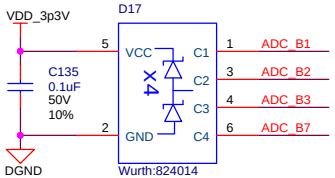
Thunderbolt Board
3-Phase Motor Control

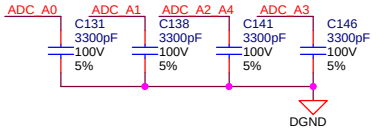


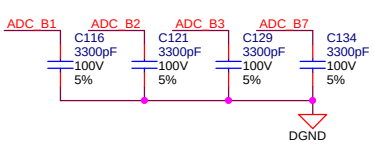
TI 14-PIN JTAG

NOTE: IT IS SUGGESTED THAT EACH F28027
HAVE ITS OWN JTAG PORT

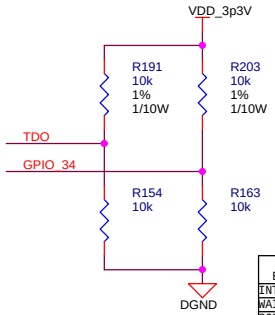








Boot-mode Selection



BOOTMODE	GPIO37/TDO	GPIO34
INT_FLASH	1	1
WAIT	1	0
SCI-A	0	1
PARALLEL IO	0	0

NOTE: WAIT STATE IS USED IF DEBUGGING WITH CODE SECURITY TURNED ON IS NEEDED

NOTE: JTAG WILL ASSERT TRSTn PIN TO ENTER EMU BOOT MODE (SEE PAGE 24 OF 28027 DATASHEET)

D3_MOTOR_DRIVE Schematic Path = /3P_MD_1

TENNANT

Title: Thunderbolt: D3 - MOTOR CONTROL DSP

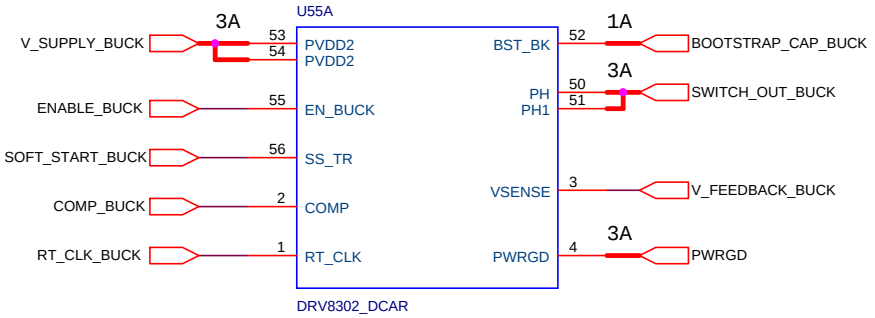
Size: Custom | Document Number: <Doc> | Rev: B

Date: Wednesday, September 25, 2013 | Sheet 0 of 24

Thunderbolt Board
3-Phase Motor OPTIONAL BUCK

12V Supply

Can Be turned off



NOTE: DRV8302 HAS THE SAME BUCK
CONVERTER AS THE TPS54160

INFO TAKEN FROM DATA SHEET

RT_CLK 1 I Resistor timing and external clock for buck regulator. Resistor should connect to GND (power pad) with very short trace to reduce the potential clock jitter due to noise.

COMP 2 O Buck error amplifier output and input to the output switch current comparator.

VSENSE 3 I Buck output voltage sense pin. Inverting node of error amplifier.

PWRGD 4 I An open drain output with external pull-up resistor required. Asserts low if buck output voltage is low due to thermal shutdown, dropout, over-voltage, or EN_BUCK shut down

BST_BK 52 P Bootstrap cap pin for buck converter

PVDD2 53,54 P Power supply pin for buck converter, PVDD2 cap should connect to GND.

EN_BUCK 55 I Enable buck converter. Internal pull-up current source. Pull below 1.2V to disable. Float to enable. Adjust the input undervoltage lockout with two resistors

SS_TR 56 I Buck soft-start and tracking. An external capacitor connected to this pin sets the output rise time. Since the voltage on this pin overrides the internal reference, it can be used for tracking and sequencing. Cap should connect to GND

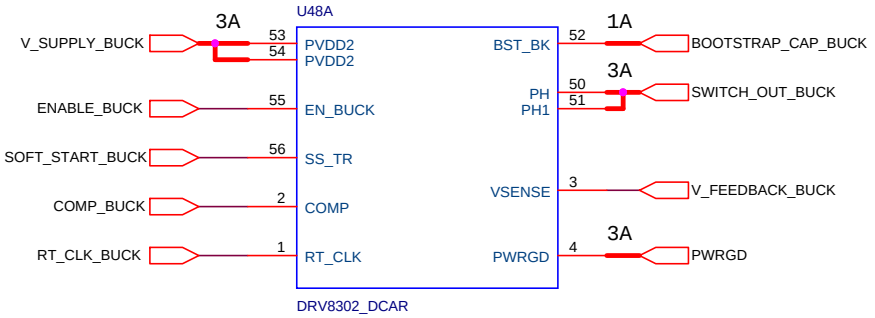
GND 57 P GND pin. The exposed power pad must be electrically connected to ground plane through soldering to (POWER PCB for proper operation and connected to bottom side of PCB through vias for better thermal PAD) spreading.

D3_MOTOR_DRIVE Schematic Path = /3P_MD_2		
TENNANT		
Title: Thunderbolt: D3 - POWER BUCK - OPTIONAL		
Size: Custom<Doc>	Document Number	Rev: B
Date: Monday, July 22, 2013	Sheet 0 of 24	

Thunderbolt Board
3-Phase Motor OPTIONAL BUCK

12V Supply

Can Be turned off



NOTE: DRV8302 HAS THE SAME BUCK
CONVERTER AS THE TPS54160

INFO TAKEN FROM DATA SHEET

RT_CLK 1 I Resistor timing and external clock for buck regulator. Resistor should connect to GND (power pad) with very short trace to reduce the potential clock jitter due to noise.

COMP 2 O Buck error amplifier output and input to the output switch current comparator.

VSENSE 3 I Buck output voltage sense pin. Inverting node of error amplifier.

PWRGD 4 I An open drain output with external pull-up resistor required. Asserts low if buck output voltage is low due to thermal shutdown, dropout, over-voltage, or EN_BUCK shut down

BST_BK 52 P Bootstrap cap pin for buck converter

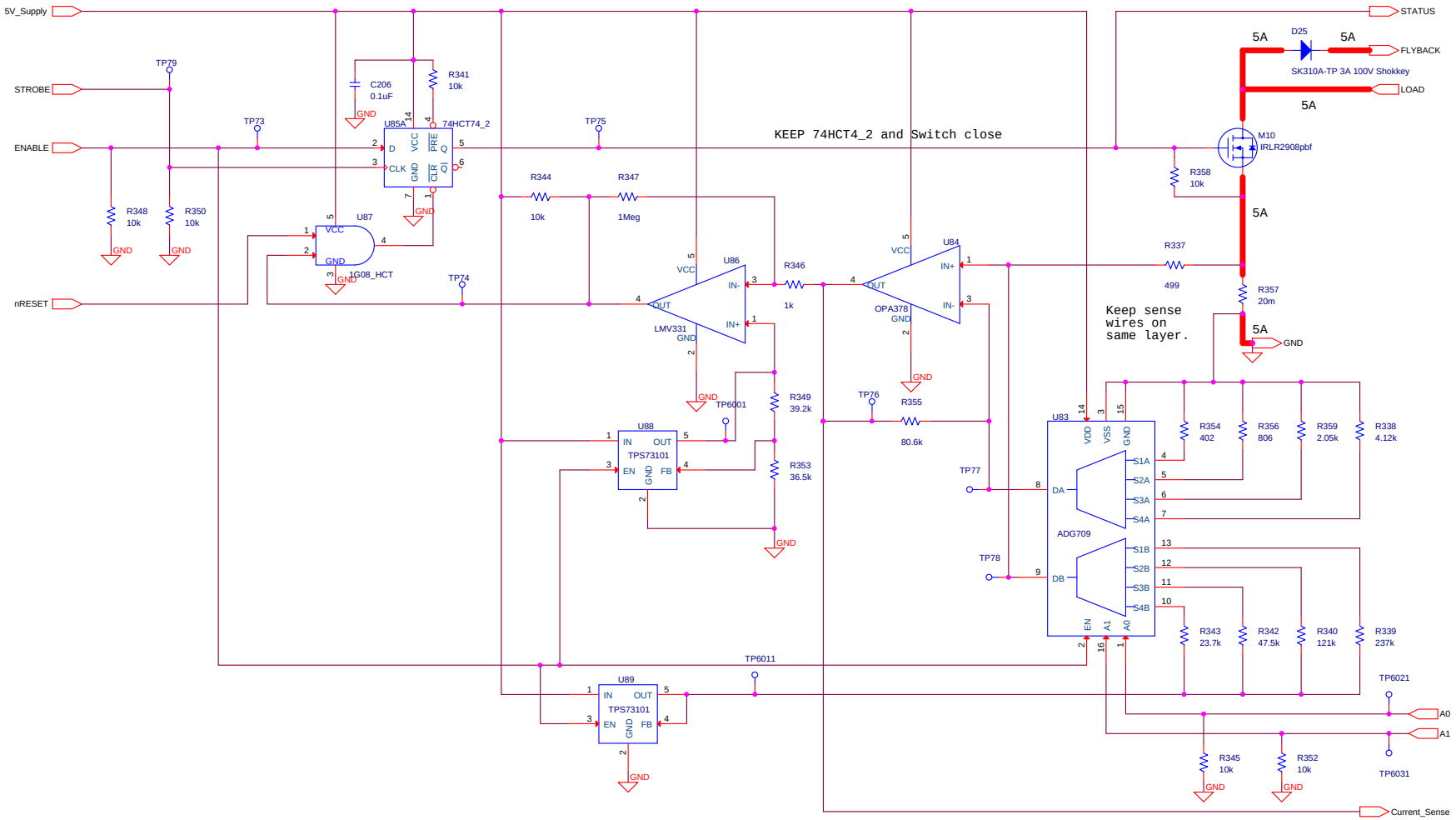
PVDD2 53,54 P Power supply pin for buck converter, PVDD2 cap should connect to GND.

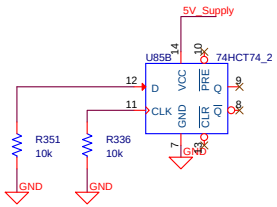
EN_BUCK 55 I Enable buck converter. Internal pull-up current source. Pull below 1.2V to disable. Float to enable. Adjust the input undervoltage lockout with two resistors

SS_TR 56 I Buck soft-start and tracking. An external capacitor connected to this pin sets the output rise time. Since the voltage on this pin overrides the internal reference, it can be used for tracking and sequencing. Cap should connect to GND

GND 57 P GND pin. The exposed power pad must be electrically connected to ground plane through soldering to (POWER PCB for proper operation and connected to bottom side of PCB through vias for better thermal PAD) spreading.

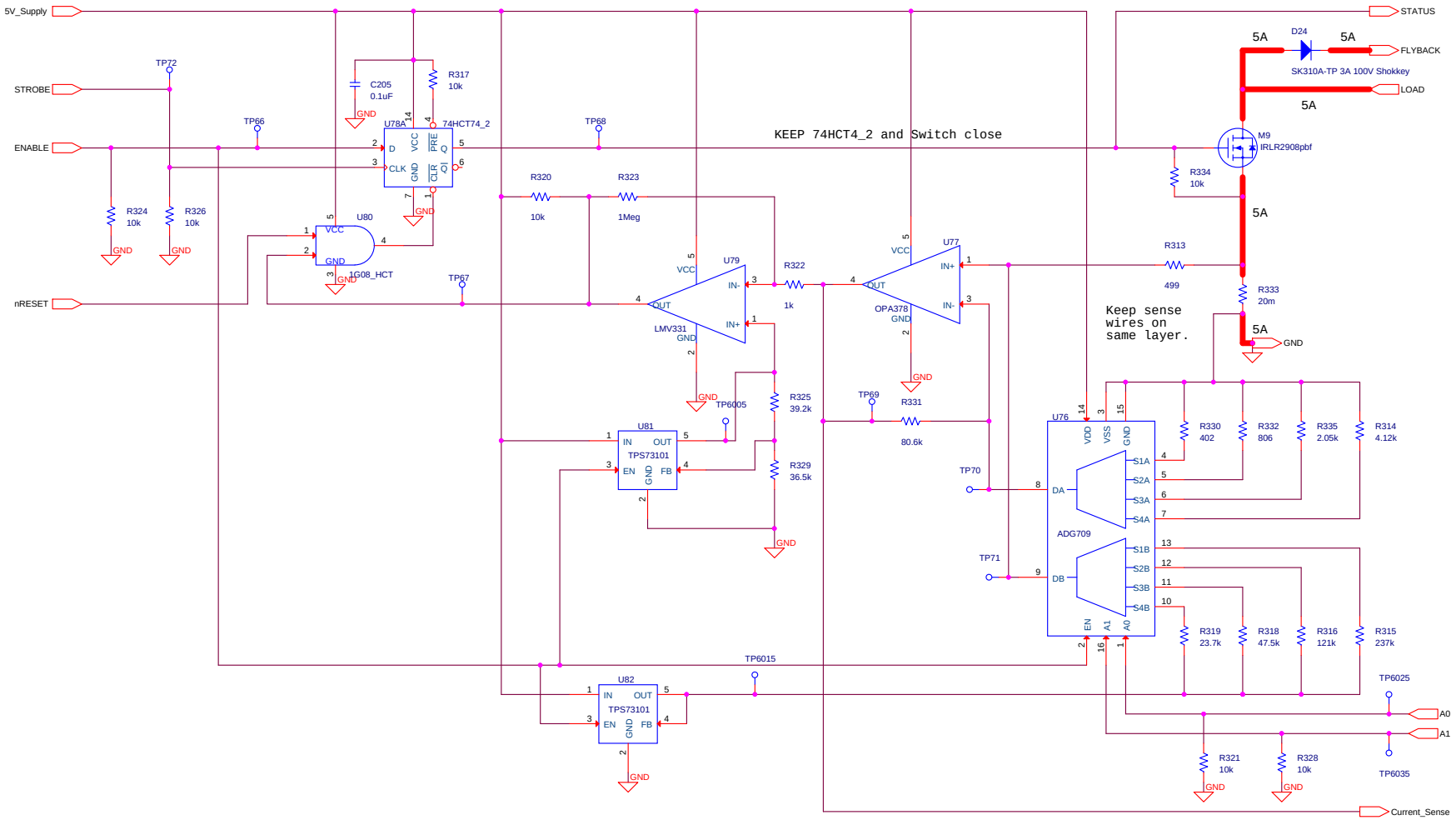
D3_MOTOR_DRIVE Schematic Path = /3P_MD_1		
TENNANT		
Title: Thunderbolt: D3 - POWER BUCK - OPTIONAL		
Size: Custom<Doc>	Document Number	Rev: B
Date: Monday, July 22, 2013	Sheet 0 of 24	



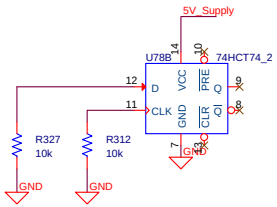


REV_B: Changes -
1) Changed Schottkey to 3A (80A non-repetitive peak) Diode

LSD	Schematic Path = /LSD0	
Low Side Driver Circuit		
<OrgAddr1>		
<OrgAddr2>		
<OrgAddr3>		
<OrgAddr4>		
Size: Custom	Document Number: Doc =	Rev: B
Date: Monday, September 23, 2013	Sheet 0 of 24	



REV_B: Changes -
1) Changed Schottkey to 3A (80A non-repetitive peak) Diode



LSD	Schematic Path = /LSD2	
Low Side Driver Circuit		
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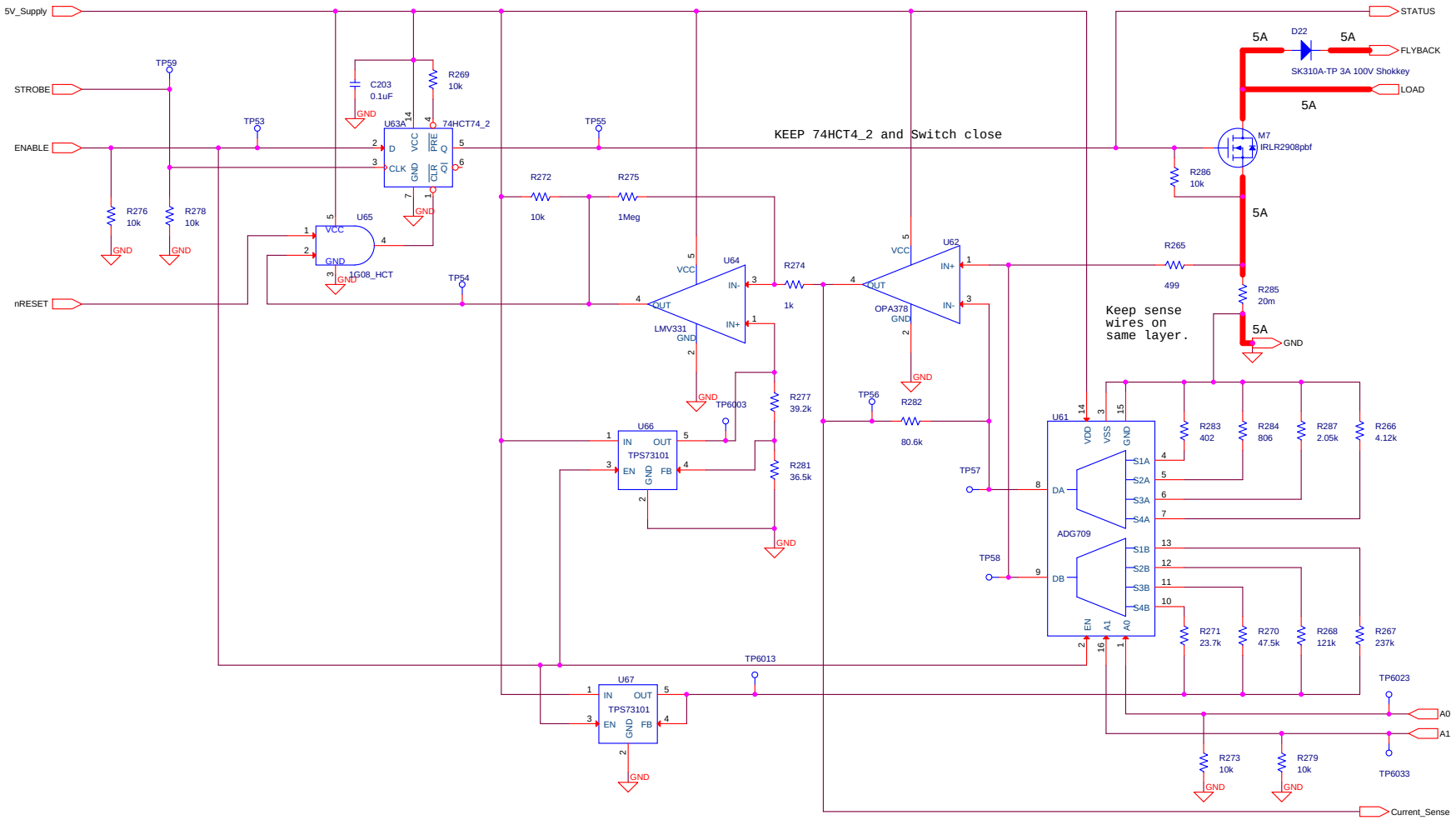
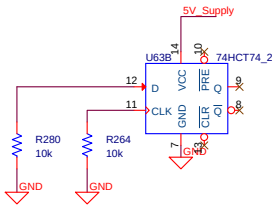
<OrgAddr2>		
<OrgAddr3>		
<OrgAddr4>		
Size: CustomDoc =	Document Number	Rev: B
Date: Monday, September 23, 2013	Sheet 0 of 24	



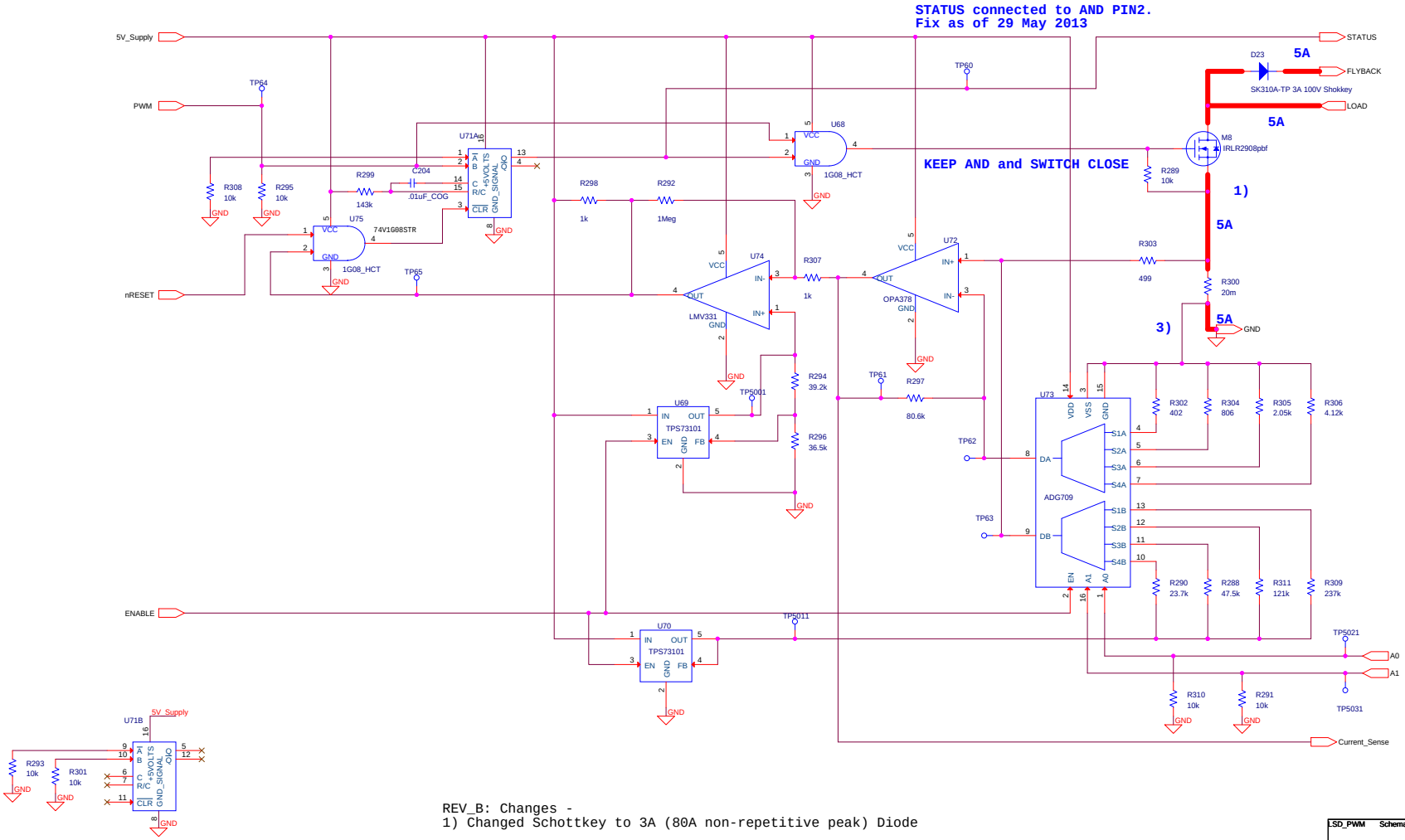


REV_B: Changes -
1) Changed Schottkey to 3A (80A non-repetitive peak) Diode

LSD	Schematic Path = /LSD1	
Low Side Driver Circuit		
<OrgAddr1>		
<OrgAddr2>		
<OrgAddr3>		
<OrgAddr4>		
Size: Custom	Document Number: Doc =	Rev: B
Date: Monday, September 23, 2013	Sheet 0 of 24	

LAYOUT NOTES

1) Cu 250mils wide. ~ 10A capability
2) All Resistors at 1% Except 1Meg and 10k ohm Resistors can be 5%
3) R5-R8 tied directly to R3 on TOP LEVEL before via to ground. USE MANY VIAS to ground out this node.

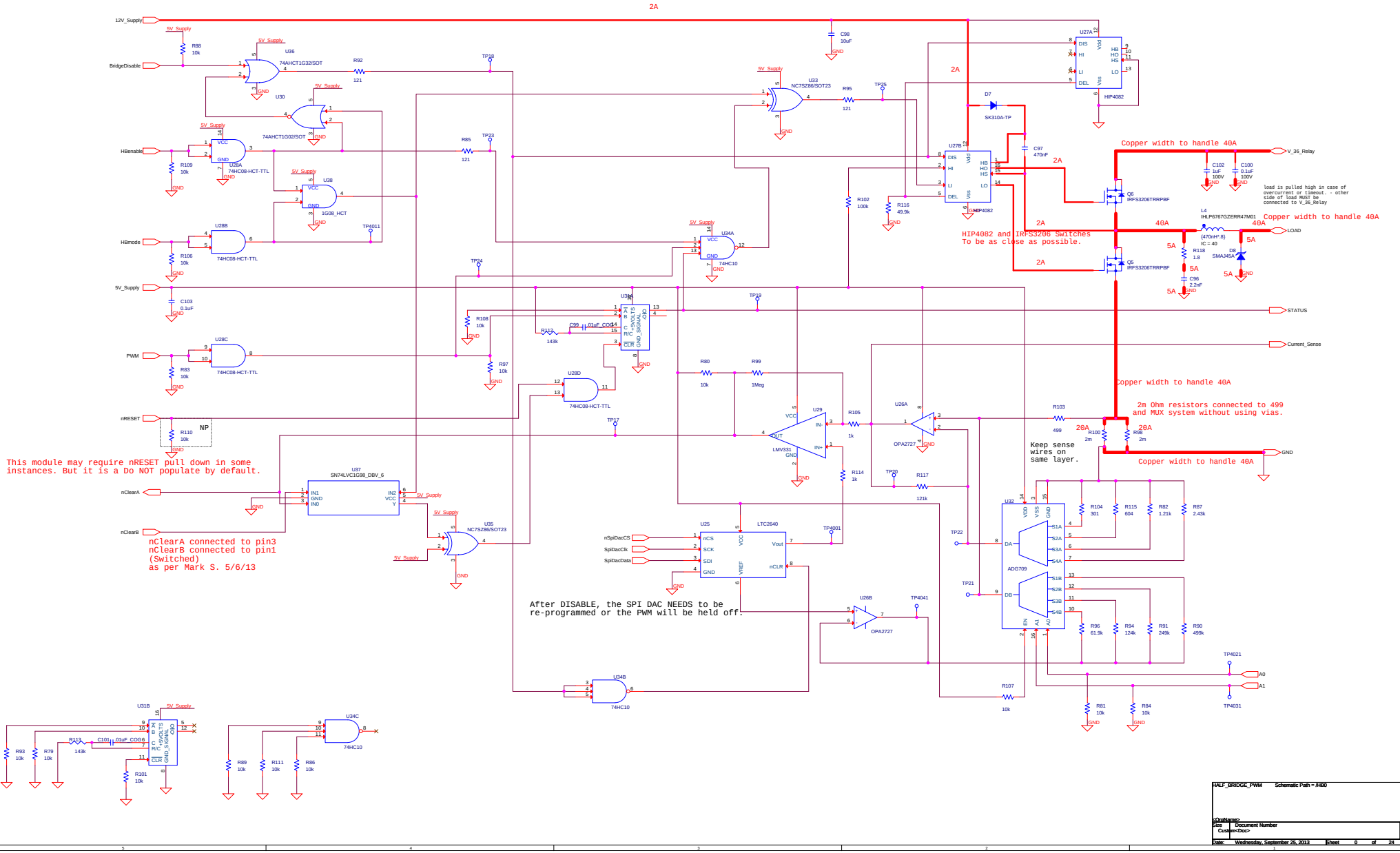


REV_B: Changes -
1) Changed Schottkey to 3A (80A non-repetitive peak) Diode

LSD_PWM	Schematic Path = /LSDP0	
Low Side Driver with PWM Circuit		
Size: Custom	Document Number: <Doc>	Rev: B
Date: Thursday, December 05, 2013	Sheet 0 of 24	

LAYOUT NOTES

1) Cu 250mils wide. ~ 10A capability. Need ~40A capability @ 1 oz Cu. May change for 2 oz Cu.
2) All Resistors at 1% Except 1Meg ohm Resistors can be 5% if no 1% available.
3) 2m Ohm resistors tied directly to 499 ohms on TOP LEVEL before via to ground. USE MANY VIAS to ground out this node.
4) To minimize ringing in the bootstrap circuit, keep the PCB traces from the HIP4082 to the external bootstrap capacitor and MOSFETs as short as possible. The bypass capacitor should be located as close as possible to the IC. Ceramic dielectric is the best choice for bypass and bootstrap capacitors.



LAYOUT NOTES

1) Cu 250mils wide. ~ 10A capability. Need ~40A capability @ 1 oz Cu. May change for 2 oz Cu.
2) All Resistors at 1% Except 1Meg ohm Resistors can be 5% if no 1% available.
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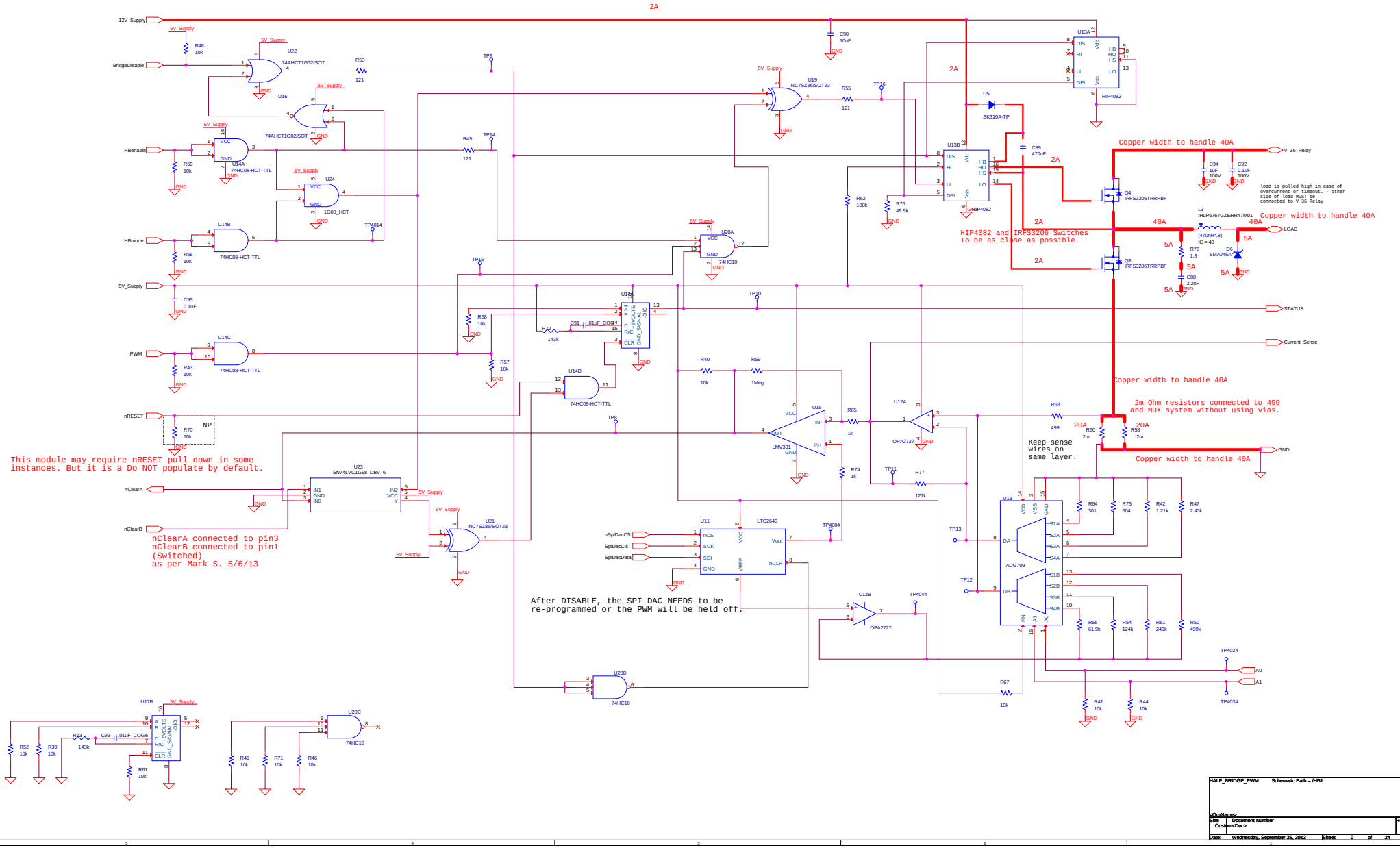
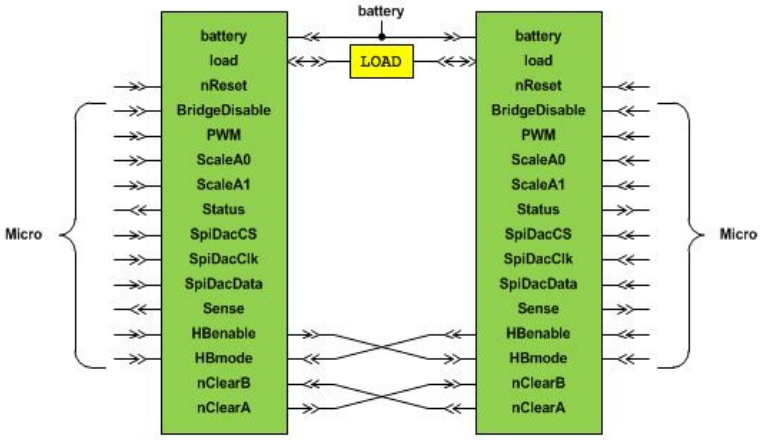
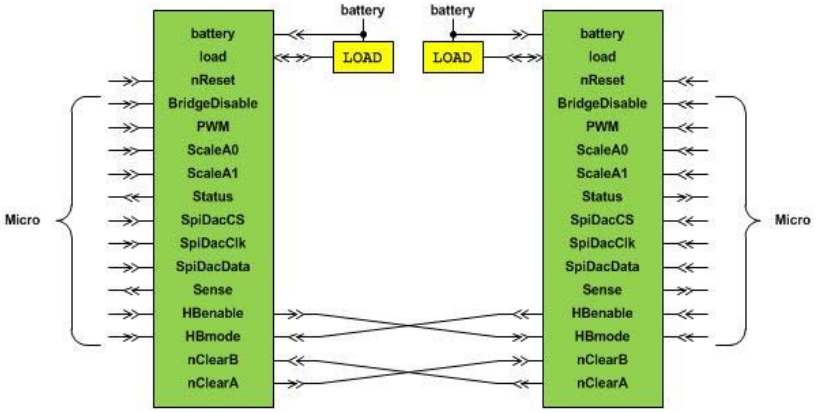


HALF_BRIDGE_PWM	Schematic Path = /HB1
<OrdName>	
Size: Custom	Document Number: <Doc>
Rev: ?	
Date: Wednesday, September 25, 2013	Sheet 0 of 24

APP NOTES

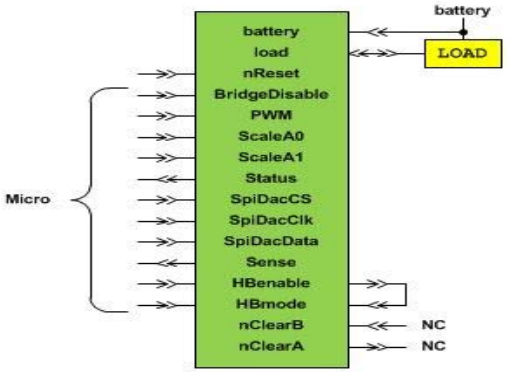


H-Bridge Application



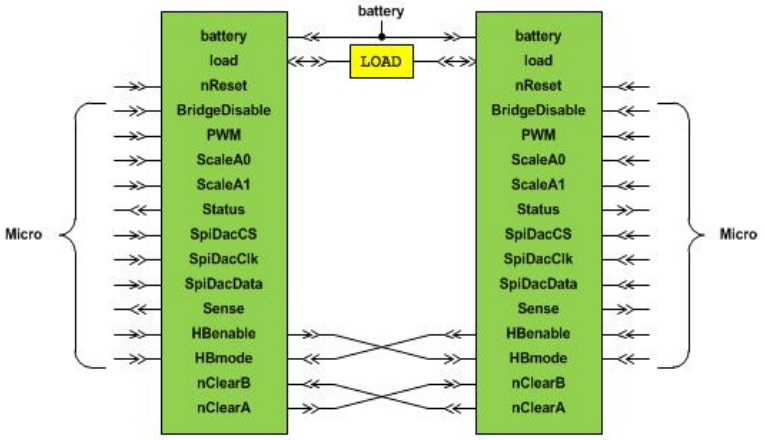
2 Half Bridge Application

Update: BridgeDisable Pull up to 5V
to solve Startup issues. 9-19-13

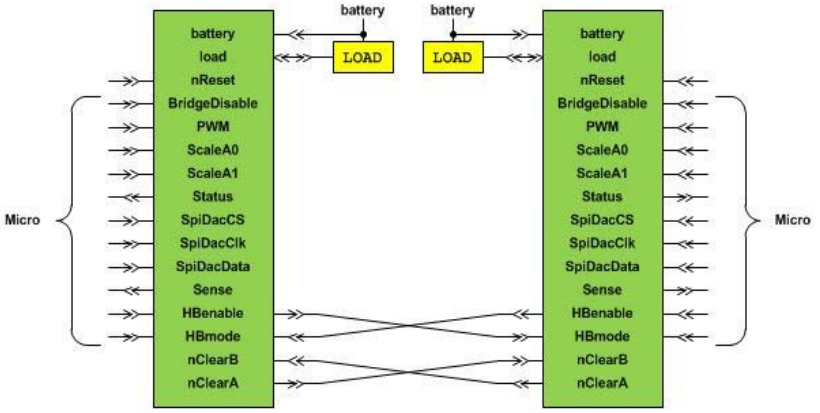


Half-Bridge Application

APP NOTES



H-Bridge Application



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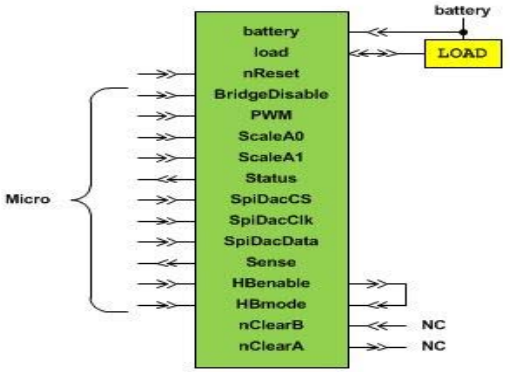

Half-Bridge Application

Rev B - Changes :
1) added 2 OR chips and 1 NOR chip for SPI chip select of the D3 Motor Drivers, added on the 2 - TOP LEVEL MAIN SCRUB SCHEMATIC
2) added Footprint for J9
3) changed 80A Reference to 100A Reference to 4 - POWER SUPPLIES SCHEMATIC

Rev C - Changes :
1) An issue was found with the off page reference connectors. They were all adjusted to fix this issue
2) Half Bridge Resistor and Capacitor changed for better thermal stability.
3) COIL GND PIN REMOVED.

Rev D - Changes :
1) Changed Diodes in Low Side Driver (LSD) circuits to make for better room and routing in layout.
2) Switched A and C on Motor 2 for 3 phase to help with Layout Placement.

Rev E - Changes :
1) Changed U90 Top level to U93 due to duplicate part number.
2) Corrected Footprints on J1,J4, U9, (U69/U70 from LSDP0)

Rev F - Changes :
1) JTAG for the 3 Phase Motor Circuit Female PCB connector is compatible with our current tools.

Rev G - Changes :
1) SPI pull up resistors changed from 10k to 1k. SPI connections on 3-Phase TX/RX switched. Changed Capacitors for BUS to 820uF through hole parts.
2) Added 4th pin for N-Channel devices for layout help in HB.

Rev H - Changes to facilitate layout.
1) Buck circuit components switched on 3- Drivers D3 and Tennant. This will help with where components are placed.

Rev J - Changes :
1) Changed a few of Micro pins.
2) Added I2C and pull up resistors to Micro and D3 Motors

Rev K - Changes :
1) A few of the QPLnumbers/footprints were wrong. Fixed.
2) 2 pins switched on micro.
3) Precharge has been modified to allow Curtis to control the Relay.

Rev L - Changes :
1) Fixed a mis-wired circuit in precharge.

Rev M - Changes :
1) De-pop'd pre-charge

Rev N - Changes :
1) Fixed power supply diode, D3, sheet 3

TENNANT		
Title: Thunderbolt: Main Scrub Board		
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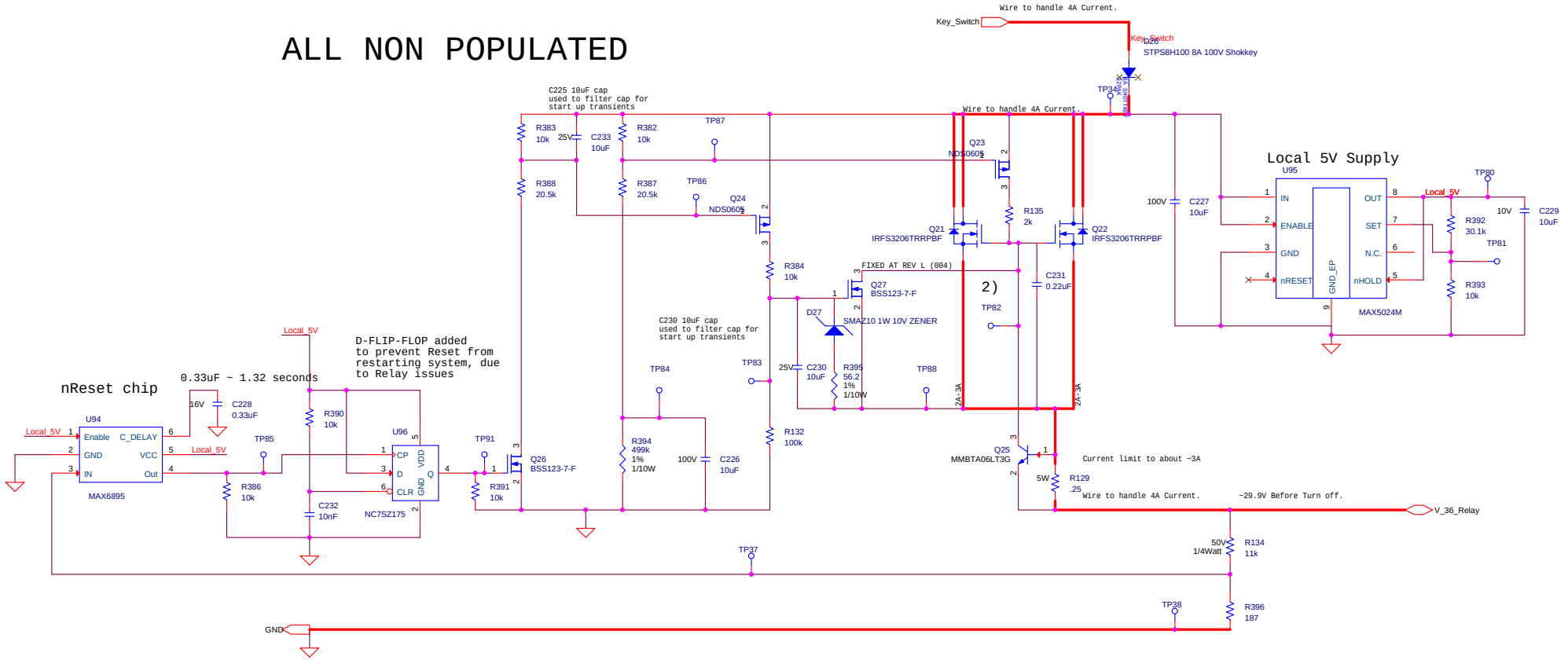
ALL NON POPULATED



PRECHARGE	Schematic Path = /PRECHARGE1	
Size: Custom<Doc>	Document Number	Rev: ?
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Thunderbolt Board
MAIN SCRUB

12V Going out the CAN J1-4 powers the User Interface Module

CAN COMMUNICATIONS

RS-232 SERIAL PORT

JTAG

PLACE HOLDER
for Accelerometer

FLASH

Decoupling Capacitors for the Micro.

Keep FB1 close
to VDDA PIN

Keep FB2 close
to GNDA PIN

YELLOW LED
CAN

GREEN LED
HEARTBEAT

Keep C224 and R381 close to U7
R381 and C224
ADDED 07/03/13 CAH

CONNECTION ERROR
SWITCHED.

SPOT_TOP_SWITCH_IN is the
LONG DURATION SPOT SCRUB

SPOT_BOTTOM_SWITCH_IN is the
SHORT DURATION SPOT SCRUB

CHECK Base Emitter
PADS on Q1 and Q2

P_SW1 & P_SW2
Poly switches.

1-794105-0 (4.28mm Pitch fit)
18 pin AMP
13A per Connector

TENNANT

Title
Thunderbolt: Main Scrub Board

Size	Document Number	Rev
Custom<Doc>		N

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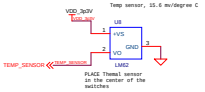
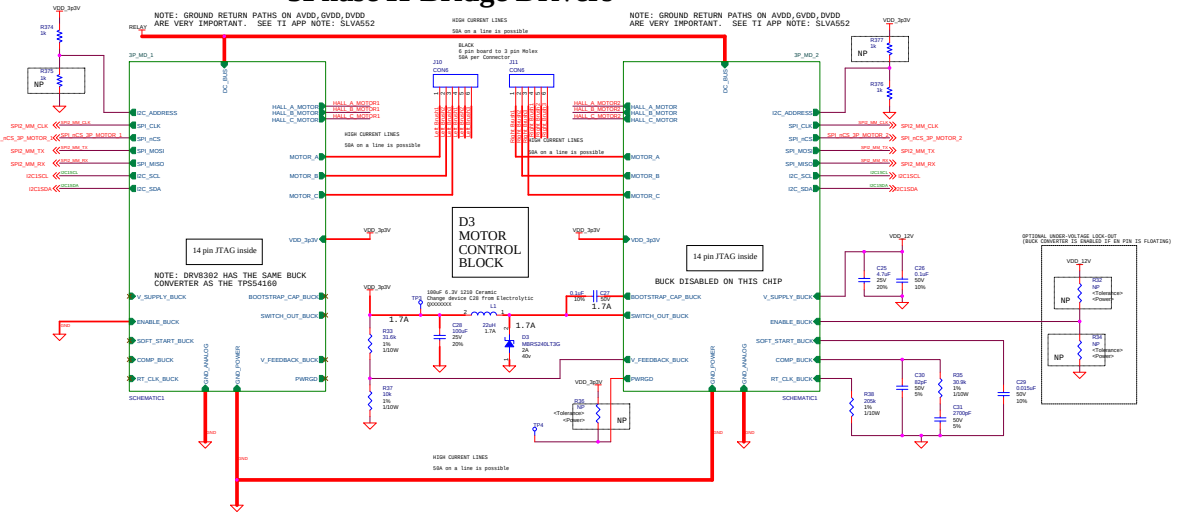
Thunderbolt Board
MAIN SCRUB: DRIVERS AND SWITCHES

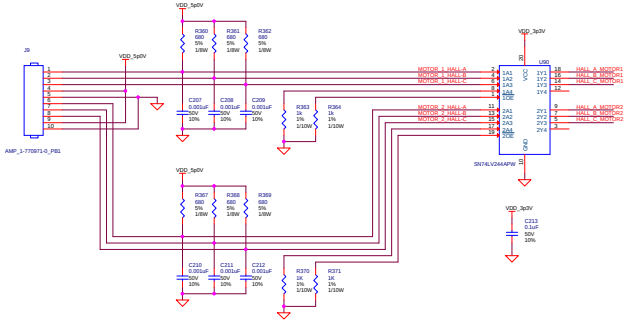
Low Side Drivers

H-Bridge Drivers



3Phase H-Bridge Drivers

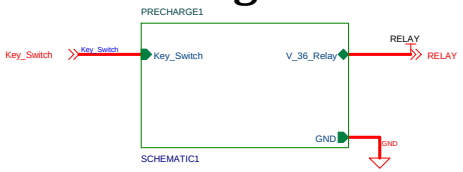


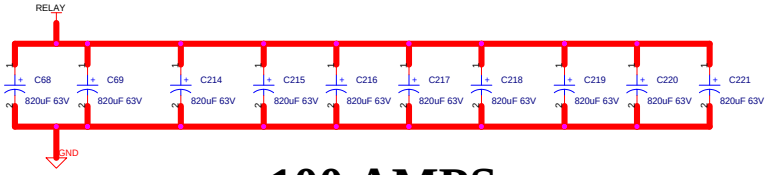


ENNANT			
File: Thunderbolt: Main Scrub Board - Drivers			
Size:	Document Number:		Rev: N
Custom	Doc<		
Date: Tuesday, April 01, 2014	Sheet 3 of 16		

Thunderbolt Board
MAIN SCRUB: SUPPLIES

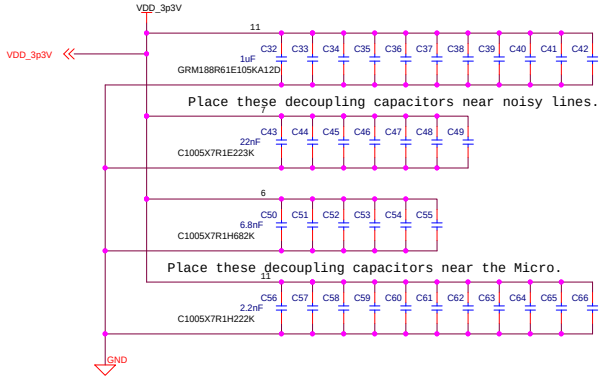
PreCharge Circuit



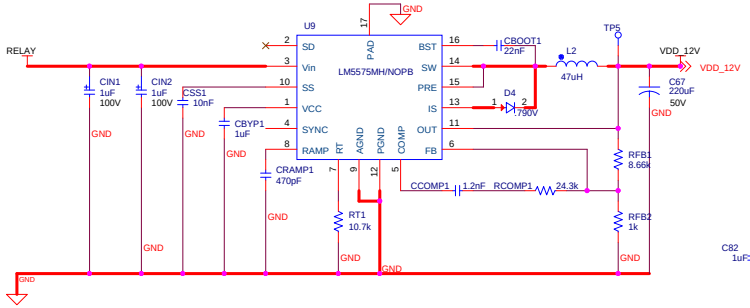


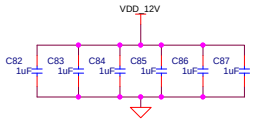
~100 AMPS

3.3V



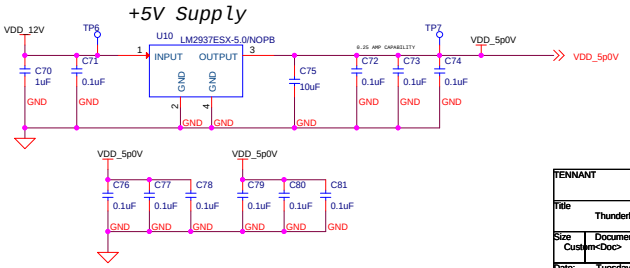
12V





5V

NOTE: 5V RAIL NOT NEEDED BY MOTOR CONTORLLER



TENNANT		
Title: Thunderbolt: Main Scrub Board - Drivers		
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Hall Sensors Removed and placed on the Top Level Schematic due to the fact that we have part of the design needing 2 and part needing 1.

D3_MOTOR_DRIVE Schematic Path = /3P_MD_2		
TENNANT		
Title: Thunderbolt: D3 - Hall Sensors		
Size: C	Document Number: <Doc>	Rev: B
Date: Monday, March 25, 2013	Sheet 6 of 7	

Hall Sensors Removed and placed on the Top Level Schematic due to the fact that we have part of the design needing 2 and part needing 1.

D3_MOTOR_DRIVE Schematic Path = /3P_MD_1		
TENNANT		
Title: Thunderbolt: D3 - Hall Sensors		
Size: C	Document Number: <Doc>	Rev: B
Date: Monday, March 25, 2013	Sheet 6 of 7	