Freedom-KL25Z Shield v14 Hardware Manual

Contents

Summary Information

Analog Discovery 2 Connections

Direct Digital I/O Signal Connections

AD2 Signal	Group	Shield Signal	Driving Peripheral	Port Bit	Other Use	Alternate Functions (See Pin Mux in Datasheet)
DIO0	General debug signals	DBG_0	GPIO	PTD0		SPI0_PCS0, TPM0_CH0
DIO1		DBG_1	GPIO	PTD2		SPI0_MOSI, UART2_RX, TPM0_CH2, SPI0_MISO
DIO2		DBG_2	GPIO	PTD3		SPI0_MISO, UART2_TX, TPM0_CH3, SPI0_MOSI
DIO3		DBG_3	GPIO	PTD4		SPI1_PCS0, UART2_RX, TPM0_CH4
DIO4		DBG_4	GPIO	PTB8		EXTRG_IN
DIO5		DBG_5	GPIO	PTB9		
DIO6		DBG_6	GPIO	PTB10		SPI1_PCS0
DIO7		DBG_7	GPIO	PTB11		SPI1_SCK
DIO8	SPI interface with uSD Card	SPI_CLK	SPI1	*(PTE2)*	Clock	SPI1_SCK
DIO9		SPI_DO	SPI1	*(PTE3)*	Data out (from peripheral)	SPI1_MISO, SPI1_MOSI
DIO10		SPI_DI	SPI1	*(PTE1)*	Data in (to peripheral)	SPI1_MOSI, UART1_RX, SPI1_MISO, I2C1_SCL
DIO11		SPI_CS	SPI1	*(PTE4)*	Chip select	SPI1_PCS0
DIO12	SMPS	SMPS_DRV	TPM0	*(PTE31)*	SMPS PWM drive signal	TPM0_CH4
DIO13		PWM_REF	TPM0	*(PTA5)*	Timing reference for center of PWM signal	USB_CLKIN, TPM0_CH2
DIO14	Unused & available	AD2_DIO_14		n/a	Available at TP16	
DIO15		AD2_DIO_15		n/a	Available at TP17	

Port I/O Overview

	Port A	Port B	Port C	Port D	Port E
0		A SMPS_VSENSE ADC_SE8	A EXTRG_IN	Debug 0	*UART1_TX RTC_CKLOUT CMP0_OUT I2C1_SDA*
1	U0_RX	A *I2C0_SDA TPM1_CH1 ADC0_SE9 TSI_CH6*	A FRDM: LLWU_P6	A Blue LED *TPM0_CH1*	SD_SPI1_MOSI
2	U0_TX	A V_LED_TEMP ADC_SE12	A ADC_SE11	Debug 1	SD_SPI1_SCK
3		A *I2C0_SDA TPM2_CH1 ADC0_SE13 TSI0_CH8*	LCD-DB8	Debug 2	SD_SPI1_MISO
4	*I2C1_SDA TPM0_CH1 NMI_b*		LCD-DB9	Debug 3	SD_SPI1_CS
5	*TPM0_CH2*		LCD-DB10	A LCD_TS_YD ADC_SE6 mux 1	SMPS-SwR-Ctl
6			LCD-DB11	A *SPI1_MOSI UART0_RX SPI1_MISO*	
7			LCD-DB12	*SPI1_MISO UART0_TX SPI1_MOSI*	
8		Debug 4	LCD-DB13		
9		Debug 5	LCD-DB14		
10		Debug 6	LCD-DB15		
11		Debug 7	*I2C1_SDA*		
12	LCD-BL-PWM TPM1_CH0		LCD-D_NC		
13	*TPM1_CH1*		LCD-NWR		
14	INT1_ACCEL				
15	INT2_ACCEL				
16	LCD_TS_YU	TSI/Debug NULL	LCD-NRD		
17	LCD_TS_XL	TSI	LCD-NRST		
18		Red LED *TPM2_CH0*			
19		Green LED *TPM2_CH1*			
20	*FRDM: Reset*				A SMPS_ISENSE_P ADC_DP0
21					A SMPS_ISENSE_M ADC_DM0
22					A ADC_SE3
23					A LCD_TS_XR ADC_SE7 mux 0
24					
25					
26					
27					
28					
29					Audio Amp Enable
30					A Audio Out DAC0_OUT
31					SMPS_DRV TPM0_CH4

Signals on FRDM-KL25Z headers used by shield	*Available signals on FRDM-KL25Z headers -- not used by shield*

Figure 1

PCB Layout

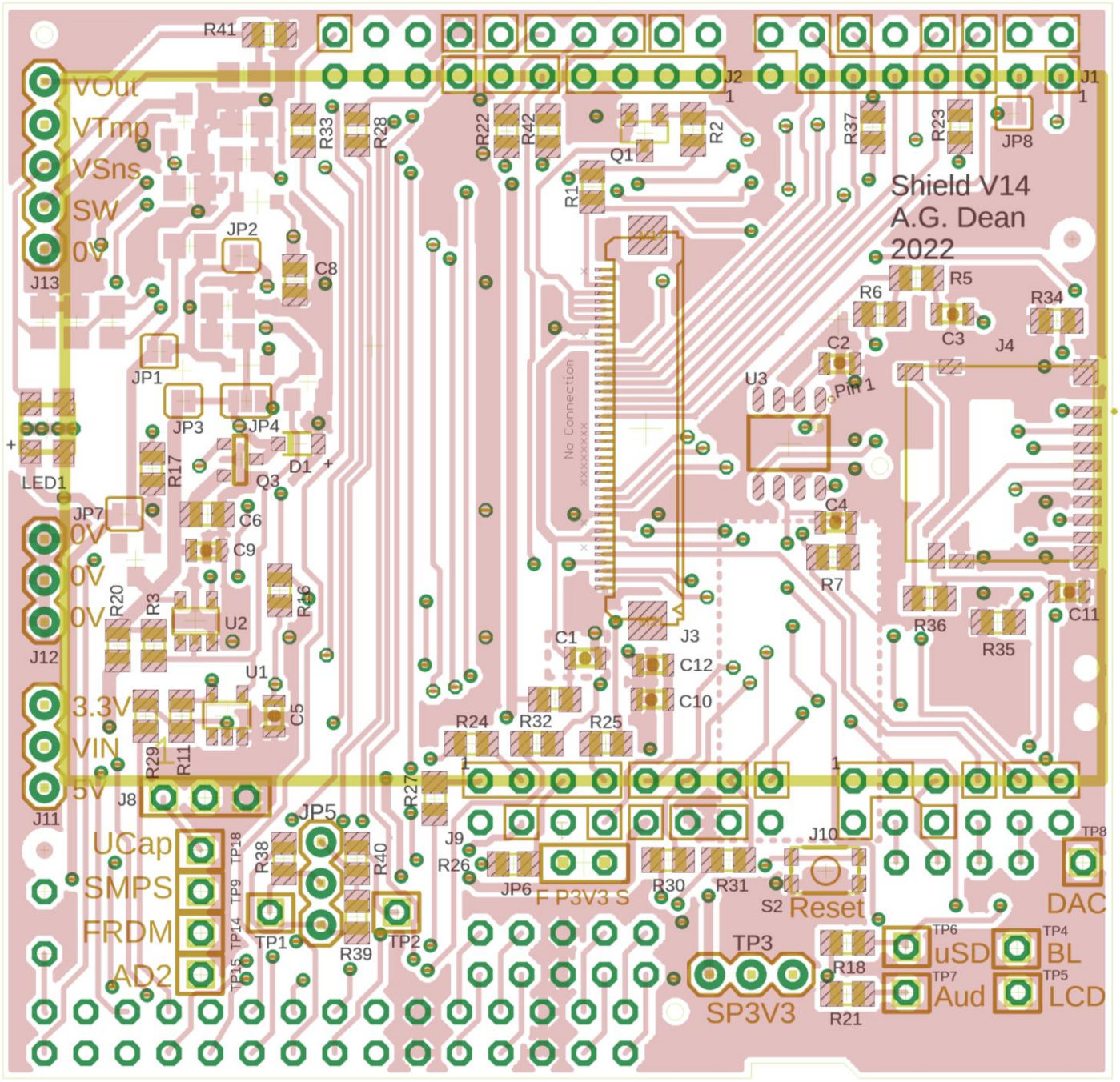


Figure 2. Top of PCB

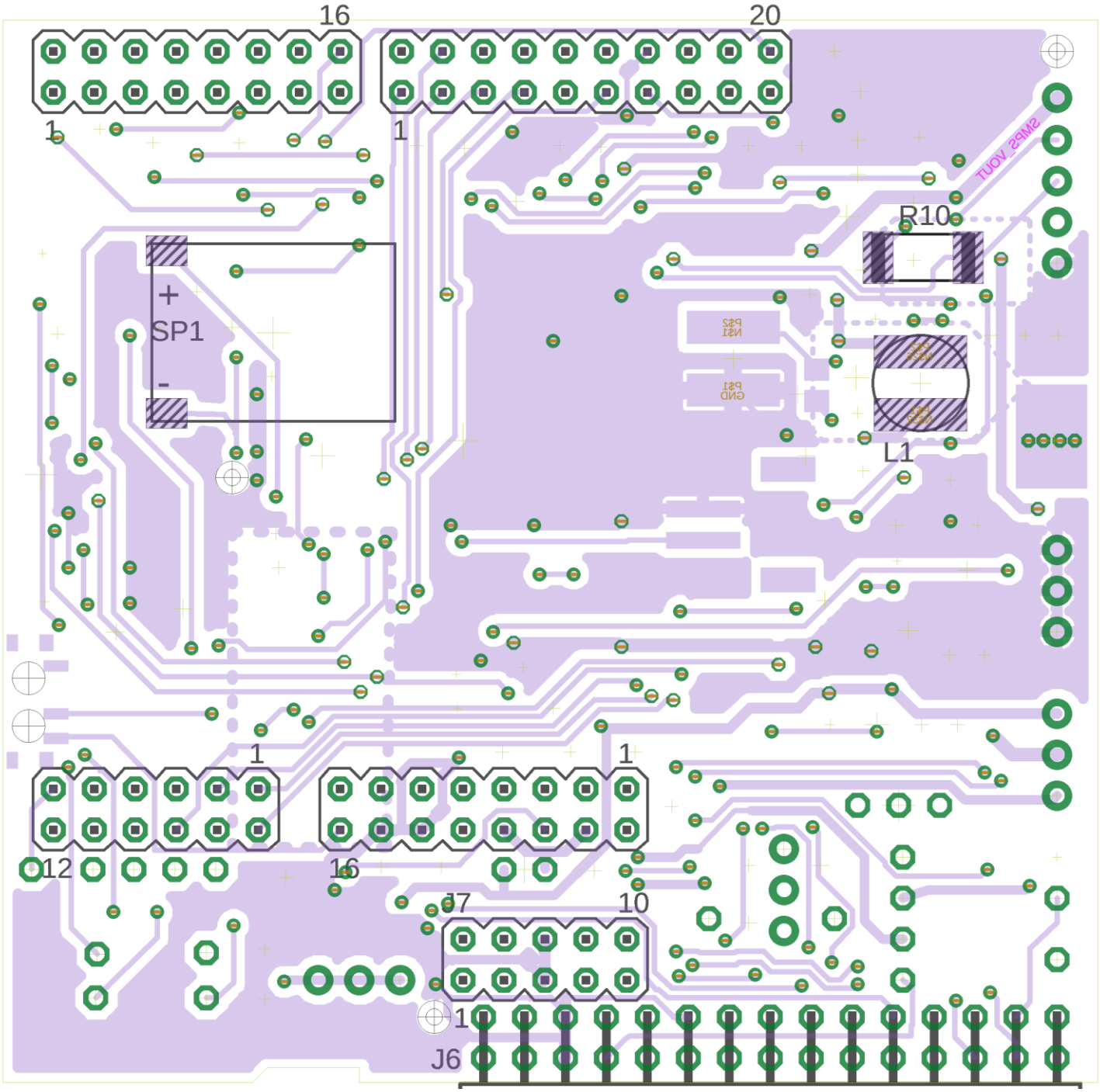
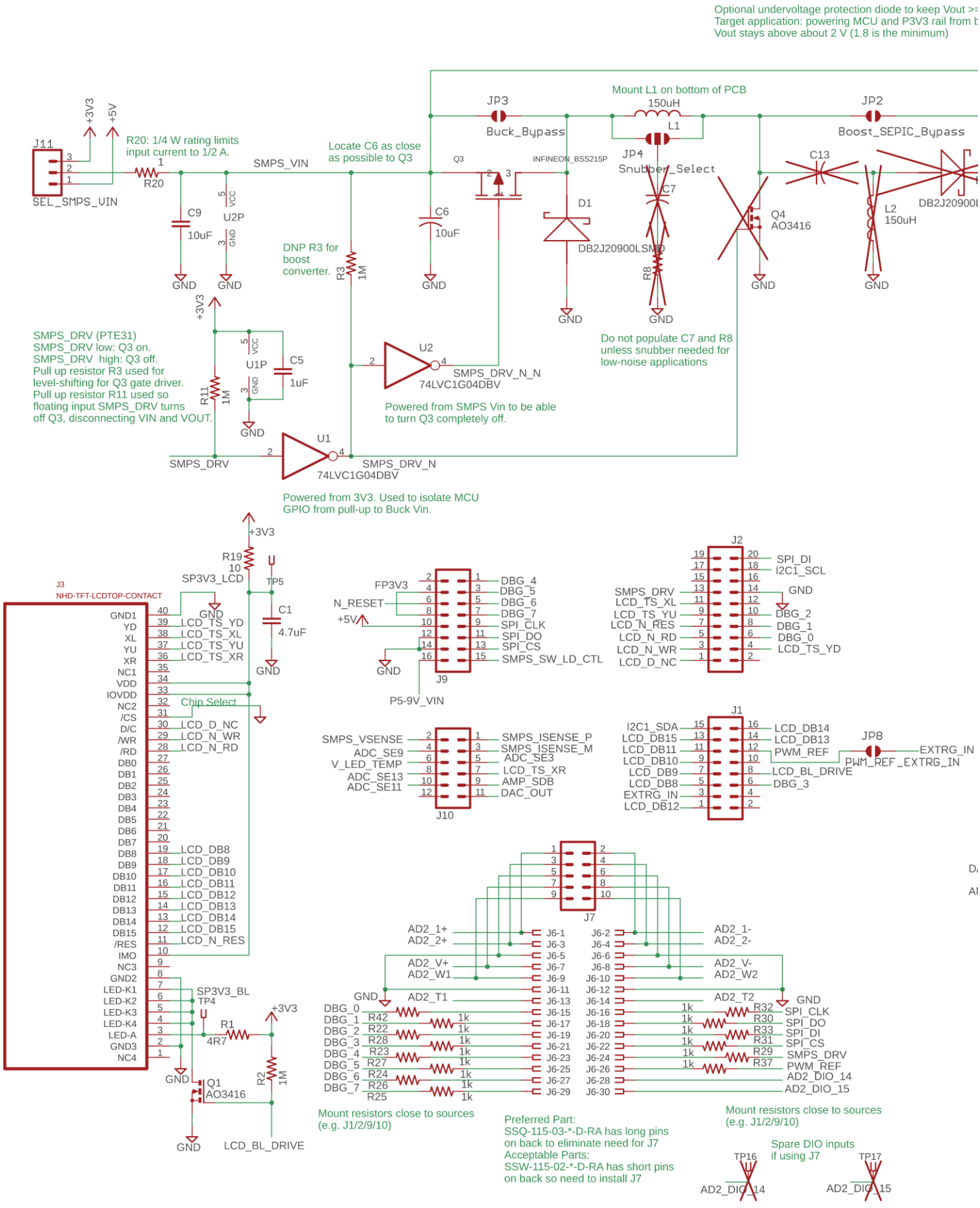
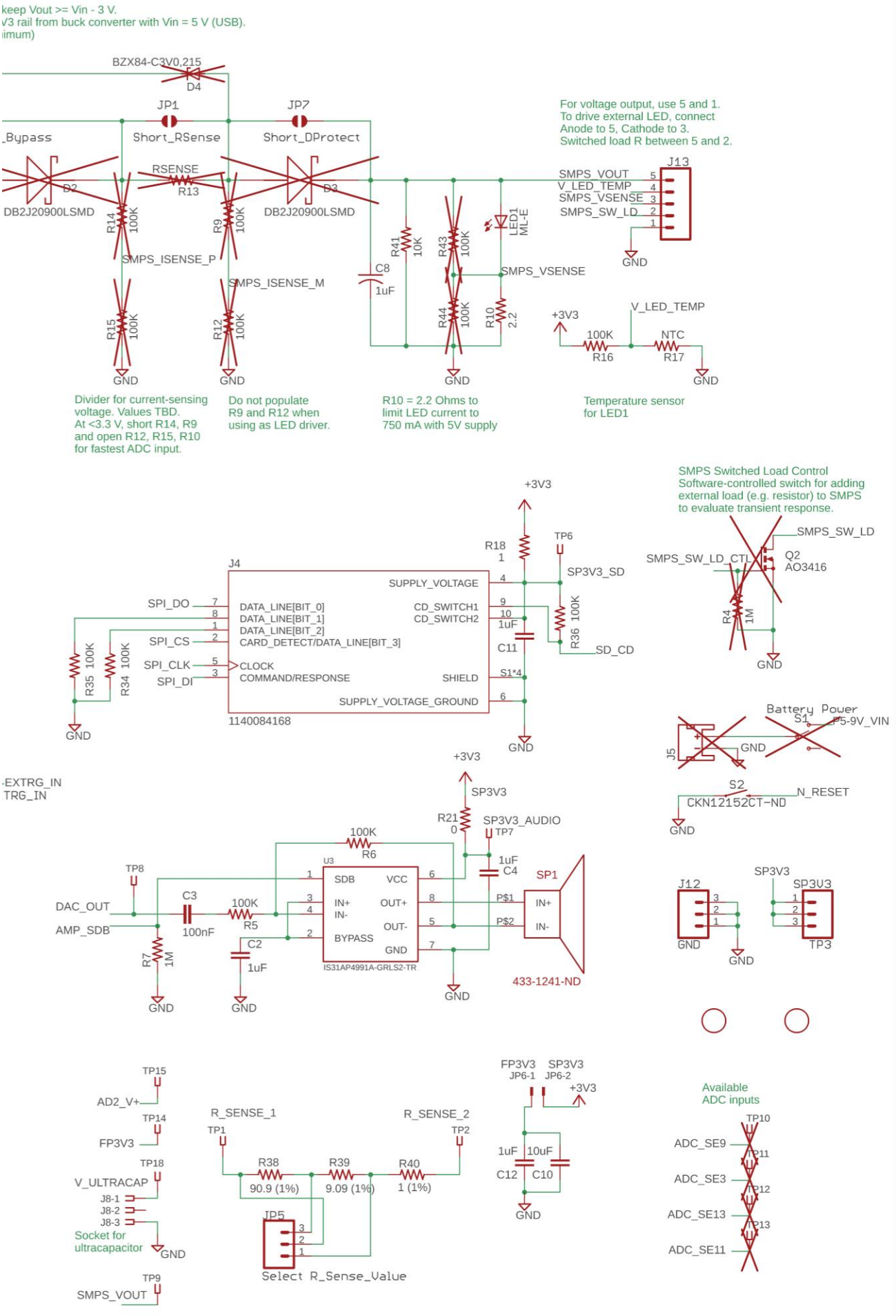


Figure 3. Bottom of PCB

Schematics


Optional undervoltage protection diode to keep Vout >=
Target application: powering MCU and P3V3 rail from b
Vout stays above about 2 V (1.8 is the minimum)
Mount L1 on bottom of PCB
150uH
JP3
Buck_Bypass
JP2
Boost_SEPIC_Bypass
L1
JP4
Snubber_Select
J11
SEL_SMPS_VIN
R20: 1/4 W rating limits input current to 1/2 A.
R20
SMPS_VIN
Locate C6 as close as possible to Q3
Q3
INFINEON_BSS215P
C9
10uF
U2P
VCC
GND
C6
10uF
D1
DB2J20900LSMD
C7
R8
C13
Q4
AO3416
L2
150uH
DB2J20900
DNP R3 for boost converter.
R3
1M
Do not populate C7 and R8 unless snubber needed for low-noise applications
SMPS_DRV (PTE31)
SMPS_DRV low: Q3 on.
SMPS_DRV high: Q3 off.
Pull up resistor R3 used for level-shifting for Q3 gate driver.
Pull up resistor R11 used so floating input SMPS_DRV turns off Q3, disconnecting VIN and VOUT.
U1P
C5
1uF
R11
1M
U2
SMPS_DRV_N_N
74LVC1G04DBV
Powered from SMPS Vin to be able to turn Q3 completely off.
U1
SMPS_DRV
SMPS_DRV_N
74LVC1G04DBV
Powered from 3V3. Used to isolate MCU GPIO from pull-up to Buck Vin.
+3V3
+5V
R19
10
SP3V3_LCD
TP5
C1
4.7uF
J3
NHD-TFT-LCDTOP-CONTACT
GND1
YD
XL
YU
XR
NC1
VDD
IOVDD
NC2
/CS
D/C
/WR
/RD
DB0
DB1
DB2
DB3
DB4
DB5
DB6
DB7
DB8
DB9
DB10
DB11
DB12
DB13
DB14
DB15
/RES
IMO
NC3
GND2
LED-K1
LED-K2
LED-K3
LED-K4
LED-A
GND3
NC4
LCD_TS_YD
LCD_TS_XL
LCD_TS_YU
LCD_TS_XR
Chip Select
LCD_D_NC
LCD_N_WR
LCD_N_RD
LCD_DB8
LCD_DB9
LCD_DB10
LCD_DB11
LCD_DB12
LCD_DB13
LCD_DB14
LCD_DB15
LCD_N_RES
SP3V3_BL
TP4
R1
4R7
Q1
AO3416
R2
1M
LCD_BL_DRIVE
FP3V3
N_RESET
+5V
P5-9V_VIN
J9
DBG_4
DBG_5
DBG_6
DBG_7
SPI_CLK
SPI_DO
SPI_CS
SMPS_SW_LD_CTL
J2
SPI_DI
I2C1_SCL
SMPS_DRV
LCD_TS_XL
LCD_TS_YU
LCD_N_RES
LCD_N_RD
LCD_N_WR
LCD_D_NC
DBG_2
DBG_1
DBG_0
LCD_TS_YD
SMPS_VSENSE
ADC_SE9
V_LED_TEMP
ADC_SE13
ADC_SE11
J10
SMPS_ISENSE_P
SMPS_ISENSE_M
ADC_SE3
LCD_TS_XR
AMP_SDB
DAC_OUT
J1
I2C1_SDA
LCD_DB15
LCD_DB11
LCD_DB10
LCD_DB9
LCD_DB8
EXTRG_IN
LCD_DB12
LCD_DB14
LCD_DB13
PWM_REF
LCD_BL_DRIVE
DBG_3
JP8
EXTRG_IN
PWM_REF_EXTRG_IN
J7
AD2_1+
AD2_2+
AD2_V+
AD2_W1
AD2_T1
AD2_1-
AD2_2-
AD2_V-
AD2_W2
AD2_T2
DBG_0
DBG_1
DBG_2
DBG_3
DBG_4
DBG_5
DBG_6
DBG_7
R42
R22
R28
R23
R27
R24
R26
R25
1k
R32
R30
R33
R31
R29
R37
SPI_CLK
SPI_DO
SPI_DI
SPI_CS
SMPS_DRV
PWM_REF
AD2_DIO_14
AD2_DIO_15
Mount resistors close to sources (e.g. J1/2/9/10)
Preferred Part:
SSQ-115-03-*-D-RA has long pins on back to eliminate need for J7
Acceptable Parts:
SSW-115-02-*-D-RA has short pins on back so need to install J7
Mount resistors close to sources (e.g. J1/2/9/10)
Spare DIO inputs if using J7
TP16
TP17
AD2_DIO_14
AD2_DIO_15


keep Vout >= Vin - 3 V.
V3 rail from buck converter with Vin = 5 V (USB).
imum)
BZX84-C3V0,215
D4
JP1
Short_RSense
JP7
Short_DProtect
_Bypass
For voltage output, use 5 and 1.
To drive external LED, connect
Anode to 5, Cathode to 3.
Switched load R between 5 and 2.
J13
SMPS_VOUT
V_LED_TEMP
SMPS_VSENSE
SMPS_SW_LD
RSENSE
R13
D2
D3
DB2J20900LSMD
DB2J20900LSMD
R14 100K
R9 100K
R41 10K
R43 100K
LED1 ML-E
C8 1uF
SMPS_ISENSE_P
SMPS_ISENSE_M
SMPS_VSENSE
R15 100K
R12 100K
R44 100K
R10 2.2
+3V3
V_LED_TEMP
100K
R16
NTC
R17
GND
Divider for current-sensing voltage. Values TBD. At <3.3 V, short R14, R9 and open R12, R15, R10 for fastest ADC input.
Do not populate R9 and R12 when using as LED driver.
R10 = 2.2 Ohms to limit LED current to 750 mA with 5V supply
Temperature sensor for LED1
SMPS Switched Load Control
Software-controlled switch for adding external load (e.g. resistor) to SMPS to evaluate transient response.
SMPS_SW_LD
SMPS_SW_LD_CTL
Q2
AO3416
R4 1M
+3V3
R18 1
TP6
SP3V3_SD
J4
SUPPLY_VOLTAGE
SPI_DO
DATA_LINE[BIT_0]
DATA_LINE[BIT_1]
DATA_LINE[BIT_2]
CD_SWITCH1
CD_SWITCH2
R36 100K
SPI_CS
CARD_DETECT/DATA_LINE[BIT_3]
1uF
C11
SD_CD
SPI_CLK
CLOCK
SPI_DI
COMMAND/RESPONSE
SHIELD
SUPPLY_VOLTAGE_GROUND
R35 100K
R34 100K
1140084168
GND
Battery Power
S1
P5-9V_VIN
J5
GND
S2
CKN12152CT-ND
N_RESET
GND
-EXTRG_IN
TRG_IN
+3V3
SP3V3
R21 0
SP3V3_AUDIO
TP7
100K
R6
U3
SDB
VCC
1uF
C4
SP1
TP8
DAC_OUT
C3
100K
R5
IN+
OUT+
P$1
IN+
AMP_SDB
100nF
IN-
OUT-
P$2
IN-
R7 1M
C2
1uF
BYPASS
GND
IS31AP4991A-GRLS2-TR
433-1241-ND
GND
GND
J12
SP3V3
SP3V3
GND
GND
TP3
TP15
AD2_V+
TP14
FP3V3
TP18
V_ULTRACAP
J8-1
J8-2
J8-3
Socket for ultracapacitor
GND
TP9
SMPS_VOUT
R_SENSE_1
R_SENSE_2
TP1
TP2
R38
R39
R40
90.9 (1%)
9.09 (1%)
1 (1%)
JP5
Select R_Sense_Value
FP3V3
JP6-1
SP3V3
JP6-2
+3V3
1uF
C12
10uF
C10
GND
Available ADC inputs
TP10
ADC_SE9
TP11
ADC_SE3
TP12
ADC_SE13
TP13
ADC_SE11

Header Signal Map

	SDA	PTB8	Debug 4
	P3V3	PTB9	Debug 5
	Reset	PTB10	Debug 6
	P3V3	PTB11	Debug 7
	P5V_USB	PTE2	SD_SPI1-SCK
	GND	PTE3	SD_SPI1-MISO
	GND	PTE4	SD_SPI1_PCSO
	P5-9V In	PTE5	SMPS_SW_LD_CTL

PTB0	SMPS_VSENSE ADC_SE8	PTE20	SMPS_ISENSE_P ADC_DP0
PTB1	ADC_SE9	PTE21	SMPS_ISENSE_M ADC_DM0
PTB2	V_LED_TEMP ADC_SE12	PTE22	ADC_SE3
PTB3	ADC_SE13	PTE23	LCD_TS_XR ADC_SE7a
PTC2	ADC_SE11	PTE29	Audio Amp Enable
PTC1	ADC_SE15	PTE30	Audio Out DAC0_Out

Debug
Secure Digital
Switch-Mode Power Supply
LCD, Backlight & Touchscreen
Audio

PTD7		PTE1	SD_SPI1_MOSI
PTD6	ADC_SE7b	PTE0	
	No Connection		VRefH
PTE31	SMPS Drive TPM0_CH4		GND
PTA17	LCD_TS_XL	PTD1	Blue LED
PTA16	LCD_TS_YU	PTD3	Debug 2
PTC17	LCD-NRST	PTD2	Debug 1
PTC16	LCD-NRD	PTD0	Debug 0
PTC13	LCD-NWR	PTD5	LCD_TS_YD ADC_SE6b
PTC12	LCD-D_NC	PTA13	

PTC11		PTC9	LCD-DB14
PTC10	LCD-DB15	PTC8	LCD-DB13
PTC6	LCD-DB11	PTA5	SMPS Timing Ref. TPM0_CH2
PTC5	LCD-DB10	PTA4	
PTC4	LCD-DB9	PTA12	LCD-BL-PWM TPM1_CH0
PTC3	LCD-DB8	PTD4	Debug 3
PTC0	EXTRG_IN	PTA2	U0TxD
PTC7	LCD-DB12	PTA1	U0RxD

Alternate Functions for Debug Signal Pins

Signal	Position in debug_GPIO[]	Pin Name	ALT2	ALT3	ALT4	ALT5	ALT6
Debug 0	0	PTD0	SPI0_PCS0		TPM0_CH0		
Debug 1	1	PTD2	SPI0_MOSI	UART2_RX	TPM0_CH2	SPI0_MISO	
Debug 2	2	PTD3	SPI0_MISO	UART2_TX	TPM0_CH3	SPI0_MOSI	
Debug 3	3	PTD4	SPI1_PCS0	UART2_RX	TPM0_CH4		
Debug 4	4	PTB8		EXTRG_IN			
Debug 5	5	PTB9					
Debug 6	6	PTB10	SPI1_PCS0				
Debug 7	7	PTB11	SPI1_SCK				
SPI_CLK	8	PTE2	SPI1_SCK				
SPI_DI	9	PTE3	SPI1_MISO			SPI1_MOSI	
SPI_DO	10	PTE1	SPI1_MOSI	UART1_RX		SPI1_MISO	I2C1_SCL
SPI_CS	11	PTE4	SPI1_PCS0				

Note: The SPI_* signals can be used for debug signals by defining DBUG_USE_SPI_SIGNALS to 1 in debug.h.

Peripheral Use

Analog

Analog to Digital Converter (ADC)

Chan.	Input Signal	MCU Signal	MUX SEL	Conn. Access	Module	Use	Shield Signal
0	ADC_SE0, ADC_DP0	PTE20	0	J10-1	SMPS	Inductor current sense plus	SMPS_ISENSE_P
1			*FRDM only*				
2			*FRDM only*				
3	ADC_SE3	PTE22	0	J10-5, TP11			
4	ADC_SE4a, ADC_DM0	PTE21	0	J10-3	SMPS	Inductor current sense minus	SMPS_ISENSE_M
4	ADC_SE4b	PTE29	1	J10-9			
5	ADC_SE5b	PTD1	1	J2-12	FRDM-KL25Z	Pin not available for ADC, used by Blue LED	
6	ADC_SE6b	PTD5	1	J2-4	LCD Touchscreen	Used to read X position.	LCD_TS_YD
7	ADC_SE7a	PTE23	0	J10-7	LCD Touchscreen	Used to read Y position.	LCD_TS_XR
7	ADC_SE7b	PTD6	1	J2-17			
8	ADC_SE8	PTB0	0	J10-2	SMPS	Voltage sense SMPS_VSENSE	SMPS_VSENSE
9	ADC_SE9	PTB1	0	J10-4, TP10			
10			*FRDM only*				
11	ADC_SE11	PTC2	0	J10-10, TP13			
12	ADC_SE12	PTB2	0	J10-6	HBLED	Temperature sensor of PCB near HBLED LED1	V_LED_TEMP
13	ADC_SE13	PTB3	0	J10-8, TP12			
14	ADC_SE14	PTC0	0	J1-3	SMPS	Pin not available for ADC: used by EXTRG_IN.	
15	ADC_SE15	PTC1	0	J10 12	FRDM-KL25Z	Pin not available for ADC: used by debugger (LLWU_P6) for low-leakage wake-up.	
23	ADC_SE23	PTE30	0	J10 11	Audio	Pin not available for ADC: used by DAC	

Digital to Analog Converter (DAC)

- DAC0 for audio output

Timers

SysTick Timer

- Used by RTXv5

Timer/PWM Module

Note: Some NXP/Freescale documentation calls a TPM an “FTM” (Flexible Timer Module).

- TPM0
  - SMPS application, frequency varies
  - 6 channels
    - Channel 1: Unused, but available for blue LED on FRDM
    - Channel 2: SMPS timing reference (overflow, center of on-time)
    - Channel 4: SMPS converter gate drive signal (active low)
- TPM1
  - LED backlight dimming, 40 kHz
  - 2 channels
    - Channel 0: LED Backlight for TFT LCD
- TPM2
  - DMA for Audio triggered by overflow at 20 kHz
  - 2 channels
    - Channel 0: Unused, but available for red LED on FRDM
    - Channel 1: Unused, but available for green LED on FRDM

LPTMR0

- With uSD card, is used by spi_io.c for operation time-out

PIT

- Channel 0 used for profiler
- Channel 0 probably used for flash timer in HBLED SMPS converter driver (verify by examining the code you are using)

Communications

SPI

- SPI1 for µSD card interface

I^2C

- Not used by shield.

UART

- Not used by shield.

Other

DMA

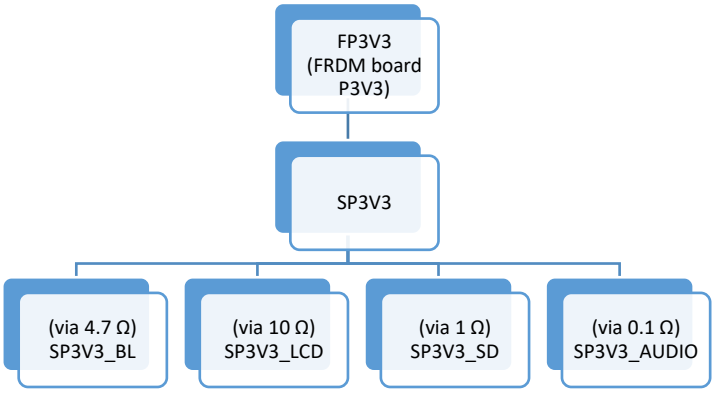
- … for audio output
- … for SMPS control loop frequency division

Circuit Reference

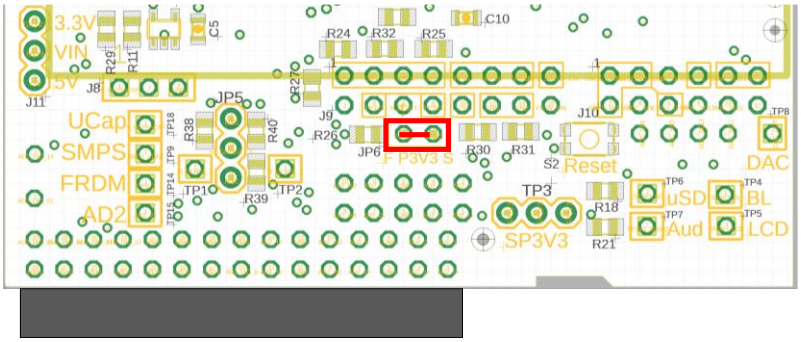
Power Distribution and Monitoring

Power Domains

The V14 board has multiple power domains:



In ECE 460/560, you will not be measuring power, so be sure to use a shorting jumper on JP6 to power the shield (SP3V3) from the FRDM board's 3.3 V rail (FP3V3).



Power Monitoring

(*Use ADC differential analog inputs to measure voltage across current-sense resistor and calculate current and power)*
The AD2's analog inputs have good performance down to 5 mV/division. The ADC resolution is 320 µV.

Typical SP3V3 currents:

- HBLED: 300 mA or more (limited by USB port)
- Baseline with LCD + BL on, debugger connected, HBLED off: 90 mA
- LCD off: 8 mA
- MCU sleeping: 0.5 mA

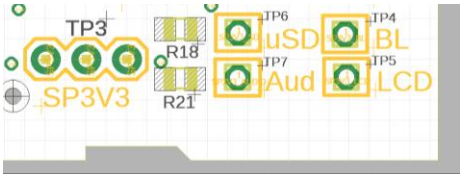
Dedicated Current Sense Resistors

There are four power domains with dedicated current-sense resistors connected to the shield's P3V3 supply rail (SP3V3).

- Measure the voltage difference across the resistor to determine the current. For example, determine the backlight current by first measuring the voltage between SP3V3 (at TP3) and BL (at TP4). It is convenient to use the AD2's differential inputs (1+ and 1-, or 2+ and 2-).
- Divide that voltage difference by the resistance (e.g. 4.7 Ω) to determine the current.
- Multiply that by the current by the voltage after the resistor (e.g. at TP4) to determine the power.

Note that you can add math channels in Waveforms to calculate and display the current and power over time.

Further measurement details will be provided later.

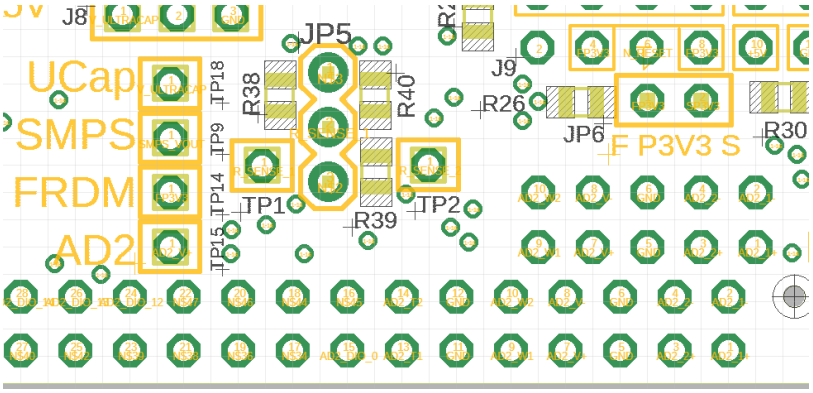


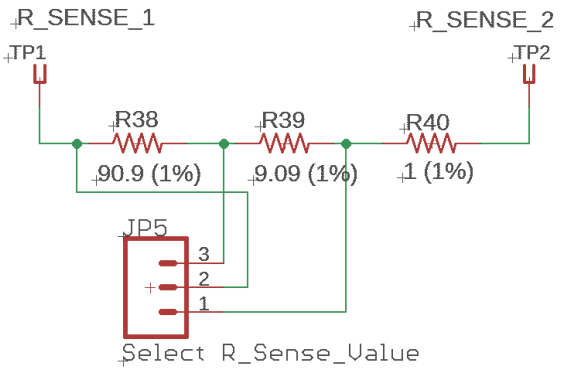
Power Domain		Test Point	Current Sense Resistor	Components Powered	Comments
LCD Backlight	SP3V3 _BL	TP4	R1, 4.7Ω	LCD backlight LEDs	
LCD	SP3V3 _LCD	TP5	R19, 10Ω	LCD (but not backlight or touchscreen)	
µSD	SP3V3 _SD	TP6	R18, 1Ω	µSD Card	
Audio Amplifier	SP3V3 _AUDIO	TP 7	R21, 0.1Ω	Audio amplifier U3 and speaker	Currently unused for measurement. 1Ω resistor causes 250 mV sag of VCC

Type	ID	Signal	Description
Power Source	TP3	Ultracapacitor	For powering board SP3V3 from ultracapacitor.
	TP9	SMPS_VOUT	For powering board SP3V3 from SMPS.
	TP14	FP3V3	For powering board SP3V3 from FRDM-KL25Z P3V3 supply rail. Is parallel with shorting jumper JP6 (labeled **F P3V3 S**)
	TP15	AD2_V+	For powering board SP3V3 from Analog Discovery 2 adjustable voltage supply.
Power Measurement	TP1	R_SENSE_1	Both terminals for adjustable current-sense resistor. Select 1, 10.09 or 100.99 Ω resistance with jumper position on JP5.
	TP2	R_SENSE_2	
	TP4	SP3V3_BL	Dedicated LCD backlight LED current-sense resistor (4.7 Ω).
	TP5	SP3V3_LCD	Dedicated LCD current-sense resistor (10 Ω).
	TP6	SP3V3_SD	Dedicated uSD current-sense resistor (10 Ω).
	TP7	SP3V3_AUDIO	Dedicated audio amplifier current-sense resistor (0 Ω currently, probably need 0.1 Ω).

Free High-Dynamic Range Resistor String

To provide better accuracy across a wide range of currents (under 1 mA to over 300 mA), a configurable string of current sense resistors is provided between TP1 and TP2. This resistor string is not connected to any specific power source or domain, and can be connected using jumper wires.





Resistance	JP5 Jumper Position	Highest Practical Waveforms Sensitivity (5 mV/div)	Resolution
1 Ω	1-2. 2 pins closest to label “JP5”	5 mA/div	320 µA
10.09 Ω	2-3. 2 pins farthest from label “JP5”	500 µA/div	32 µA
101.99 Ω	No jumper used	50 µA/div	3.2 µA

Miscellaneous Test Points

Type	ID	Signal	Description
Output Signal	TP8	DAC_OUT	Voltage output of DAC. Goes to audio amplifier input.
Spare ADC Input	TP10	ADC_SE3	
	TP11	ADC_SE9	
	TP12	ADC_SE11	
	TP13	ADC_SE13	

Subsystems

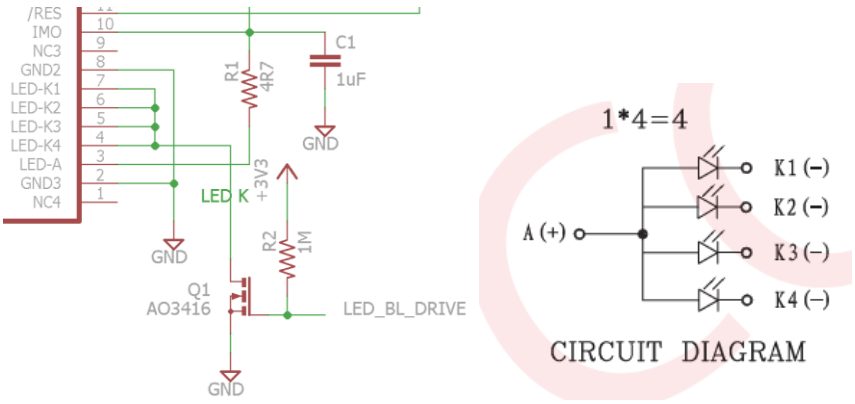
TFT Liquid Crystal Display

Newhaven Display NHD-2.4-240320CF-CTXI#-FT

Name	I/O Port	Direction	Description
LCD-DB8	Port C Bit	Input/Output	Data bus bits to LCD
LCD-DB9	Port C Bit		
LCD-DB10	Port C Bit		
LCD-DB11	Port C Bit		
LCD-DB12	Port C Bit		
LCD-DB13	Port C Bit		
LCD-DB14	Port C Bit		
LCD-DB15	Port C Bit		
LCD-D_NC	Port C Bit	Output	Data/~Control
LCD-NWR	Port C Bit	Output	~Write
LCD-NRD	Port C Bit	Output	~Read
LCD-NRST	Port C Bit	Output	~Reset

LED Backlight Driver

Name	I/O Port	Direction	Description
LED_BL_DRV TPM1_CH0	Port A bit 12	Output	TFT LCD LED backlight drive (active high)



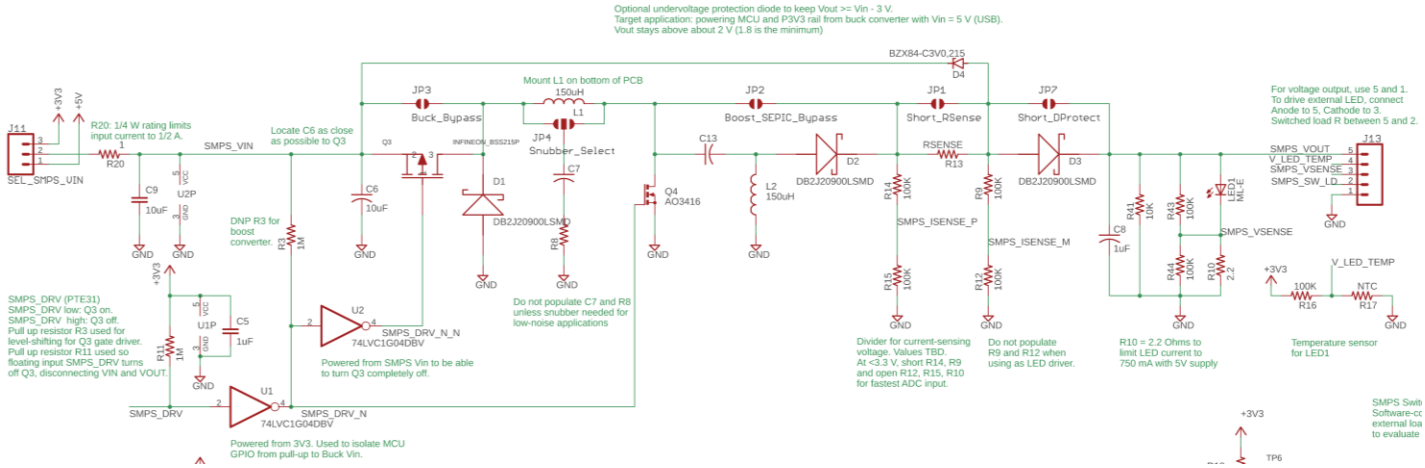
Resistive Touch Screen

Name	I/O Port	Peripheral Signal	Direction	Description
LCD_TS_YD	Port D bit 5	ADC_SE6 mux 1	Analog Input/ Digital Output	Bottom terminal
LCD_TS_XL	Port A bit 17		Digital Output	Left terminal
LCD_TS_YU	Port A bit 16		Digital Output	Top terminal
LCD_TS_XR	Port E bit 23	ADC_SE7 mux 0	Analog Input/ Digital Output	Right terminal

Analog Audio Output

Name	I/O Port	Direction	Description
Audio Amp Enable	Port E bit 29	Digital Output	Enables audio amp when 1
Audio Out	Port E bit 30	Analog Output	DAC 0 Output

Switch-Mode Power Converter



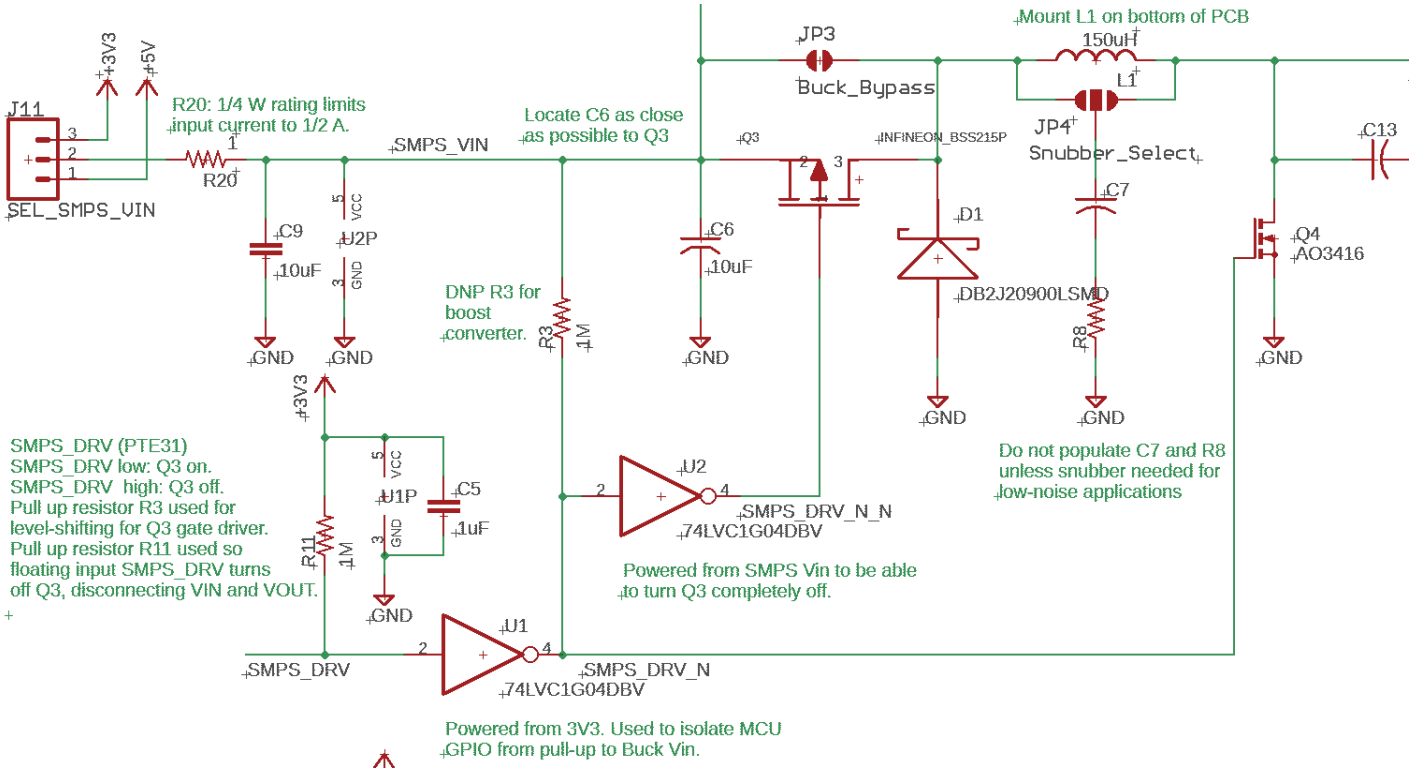
The PCB can provide a buck, boost or SEPIC converter, based on which parts are populated. The converter is asynchronous, using a P-MOSFET or N-MOSFET and a Schottky diode as the switches.

Table 1. SMPS Signals

Name	I/O Port	Position on Connector	Peripheral Signal	Direction	Description
SMPS_VIN		J11 pin 2		MCU -> SMPS	Supply voltage input to SMPS converter
SMPS_DRV	PTE31		TPM0 _CH4	MCU -> SMPS	Drive signal for SMPS converter (active low)
PWM_REF	PTA5		TPM0_CH2	MCU -> Scope	PWM cycle timing reference
SMPS_VSENSE	PTB0	J13 pin 3	ADC_SE8	SMPS -> MCU	Voltage sense: LED current (I_{LED}*2.2 Ω), or half of SMPS_VOUT
SMPS_ISENSE_P	PTE20		ADC_DP0	SMPS -> MCU	Current sense +: Positive side of R13 current sense resistor
SMPS_ISENSE_M	PTE21		ADC_DM0	SMPS -> MCU	Current sense -: Negative side of R13 current sense resistor
SMPS_SW_LD_CTL	PTE5		GPIO	MCU -> SMPS	Drive signal for switched load resistor on SMPS converter (active high)
SMPS_SW_LD		J13 pin 2		MCU -> SMPS	Switched load resistor connection
SMPS_VOUT		J13 pin 5			

Identifier	Type	Name	Description	Default for ECE x60/x61
JP1	Solder Jumper	Short_RSense	Short out if not using R_{Sense} (R13) to measure SMPS output current	Shorted
JP2	Solder Jumper	Boost_SEPIC_Bypass	Short out if using buck configuration	Shorted
JP3	Solder Jumper	Buck_Bypass	Short out if using boost or SEPIC configuration	
JP4	Solder Jumper	Snubber_Select	Short out if using snubber circuit (C7 and R8) for low EMI applications	
JP7	Solder Jumper	Short_DProtect	Short out if not using output protection diode D3	Shorted
J11	Connector	Sel_SMPS_VIn	SMPS input voltage selection – 3.3 V or 5 V	Either position 1-2 or 2-3

Drive Signal Conditioning

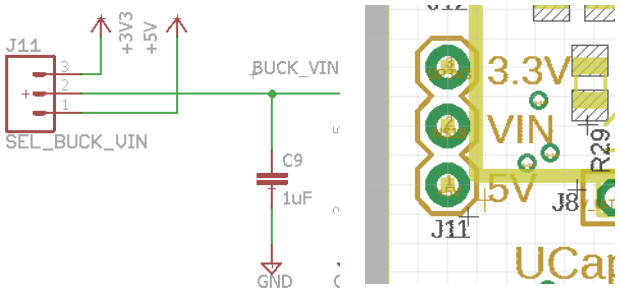


U1 inverts the SMPS_DRV signal from the MCU, speeds up its transitions, and buffers the MCU from the pulled-up voltage. If the input to U1 is disconnected, R11 pulls it high, causing U2 to disable the Q3. R3 provides level-shifting up to SMPS_VIN.

- Buck: U1 inverts the drive signal again to drive Q3, a P-channel MOSFET.
- Boost: U3 drives Q4, an N-channel MOSFET.
- SEPIC: TBD

Input Voltage Selection

Select the input supply voltage for the SMPS converter with J11 by shorting VIN to 3.3 V or 5V. You can quickly and safely cut off power to the converter by removing J11.



You can also connect an external voltage source to VIN. VIN is limited by voltage ratings of C1 (16 V) and these parts:

- Buck: U1 (5.5 V), D1 (20 V), Q3 (20 V). Supporting a higher VIN requires replacing U1 with a circuit which can translate the drive signal (output of U3) up to VIN to turn off Q3. Replacing Q3 with a transistor with a higher threshold voltage could also help.
- Boost, SEPIC: D3 (20 V), Q4 (20 V).

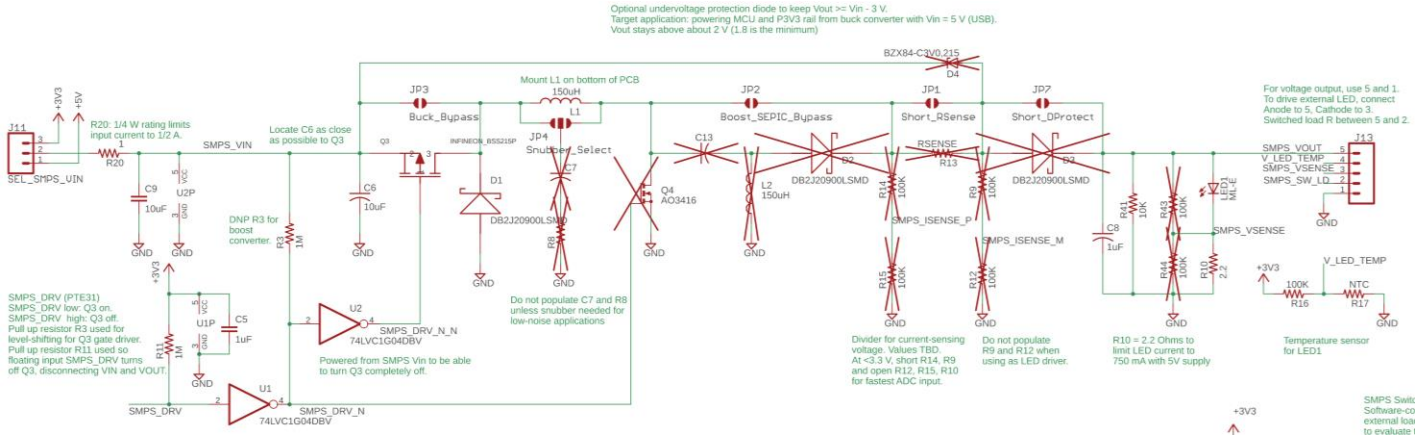
Output voltage is limited by C8 (25 V) and the feedback to the MCU (max 3.3 V after division by R14, R15 or R9, R12).

Snubber for EMI Reduction

R7 and C8 are for an optional snubber (SMPS – Snubber) to reduce noise. They are generally not needed.

Converter Configurations

Buck Converter



Populate the PCB as shown below to create a buck converter. Short JP1, JP2 and JP7 with solder. The maximum output current is limited by Q3, D1 and L1, as well as the input power supply. The maximum output voltage is limited by C8 and the ADC inputs.

- V14 Components
  - TBD
- V13 Components
  - Note that Q3, D1 and L1 have changed.
  - L1: SDR0604-121KL. $I_{RMS\ Max}$ = 0.48 A, I_{sat} = 0.60 A, R_{DCMax} = 0.93 Ω
- V12 Components
  - Q3: BSS215P. Max I_D @ 25C = -1.5 A. $R_{DS(on)}$ = 105-280 mΩ, Max V_{DS} = -20 V. Body diode $I_{SContinuous}$ = -0.5 A, $I_{SPulsed}$ = -6 A.
  - D1: DB2J20900LSMD. V_{RMax} = 20 V, I_{FAve} = 0.5 A, I_{FSurge} = 3 A
  - L1: SDR0604-680KLCT-ND. $I_{RMS\ Max}$ = 0.62 A, I_{sat} = 0.84 A, R_{DCMax} = 0.52Ω

Boost Converter

Populate the PCB as shown below to create a boost converter. Short JP3 with solder. The maximum output current is limited by Q4 (AO3416), D3 (DB2J20900LSMD) and L1 (SDR0604-680KLCT-ND). The maximum output voltage is limited by C8 and the ADC inputs.

- V14 Components
- V13 Components
  - Note that Q3, D1 and L1 have changed.
  - L1: SDR0604-121KL. $I_{RMS\ Max}$ = 0.48 A, I_{sat} = 0.60 A, R_{DCMax} = 0.93 Ω
- V12 Components
  - Q1: AO3416. Max I_D @ 25C = 6.5 A. $R_{DS(on)}$ = 34 mΩ, Max V_{DS}=20 V. Body diode I_{Max} = 2 A.
  - D3: DB2J20900LSMD. V_{RMax} = 20 V, I_{FAve} = 0.5 A, I_{FSurge} = 3 A
  - L1: SDR0604-680KLCT-ND. $I_{RMS\ Max}$ = 0.62 A, I_{sat} = 0.84 A, R_{DCMax} = 0.52Ω

Add schematic

Voltage- and Current-Sensing Configurations

The converter supports various configurations to sense output voltage or current.

HBLED Driver Configuration with Voltage-Mode Control (Buck – HBLED)

Add schematic

Short JP1 with solder. Use SMPS_VSENSE as a single-ended input to measure the LED current via R10. R10 is sized to limit maximum current through LED1 to a safe level regardless of buck converter output (given a maximum input of 5 V). Reduce the resistance of R10 to improve energy efficiency.

Voltage Source with Voltage-Mode Control (Buck – VSVM)

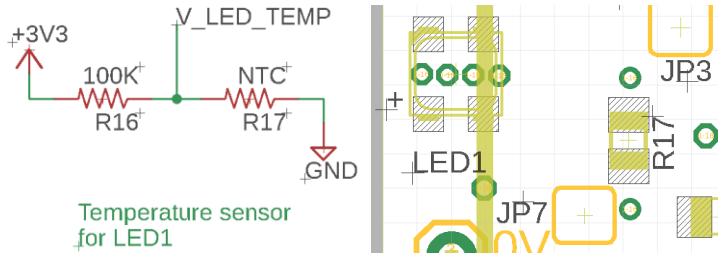
Add schematic

Voltage Source with Current-Mode Control (Buck – VSCM)

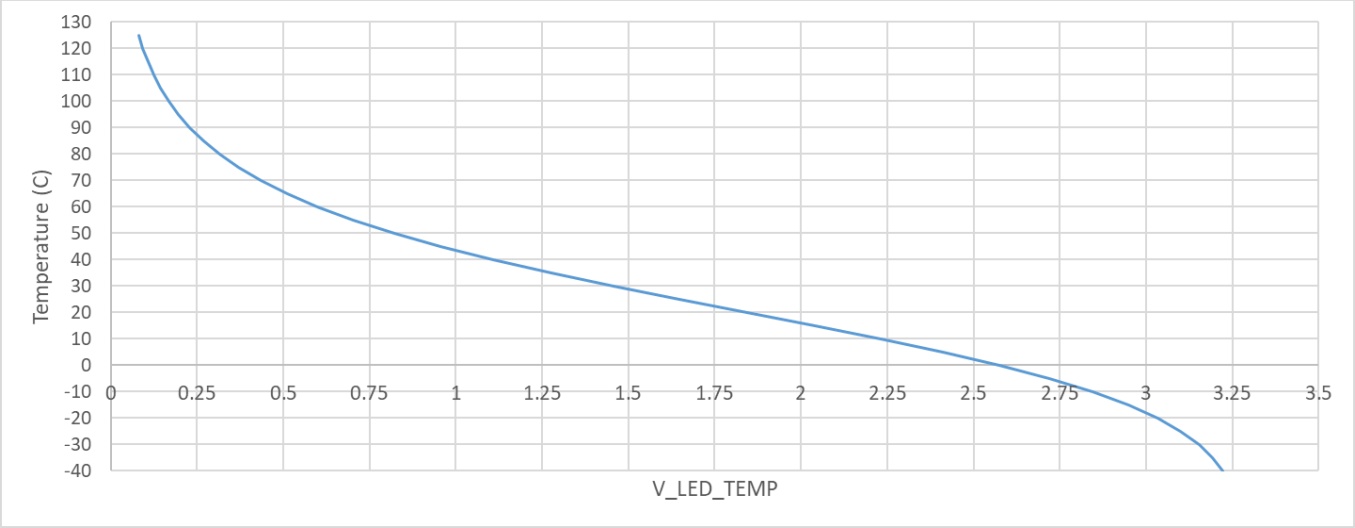
Add schematic

Use SMPS_ISENSE_P and SMPS_ISENSE_M as differential inputs to measure the load current via R13.

HBLED Temperature Sensor



A thermistor R17 (NCP21WF104J03RA) in a voltage divider circuit can be used to determine the temperature of the PCB near the HBLED. It is connected to the ADC via signal V_LED_TEMP (ADC channel SE12 on PTB2). The resistor is nominally 100 kΩ at 25°C. The graph shows the relationship between V_LED_TEMP and the temperature, given R16 is connected to 3.3V. The maximum LED junction temperature is 125°C, but the temperature at the thermistor may be much lower (due to thermal resistance between the LED junction and the thermistor).



MicroSD Card

Name	I/O Port	Direction	Description
SPI_CLK	PTE2	MCU Output	SCK, SPI Clock
SPI_CS	PTE4	MCU Output	PCS0, SPI Chip Select
SPI_DI	PTE3	MCU Input	MISO, SPI Data in (to MCU)
SPI_DO	PTE1	MCU Output	MOSI, SPI Data out (from MCU)

External Battery Support

An external Li-Ion cell can be used to power the shield and Freedom board through the P5-9V_VIN connection, which can drive the Freedom's linear regulator. S1 allows the power to be switched by the user.

Mounting Information

TFT Liquid Crystal Display

The connector should already be mounted. Display connection and disconnection instructions appear in the Mechanical section below.

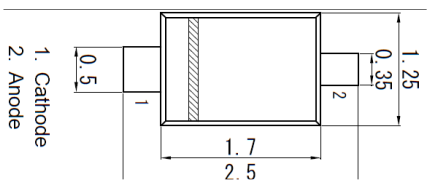
If the connector is not already mounted, the following procedure is recommended:

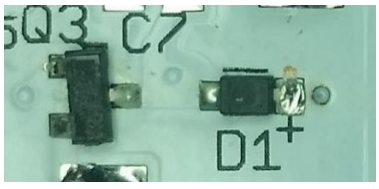
- Apply flux (no-clean or water-soluble preferred) to the connector lead pads.
- Lightly tin the pad for one mounting tab of the connector. If the solder is too thick, then the connector leads won't touch the pads, complicating soldering.
- Align the connector on the PCB so leads are centered over pads.
- Reflow the solder on the pad, connecting the mounting tab
- Verify proper lead alignment (x, y) and that leads touch their pads (z).
- Solder the other mounting tab with a small amount of solder.
- Confirm proper alignments and lead contact with pads.
- Apply flux (no-clean or water-soluble preferred) to leads.
- Solder leads to pads using one of these methods:
    - Solder paste: apply a small amount of solder paste to the leads with a toothpick. Mixing flux with the solder paste will reduce its viscosity and make it easier to apply. This especially helps with older solder paste.
    - Solder wire: Solder each lead by touching it and its pad with a fine-tip soldering iron coated with a small amount of solder. Too much solder will result in solder bridges. Keep the tip clean of debris and old flux.
- Remove flux as needed.

SMPS Converter

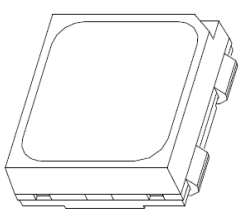
The SMPS converter can be configured to drive a high-brightness LED based on current feedback, or generate a constant voltage based on voltage feedback.

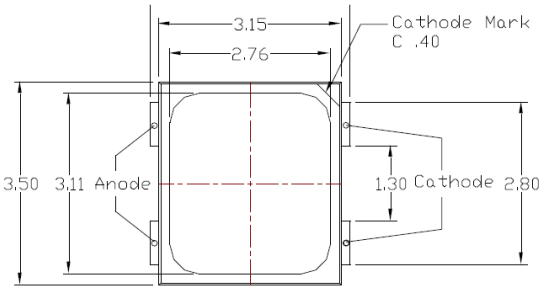
Mount diode D1 so the cathode (bar, wide lead) is to the left.

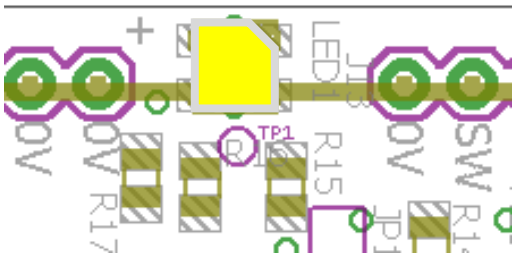




High-Brightness LED (Cree XLAMP-MLE)







The cathode connections are marked by the missing corner on the LED package (upper right in all figures above). That corner should be placed near the LED1 label. The anode connections should be next to the + symbol.

Analog Audio Output

Audio Amplifier

IC U2 is rotated 180^{o} so that pin 1 of U2 (marked by a small circle on the IC package) is next to C2 – at the 1:30 position.

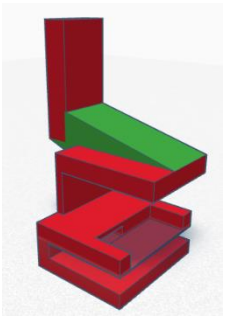
Speaker

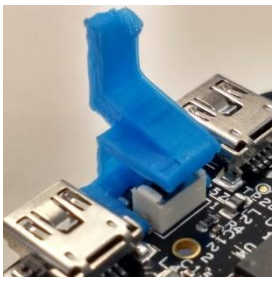
Mount the speaker after mounting all surface mount components on top of PCB. Attach the speaker to the PCB with hot-melt glue or double-sided tape. Then solder the leads to the pads.

Mechanical

Optional: Reset Switch Extender

The shield blocks easy access to the FRDM-KL25Z's reset switch. The design for a switch extender is available at TinkerCAD.com (https://www.tinkercad.com/things/6tj7AOvGaO3) or by searching for "switch extender" or the #NCSU ECE tag. Slide it over the edge of the FRDM-KL25Z board and onto the reset switch.





Using Display Connector J3

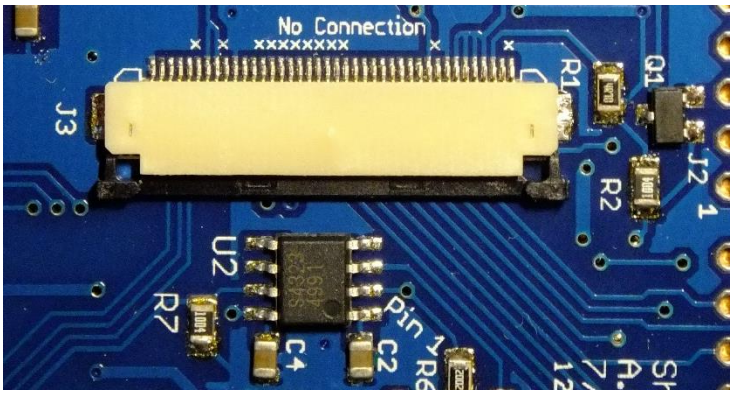


Figure 4. Connector J3 holds the LCD cable. The dark portion is a sliding locking bar.

Optional: Trim the top of the pins from J7 (SPI) and J8 (DAC) to prevent possible damage to the LCD cable.

Connecting LCD

1. Open connector J3 by pulling the two locking tabs (on either end of the dark brown plastic locking bar) toward U2.
2. Slide the bezel over the shield from the uSD card end until it stops.
3. Insert the LCD cable (with the shiny gold contacts facing up) into connector J3.
4. Push J3's locking bar tabs away from U2 to slide in the locking bar.
5. Gently press the LCD into place in the bezel.

Removing LCD

1. Gently pry up the LCD. If using the bezel, insert a thin, wide tool in the bezel gap near the USB connectors.
2. Slide out J3's locking mechanism.
3. Disconnect the LCD cable.
4. Slide the bezel off the shield.

Optional: RGB LED Light Pipe

TBD: use 3/16" square acrylic rod.

Troubleshooting

LCD

Blank white display: Backlight is powered, but LCD controller is not initialized. Confirm cable is properly seated and cable latch is fully closed.

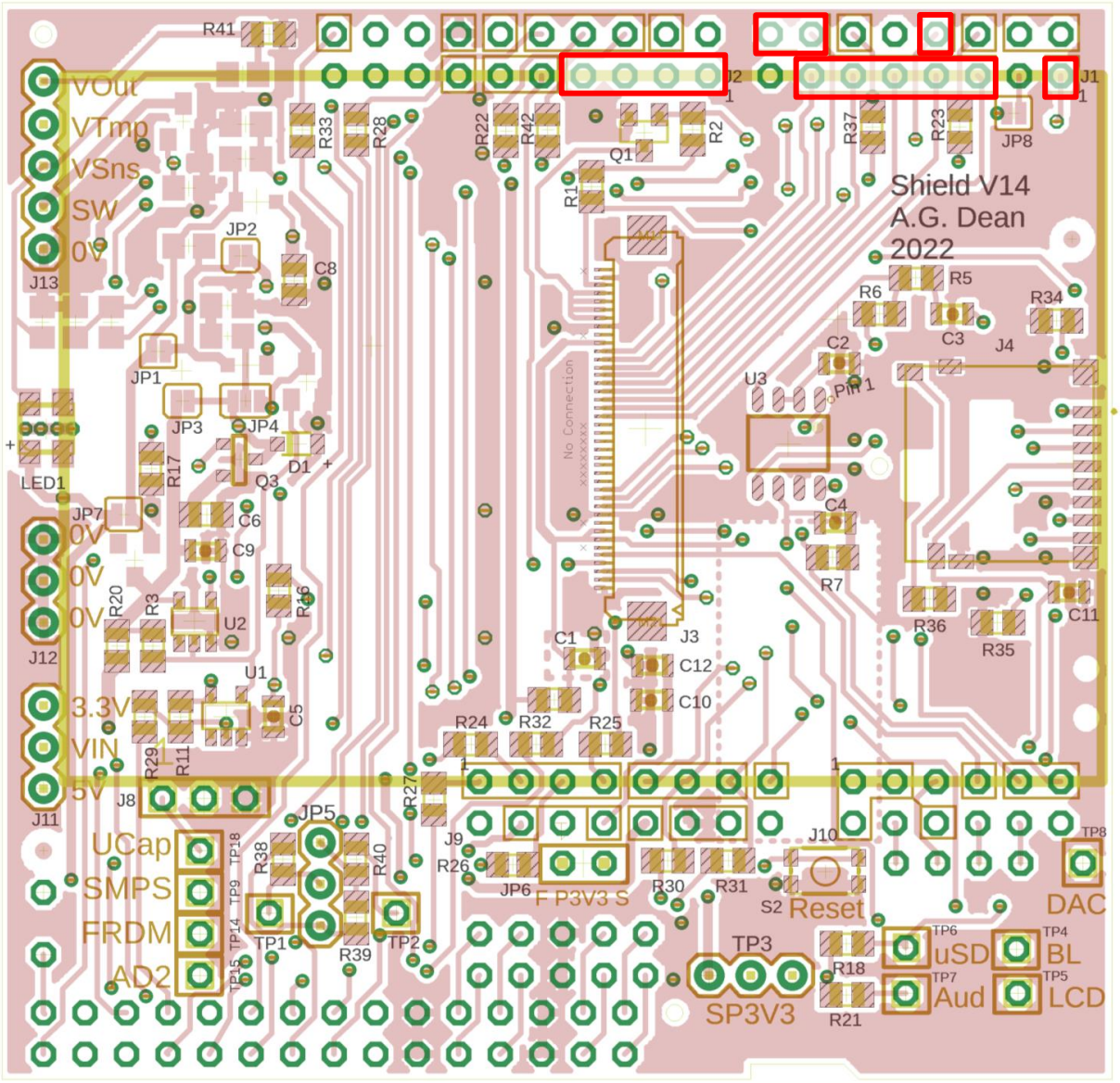


Figure 5. FRDM connections used by LCD (in addition to P3V3 and ground). Make sure there is continuity between each of these pins and the corresponding pin on the bottom of the FRDM board.

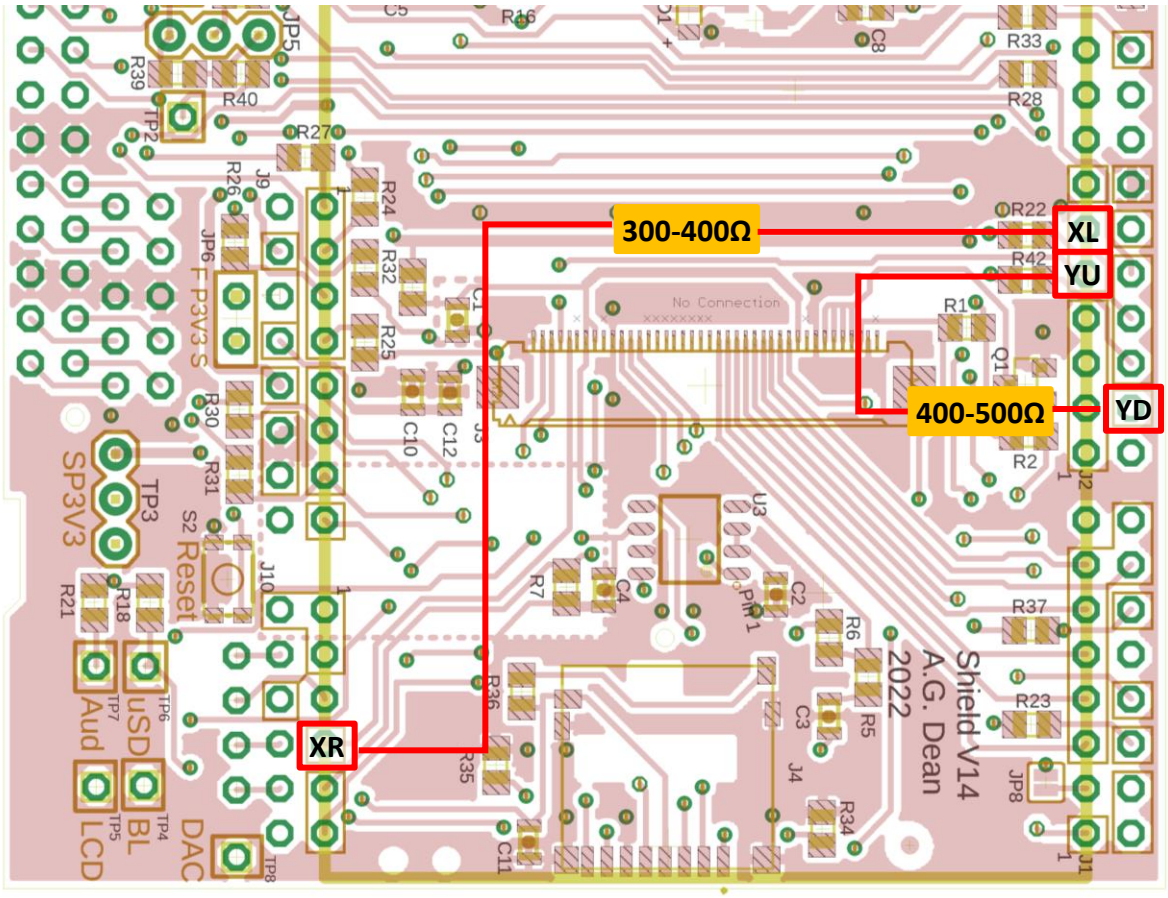


Figure 6. FRDM connections used by touchscreen. Make sure there is continuity between each of these pins and the corresponding pin on the bottom of the FRDM board. Also, verify resistances between marked pins are as shown to confirm these four signals are connected to the LCD through J3 correctly.

SMPS Converter/HBLED

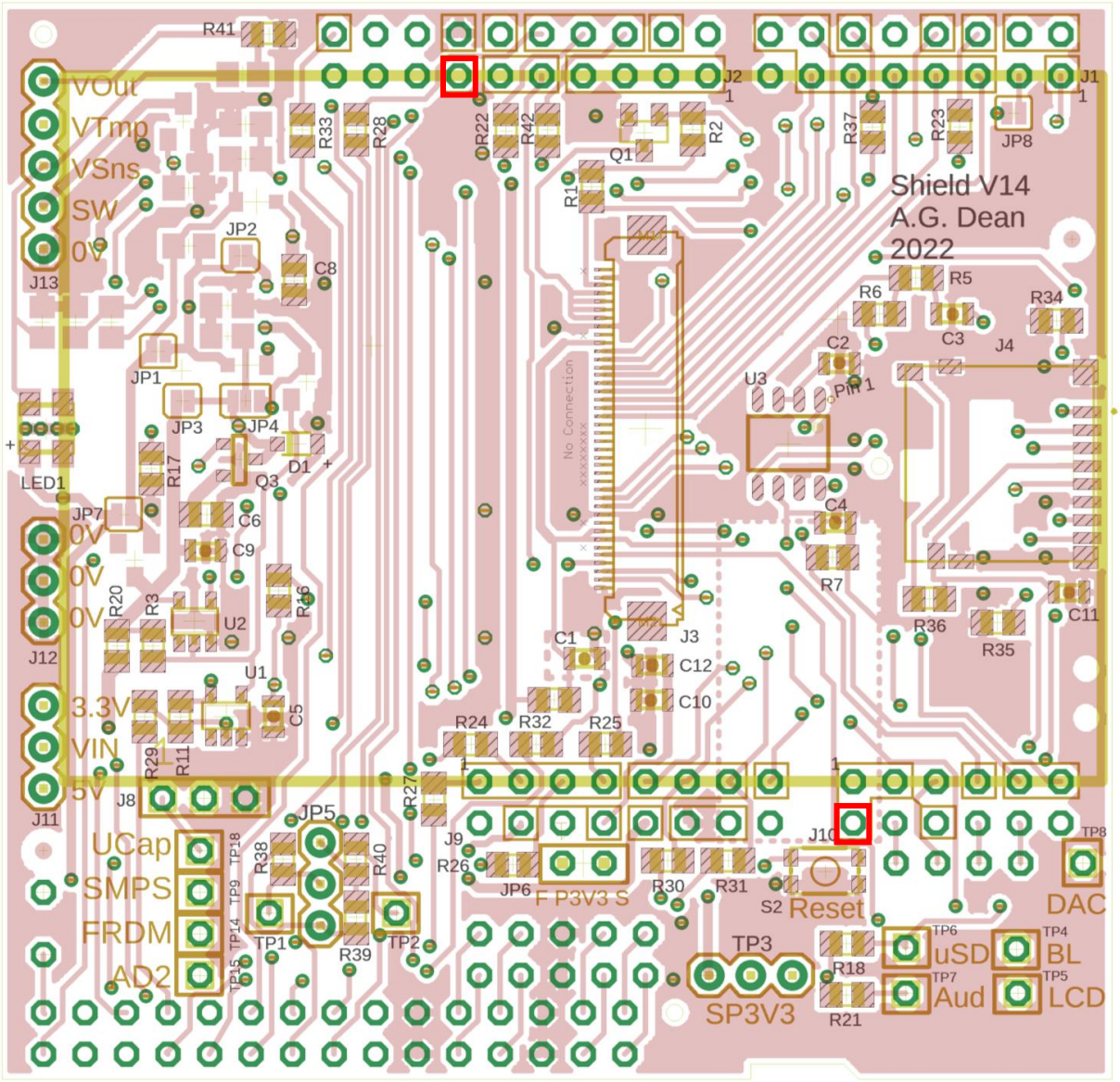


Figure 7. FRDM connections used by SMPS converter (in addition to power and ground).

Alternatives

Skinny Stack

	Height (mm)	
Item	**Original**	**Skinny**
Foot	5.32	1
FRDM PCB	1.21	1.21
Socket Insulation	8.2	4.57
Pin Insulation	2.7	1.52
Shield PCB	1.6	1.6
Components	4.15	2
LCD	3.75	3.75
Total	**26.93**	**15.65**

Reduce the thickness of the Freedom/Shield/LCD stack:

- Using shorter headers.
    - Female (Freedom): Samtec SLW low-profile series , insulation is 0.180" (4.57 mm) high. Insertion depth 2.16 mm to 2.92 mm. Mated stacking height 6.09 mm.
        - 12 pin: SAM1088-06-ND, $1.95. Value added
        - 16 pin: SAM9949-ND, $2.23. SAM1092-08-ND, $1.41, VA
        - 20 pin: SAM1090-10-ND, $3.12. VA. SAM11803-ND, $2.60 Imm.
        - (40 pin: SAM11804-ND, $5.18)
    - Male (Shield): Samtec Flex Stack TLW. Insulation 1.52 mm, 2.67 mm mating pin length.
        - 12 pin
        - (40 pin: SAM1100-40-ND, $7.72)
        - (72 pin: SAM1096-36-ND, $11.86)
- Replace adhesive feet with shorter ones (e.g. 2 mm) as needed to clear header pins
- Remove Freedom board reset switch, relocate (location TBD. Perhaps on header?)

Changes

Possible Future Changes

- Searches
    - Identify headers/connectors with less insertion force.
        - Explicit LIF? Expensive (x2)
        - Shorter pins? Headers need mating pins to be 3.7 to 6.3 mm long
    - Evaluate footprint compatibility with other KL boards: 26, 27, 28
    - Add IR phototransistor and IRLED. Examples of matched pairs from from Wurth at Digikey. Want 3 V operation, mount on front of board?
    - Look for compatible lower-power LCD -- at least with more efficient backlight.
- Minor
    - Move inductor and R10 to top?
    - ***Add labels showing key signals on headers (or at least circle them)***
    - Move battery connector and L1 toward edge of board to make space for Li-Ion cell. Watch out for Reset Switch Extender!
    - Make domain capacitors disconnectable to simplify power measurement? Could use solder jumpers. Or just cut trace (if cap is laid out as a leaf node).
- Major
    - **Add better voltage regulator to bypass LDO (or let AD2 supply the voltage) and reduce existing U1 V_{DO} of 0.9 V**
    - Discarded/Deferred
        - LCD with hot bar connection?
        - Magnetometer for compass?
        - SPI RAM?
        - Microphone?
- *Other*
    - Light pipe for RGB LED. Swizzle stick, or 3/16" (4.75 mm) square bar stock (like this)
    - *Supporting equipment (not on shield)*
        - *Easier to connect/disconnect AD2*
        - *Easier to connect/disconnect OpenSDA*
            - *2 2-pin female-male jumper wires with shorting jumpers*

Changes for v14 (green)

- Debug Support
  - Replaced Debug, ADC and SPI connectors with direct connection (J6) to Analog Discovery 2 for simplicity and signal integrity. Also removed expansion connector.
  - Added SMPS_Drv signal to connector with series resistor.
  - Add TP/pads for unused valuable I/O (ADC inputs, etc.)
- SMPS Enhancement
  - Added support for SMPS configuration as SEPIC.
  - Added output protection diode to SMPS, with shorting solder jumper
  - Add Zener diode option for SMPS output as hardware safety.
- Power monitoring
  - Added more capacitors per voltage domain. Added more capacitance for LCD power supply (C1, 1 uF -> 4.7 uF).
  - Added string of multiple current sense resistors for more dynamic range.
  - Added support to monitor shield power consumption: JP5, JP6, JP7. Backlight current too. Series resistors with connections brought out to header for AD2 connection.
  - Add series resistors on digital debug output signals (J6), uSD (J4), other signals (SMPS_DRV) to reduce EMI.
  - Added current sense resistor, shorting jumper and capacitor for audio amp.
- Moved or renamed signals
  - Moved LCD_TS_YD signal to ADC channel 6 (PTD5(b), J2-4). Done to free up EXTRG input for SMPS control.
  - Moved LCD_TS_YU and LCD_TS_XL to non-ADC inputs (PTA16 and PTA17). Only LCD_TS_XR and LCD_TS_YD need ADC inputs.
  - Moved DBG1-3 to PTD2, 3, 4, and added DBG0 at PTD0. Done to free up 4 more ADC inputs on PTB.
  - Connected LED temperature sensor (V_LED_TEMP) to ADC input 12 (PTB2, J10-6).
  - Renamed Buck_ signals to SMPS_
- Other
  - Replaced audio amp with current version with standard footprint. IS31AP4991A-GRLS2 is SOP-8/8-SOIC. 706-1428-1-ND (cut tape)
  - Changed speaker to wired vs. faked “surface-mount”. Attach speaker with double-sided tape or glue.
  - Freed up space around HBLED for mounting reflector.
  - Added ultracapacitor socket with 0.2” lead spacing.
  - Positioned parts to hold LCD in place:
    - Left: ultracap socket
  - Added uSD Card Detect signal pull-up resistor, but not connected to any digital input**.**
  - Removed D2 (from battery connector).
  - Added duplicate reset switch on shield.

Changes for v13 (green)

- Separated fiducials from vias, holes.
- Added mounting holes (~1mm) to hold board during assembly.
- Moved LCD TS_XL from PTC1 to PTC2.
- To reduce unique part count, changed R5, R6 to 100K. Changed C3 from 220 nF to 100 nF.
- Added support for measuring power for P3V3, (with subdomains for LCD (w/o LED backlight) and uSD. Used solder pad jumpers JP5, JP6, JP7. Also added pads for optional resistors R18, R19, R20 to measure current.

Changes for v12 (blue)

- Moved C1 from J3 to simplify soldering.
- Mark unused pins on J3 as X on silkscreen with limited success.
- Moved Q1, R1, R2, C1 to allow use of ½" wide magnetic tape.
- Added fiducials to aid automated assembly.
- Note: Should white shorting jumper for J11 (better visibility).

Changes for v11 (green)

- Rotated parts to consistent horizontal orientation.
- Added support for boost or buck converter.
- Added generic expansion header (J14).

Changes for v10 (tan)

- Moved some connectors slightly inwards.

Changes for v9 (white)

- Moved two touchscreen ADC input channels to make space for differential ADC input of current-sense resistor.
- Added jumper to select 3.3V or ~5V input voltage for buck converter
- Added and moved existing BUCK sense channel to support differential inductor current sense
- Added headers for debug signals
- Changed 0603 components to 0805 (R1-7, R11)